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HAP Condition Assessment Manual Revision 1.1

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December 2012

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Environmental Sciences Division

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1. INTRODUCTION

The Hydropower Advancement Project (HAP) is a systematic approach to best practices implementation to improve the efficiency, capability, water utilization and value of existing US hydropower plants.

The HAP considers three performance levels for hydropower facilities: installed performance level (IPL), current performance level (CPL), and potential performance level (PPL). IPL is that achievable by the facility under design conditions immediately after commissioning (installed name-plate capacity performance in most cases). CPL may be lower than the IPL due to wear and tear or due to the changes in the constraints placed on a facility that prevent it from operating as originally designed. PPL could be achieved under current operating constraints by upgrading technology and implementing best practices for operations and maintenance. HAP assessments will identify equipment and operational process improvements that move the CPL toward PPL.

The HAP will highlight opportunities for improvement of US hydropower value in two categories: (1) efficiency improvements and (2) utilization improvements. Efficiency improvements, defined herein as equipment and process upgrades that increase the *efficiency* of generation on an instantaneous and annual average basis, thereby enabling increased energy production from the water passing through turbines. Utilization improvements, defined herein as equipment and process upgrades that enable a project to *use* more of the available water in streams, which will also increase energy production. The distinction between *efficiency* (generation per unit of water passing through turbines) and *utilization* (generation per unit of water passing the project on an annual average basis) is non-trivial in detecting trends in the results of systematic assessments of the US hydropower fleet, and for modeling the effectiveness of federal or commercial RDD&D[1] investments for hydropower improvement. The potential for increased production and value of grid services resulting from efficiency upgrades in the first category is predictable and scalable according to common design features of the hydropower technology. The potential for increased production and value of grid services from utilization upgrades in the second category is less predictable and more varied because it depends on site-specific hydrologic and environmental contexts. Improvements in unit reliability and availability contribute to both of these categories—first, by enabling increased flexibility to maintain units at efficient loads, and second, by maximizing the volumetric capacity of the powerhouse.

The HAP is currently a three phase effort to identify and assess performance improvement opportunities at existing hydropower plants. Phase I will focus on the compilation of hydropower best practices and development of standardized assessment methodologies to identify efficiency and utilization improvements. During Phase I, three demonstration and seven baseline assessments will be performed to verify and refine the developed assessment methodologies. Phase II will carry out 40 facility assessments at a diverse selection of existing hydropower plants to identify and catalog the potential for increased generation within the existing hydropower fleet. The results of these assessments will highlight potential upgrade projects that can be further studied in the future. Dependent on program budget and direction, Phase III will assist the hydropower industry to execute detailed feasibility studies of improvement projects including engineering designs and cost-benefit analyses.

This Manual will provide objectives, methodology, and quantitative rating tools for hydropower asset condition assessment; as well the procedure, scope of work, and personal requirement for facility assessment. The Appendices to this Condition Assessment Manual are the crux of information and guidance to which hydropower professionals will refer to ensure that assessment efforts are the HAP standard assessment methodology. They include:

[1] Research, Development, Demonstration, and Deployment

1. Workbooks for quantitative condition rating of individual components;
2. Guides for condition assessment of individual components;
3. Inspection Form and Check List for each individual component.

The scope of assets to be assessed will include all major components in mechanical, electrical, civil, and Instruments & Controls (I&C) systems, as well as some auxiliary mechanical components. Each component to be assessed will have a Guide to describe how its condition will be evaluated and a corresponding Excel Workbook to record and calculate the condition scores, while the Inspection Form and Check List is to provide the assessment team members with a useful notebook used for on-site inspection and data collection.

The intended users of this Condition Assessment Manual (including Appendices) are the hydropower professionals or experts who will execute HAP Phase II assessments. Other potential users include on-site plant staff, technical staff, plant managers, or asset managers who are going to use the assessment tools or assessment results for further analysis supporting their investment decisions at the existing facilities.

Although the calculation of Condition Indices has been embedded in the Excel Workbooks, the overall structure of HAP condition assessment, including the calculation formula, is still provided in this Manual for the assessment teams to better understand how the collected data will be utilized for quantitative condition analysis.

2. CONDITION ASSESSMENT OBJECTIVES

The HAP is designed for both performance analysis and condition assessment of existing hydropower plants. The performance assessment is to quantify unit and plant performance and to investigate the opportunities for operations-based, equipment-based, and maintenance-based performance improvements leading to additional generation. The quantitative condition assessment aims to characterize and trend asset and asset component conditions across the US existing hydro fleet. The use of a standard assessment methodology (the HAP methodology in this case) is crucial for comparing and trending the hydro asset conditions across different facilities, owner fleets, regions, and within the overall US hydropower inventory. Such trends will be useful in programming research and development efforts to improve hydropower availability, cost, and value in the future.

This document, as the general section of the Condition Assessment Manual, addresses the methodology and processes of quantitative condition assessments as well as the condition rating tools. One of the condition rating tools is the Excel Workbooks which will be used to standardize the recording of information, scoring based on that information, and calculation of condition ratings. The Guides will provide standard processes and rating scales that produce consistent, repeatable, and objective condition scores. Collectively, these condition results from 50 or so sample plants (around 200 units) will be quantitatively and statistically analyzed to answer questions such as

1. What is the average condition of existing hydro assets?

2. What percentages of assets (at level of plant, unit, component or part) are in need of investment to achieve a fair or good operating condition?

Combined and correlated with the results from performance analyses, these condition results can be used to answer questions such as

1. How much capacity, efficiency or annual energy would be gained through an upgrading program? How would the gains correlate to unit/plant condition?

2. How does the degradation of unit efficiencies correlate to the age of runners (or the age of generator winding)?

In addition, the database of performance and condition assessment results, in anonymous form that protects plant-specific data, will provide asset managers with a benchmark to better understand the conditions of their facilities and help make decisions on further assessment and upgrade investment.

3. CONDITION RATING FRAMEWORK

In the context of HAP condition assessment, the assets of hydropower fleet are classified hierarchically as Plants, Units, Components (Subsystems, Structures), and Parts/Items as illustrated in Figure 1. More detailed hydropower asset hierarchy can be found in the HAP Taxonomy that is organized by physical and functional layers within a hydropower facility based on several sources (TVA 2010, ASME 1996, Roose and Starks 2006). The Taxonomy provides the basis for the categorization of the hydro assets for HAP condition assessments and also for the documentation of Best Practice Catalog and Condition Assessment Guides.

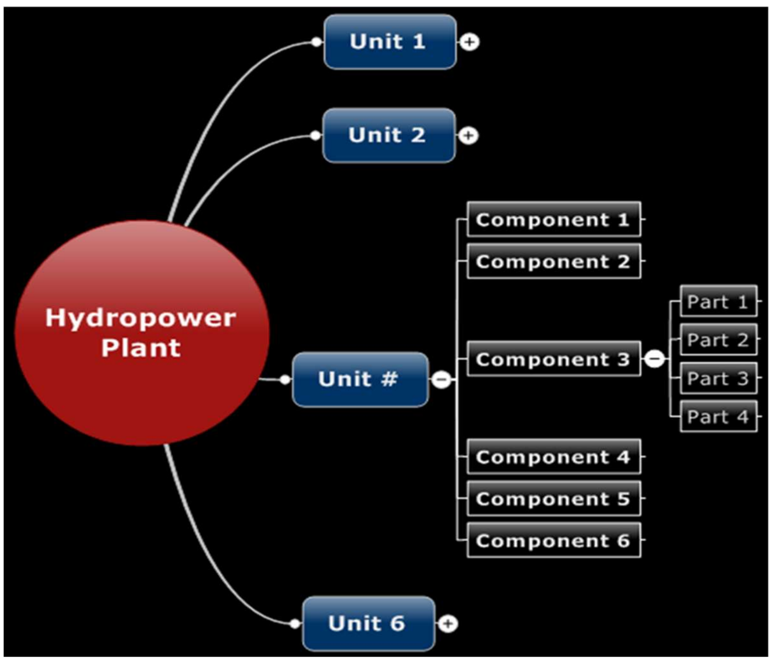

Figure 1. Illustrative hierarchy of hydro assets.

The power generating units are essentially the core of a hydro plant, but the scope of unit in HAP condition assessment is extended from the turbine-generator equipment to the "water to wire" system; including civil, mechanical, electrical and I&C components (e.g., intake, water conveyance, turbine, generator, transformer). The scoring process is a bottom-up aggregation of scoring, with the parts of a component aggregated to a component score, component scores aggregated to unit scores, and unit scores aggregated to facility scores. For example, to assess the condition of a turbine, turbine parts are first scored and the overall turbine condition can then be evaluated based on the turbine parts scores. When all the components are assessed, the overall unit condition and plant condition can be evaluated.

The following five condition parameters will be scored for each part:

- **Age:** The years that a part or equipment has been in service since initially commissioned or previously replaced.

- **Physical Condition:** This is a very general term. It refers to those features and performances that are observable or detected through visual inspection, measurement and testing. The meaning of Physical Condition can vary from component to component and from one part to another. For turbine runners, it means surface roughness, cracks, cavitation etc., while for generator windings it may refer to Insulation Resistance and Polarization Index. In the HAP condition assessment, the physical condition is scored based on visual inspections and data collection from previous tests and measurements.

- **Installed Technology Level:** It indicates advancement levels of designing, machining, installation and materials. The technology level may have an effect on the unit and plant performance, and the outdated technologies may bring difficulties for parts replacement and prolonged outage period when it fails.

- **Operating Restrictions:** With the evolution of economy, power market and technology, and the changes of site flow condition and environmental requirements (e.g., DO levels, instream flows), the design standard may have changed or the original design may currently constrain the operations (e.g., Francis turbine aeration devices). In addition, the operating restrictions arising from deterioration of aging assets are also considered.

- **Maintenance Requirement:** It reflects the historical and current demands for the repairs and maintenance, particularly the amount of corrective maintenance.

- For electrical components (e.g., Generator, Transformer), the results from some specific tests and data analyses might be more important than visual inspection as indications of equipment health and condition. Although they could be categorized into Physical Condition, to emphasize their importance to the equipment condition assessment, they are treated as additional condition parameters. For instance, the aggregation of electrical tests for generator Stator including insulation resistance (IR) test, polarization index (PI) test, bridge test for winding resistance, and so on will be treated as one of generator condition parameters. For the I&C system, a different set of condition parameters are developed to better indicate the health and condition of I&C components. The details refer to Appendices, Guides of individual component condition assessment.

Again, the turbine is used as one example of components to illustrate the rating process. Different types of turbines consist of different parts, and the major parts of the three major turbine types (Francis, Propeller/Kaplan and Pelton) are listed in Tables C-1, C-2, and C-3, respectively, in Appendix H. Each individual unit in a plant has one table for the turbine parts and turbine scoring. Assuming in XXX Hydropower Plant, Unit 1 has a Francis turbine, the following Table 1 is used for the turbine condition assessment. In Table 1, the matrix of condition scores, $S_C(J, K)$, are assigned by the assessment team to each turbine part and each condition parameter, based on the on-site inspections and collected data/information using the established turbine rating criteria (Charts 1–5, Appendix H).

Table 1. Turbine condition assessment and scoring: XXX Hydropower Plant

Francis Turbine Unit ____	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Spiral/Scroll Case	4.1.1.1							1.5
Stay Ring/Vanes	4.1.1.2							1.5
Wicket Gates Mechanism/Servomotors	4.1.1.3							3.0
Runner	4.1.1.4							5.0
Draft Tube	4.1.1.5							2.0
Main Shaft	4.1.1.6							1.0
Guide Bearings	4.1.1.7							1.5
Mechanical Seal/Packing	4.1.1.8							1.0
Head Cover	4.1.1.9							1.5
Vacuum Breaker/PRV	4.1.1.10							1.5
Aeration Devices	4.1.1.11							2.0
Bottom Ring	4.1.1.12							1.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	*0.00*
							Condition Indicator -->	*0.00*

The Data Quality Score, $S_D(K)$, as an independent metric reflects the quality of available information and the confidence of the information used for the part assessment. In some cases, data may be missing, out-of-date, or of questionable integrity; any of these situations could affect the accuracy of the associated condition scores, where the Data Quality Indicator is used as the means of evaluating and recording confidence in the Condition Indicator (MWH 2010). The data quality scores of each assessed part/item are determined by the on-site evaluators based on the data availability, integrity and accuracy. The rating criteria for Data Quality Indicator are developed for the turbine in Chart 6, Appendix 1.07.

Any score cell in Table 1 (actually, in any component Rating Tables) allows "pass by" if any part does not exist in a particular unit (e.g., draft tube may not exist for some turbines), and "NA" is input to exclude this part from the score processing. Similarly, if any of the condition parameters is inapplicable to one particular part, "NA" will be also input to exclude this parameter (e.g., The Electrical Tests for generator Stator is not applicable for any other generator parts, so "NA" will be input into the cells of other parts for this generator condition parameter). This mechanism permits the necessary flexibilities for the differences among the units and plants while maintaining a standardized evaluation process. In Table 1, two categories of weighting factors, $F(J)$ or $F(K)$, are predetermined to reflect the relative importance of each condition parameter or each part to the overall turbine condition assessment.

To assess the "water-to-wire" condition of a unit, a total of 19 components have been tentatively considered to compose a Unit. Each of these components will have one scoring table corresponding to each individual unit, as Table 1 is for Unit 1 Turbine Condition Assessment. Some components (such as Transformer) are often shared by several (or all) turbine-generator units in a plant. If so, this common component is assessed only once and its Condition Indicator (CI) would be applicable to all the sharing units (i.e., one scoring table corresponds to all sharing units). It is also recognized that some parts and components are not immediately attached to one specific unit (not as clear as the turbine and turbine parts), and they have to be mapped and identified for a specific unit. For instance, as shown in Figure 2, the upstream pressurized water conveyance system may be partially shared by several turbine-generator units, in which the penstock sections have to be numbered and all sections/parts are mapped into the different individual units. Table 2 lists the parts/items of the Pressured Water Conveyance for Unit 1 in the scheme shown in Figure 2.

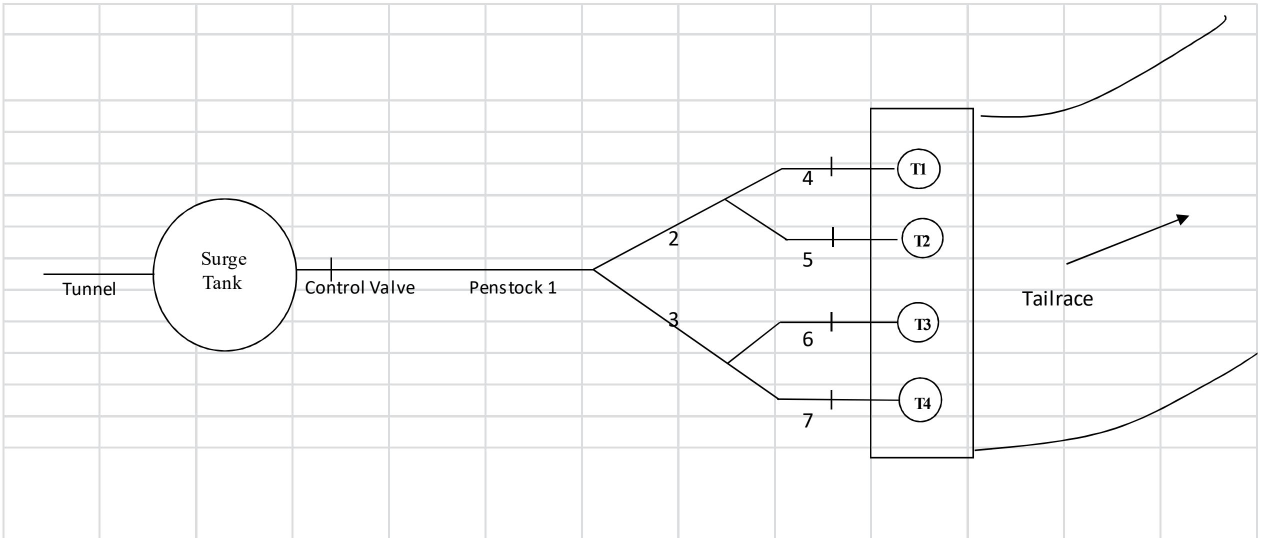

Figure 2. Mapping of pressured water conveyance for individual unit.

Table 2. Pressured water conveyance condition assessment and scoring: XXX Hydropower Plant

Pressurized Water Conveyance for Unit 1	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Tunnel	3.3							2.0
Penstock 1	3.4.1							3.0
Penstock 2	3.4.1							2.0
Penstock 4	3.4.1							2.0
Bifurcation 1	3.4.2							1.0
Bifurcation 2	3.4.2							1.0
Linings & Coatings	3.4.3							1.0
Foundation & Supports	3.4.4							1.0
Air Vent/Pressure Relief Valve	3.4.5							1.0
Joints & Coupling	3.4.6							1.0
Surge Tank	3.6							1.5
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	0.00
							Condition Indicator -->	0.00

For the electrical and I&C components, the parts/items listed in the condition assessment tables might be categorized according to the different functionalities, while for the mechanical and civil components, the parts/items are more likely organized by their physical and structural features.

Once the component parts scoring table is established (such as Table 1 or Table 2) and a matrix of scores S_C (J, K) are assigned, the final condition score of the component (i.e., the component Condition Indicator, *CI*) can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,N} S_C(K,J)\times F(K)\times F(J)}{\sum_{K=1,M}^{J=1,N} F(K)\times F(J)} \quad (1)$$

Here, M = the total number of parts/items associated with a component; K = the identification No. of Parts/Items (from 1 to M); N= the total number of condition parameters; J = the identification No. of condition parameters (from 1 to N, respectively, for the physical condition, age, technology level,…), $S_C(K, J)$ = the condition score of a part/item for a condition parameter; $F(J)$ = the weighting factor for a condition parameter, determined based on the relative importance of the condition parameter to the overall condition assessment; $F(K)$ = the weighting factor for a part/item, determined by the relative importance of the part/item to the overall condition of the component. All the weighted factors have been pre-determined during the process development stage based on consensus among experienced hydropower engineers and plant O&M experts, but are subject to adjustment later by the HAP core technical team according to the special layout/design of individual hydropower plants and the industry comments that will be received. By the weighted summation, the range of absolute values of weighting factors has no effect on the final score (*CI*) of a component.

The computation results in a value of *CI* between 0 and 10. As shown in Table 3, which is cited from HydroAMP (2006) and subject to verification during the HAP demonstration and baseline assessments, a *CI* of 7 or greater is considered "Good," 3 to 7 "Fair," and less than 3 "Poor." Based on the range of *CI*, the operating restriction or decision for further evaluation would be able to make.

Table 3. Condition indicator (*CI*) and condition-based suggestions

$7 \le CI \le 10$	**Good**	Continue O&M without restriction
$3 \le CI \le 7$	**Fair**	Continue operation but re-evaluation suggested
$0 \le CI \le 3$	**Poor**	Immediate evaluation and O&M adjustment required

The Data Quality Indicator of a component, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K)\times F(K)}{\sum_{K=1,M} F(K)} \quad (2)$$

$S_D(K)$ = the data quality score for a part/item, assigned by the assessor based on the developed Data Quality rating criteria for each component; M, K and $F(K)$ are the same as used in equation (1). The *DI* will result in a score between 0 and 10.

Table 4 aggregates all the components *CI*s for Unit #. The Unit Condition Indicator, *UCI*, is the weighted summation of the *CIs* of all components associated with the unit:

$$UCI = \frac{\sum_{i=1,N} CI(i)\times W(i)}{\sum_{i=1,N} W(i)} \quad (3)$$

Similarly, the unit Data Quality Indicator *UDI* is calculated as

$$UDI = \frac{\sum_{i=1,N} DI(i)\times W(i)}{\sum_{i=1,N} F(i)} \quad (4)$$

Here, N = the total number of components associated with the unit. Currently, a total of 19 components will be assessed; they are associated with the efficiency, and reliability or availability of generating units. In the future, more components/subsystems for the balance of the plant would be added. i = the identification No. of the component (from 1 to N); CI (i) = the condition score of component (i), DI (i) = the data quality score of component (i); W (i) = the Weighting Factor of component (i), which is predetermined based on the importance of the component to overall power generation and reliability, but they may be subject to changes later by the HAP core technical team according to the special layout and design of individual hydropower plants. By the weighted summation, the range of absolute values of weighting factors has no effect on the Condition Indicators of the unit and plant.

Table 4. Synthesis of components indicators to unit indicators: XXX Hydropower Plant: Unit #

Components	Component Code in Taxonomy	Weighting Factors $W(i)$	Condition Indicator $CI(i)$ (0-10)	Data Quality Indicator $DI(i)$ (0-10)
Trashracks and Intake	3.1/3.2	2.0		
Penstock/Tunnel/Surge Tank	3.3/3.4/3.6	1.5		
Control/Shut-off Valve	3.5	1.0		
Flume/Open Channel	3.7	1.0		
Draft Tube Gate	3.8	0.2		
Leakage and Release	2.1/2.2/2.3	1.5		
Turbine	4.1.1	2.0		
Governor	4.1.2	1.0		
Generator	4.1.3	3.0		
Exciter	4.1.4	1.0		
Transformer	4.1.5	2.5		
Circuit Breaker	4.1.6	0.5		
Surge Arrester	6.1	0.5		
Instruments & Controls	4.3	0.5		
Powerhouse Crane	4.2.1	0.5		
Station Power Service	4.2.2	0.5		
Compressed Air System	4.2.3	0.5		
Raw Water System	4.2.4	0.5		
Lubrication System	4.2.5	0.5		
Unit Indicators			***0.00***	***0.00***

Note: Circuit Breaker, Surge Arrester, Powerhouse Crane, Station Power Service and Compressed Air System will be considered for future additions.

Finally, all the *CIs* of components and units will be aggregated into Table 5 to provide an overview of a plant and units condition. The plant *CI* is simply the average of *CIs* of all assessed units in the plant.

Table 5. Aggregated plant condition indicators: XXX Hydropower Plant

Components	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Units Average
Trashracks and Intake							
Penstock/Tunnel/Surge Tank							
Control/Shut-off Valve							
Flume/Open Channel							
Draft Tube Gate							
Leakage and Release							
Turbine							
Governor							
Generator							
Exciter							
Transformer							
Circuit Breaker							
Surge Arrester							
Instruments & Controls							
Powerhouse Crane							
Station Power Service							
Compressed Air System							
Raw Water System							
Lubrication System							
Unit Condition Indicators (*UCI*)							
Plant Condition Indicators (*PCI*)							

4. SURVEY METHODOLOGY AND SAMPLING TECHNIQUES

As aforementioned, upon completion of the 50 facilities assessments, the collective results will be used to trend the current performance level and characterize the improvement potential of the US conventional hydropower fleet (Note: the HAP assessments at current stage are focused on the US large hydro fleet, that is the individual plant capacity is not less than 30 MW.) However, statistically valid estimates of nationwide opportunities will require survey techniques that support expansion of the results from the 50 assessments to the entire fleet. Simple selection of a range of representative facilities will provide useful insights to the industry, but may not provide a statistically valid basis for expansion of the results.

In addition, consistency and comparability across assessment teams will be important for this nationwide assessment. Aggregation of unit and facility level results across the multiple assessment teams will require a high degree of standardization of methodology, which the Assessment Manual addresses. Inter-team consistency can be enhanced by on-site training, including mock assessment of a single facility by all assessment teams followed by inter-team comparison and alignment of results. Additionally, to minimize the unavoidable inter-team variability, the aggregated assessment results will be replicated and compared by using a random subset of the assessed facilities to characterize the remaining.

4.1 CHARACTERISTICS OF THE US LARGE CONVENTIONAL HYDROPOWER FLEET

To design a valid sampling technique, it is necessary to review the "population" of this study, that is, the US fleet of large conventional hydro facilities. Based on FY11 NHAAP database, there are total 395 large hydro plants in the United States, in which 357 are conventional hydro plants, 24 pumped storage hydro plants, and 14 combined plants. The following is a summary of the unit and plant level statistical information for large conventional hydro facilities:

a. **The number of large CH plants is 357**, which is the population size of large conventional hydro plants in the United States. Among this population of plants, the numbers of plants with different ages:
Number of CH plants built before 1990 = 320
Number of CH plants built before 1980 = 294
Number of CH plants built before 1970 = 271
Number of CH plants built before 1960 = 198

b. **The number of units at the 357 conventional hydro plants is 1,521**, in average 4–5 units per plant. This is the population size of the units in the fleet of large conventional hydro.

c. Number of Turbine types

Turbine Type	Number of Units	Percentage (%)
Francis	864	51.9%
Francis (H>300 ft)	241	14.5%
Kaplan	312	18.7%
Propeller	130	7.8%
Pelton	39	2.3%
Axial Flow Turbine (Bulb, Pit or Tubular)	34	2.0%
Pump-Turbine (Pumped storage)	67	4.0%
Unknown or other types	220	13.2%
Total No. of units	1,666	100.0%

d. Number of Plants per 18 Hydrologic USGS Regions and Alaska

Region	Region Name	Number of Hydro Plants	Percentage
1	New England	19	5%
2	Mid Atlantic	15	4%
3	South Atlantic-Gulf	58	15%
4	Great Lakes	11	3%
5	Ohio	21	5%
6	Tennessee	28	7%
7	Upper Mississippi	6	2%
8	Lower Mississippi	5	1%
9	Souris-Red-Rainy	0	0%
10	Missouri	27	7%
11	Arkansas-White-Red	23	6%

Region	Region Name	Number of Hydro Plants	Percentage
12	Texas-Gulf	7	2%
13	Rio Grande	2	1%
14	Upper Colorado	5	1%
15	Lower Colorado	7	2%
16	Great Basin	3	1%
17	Pacific Northwest	75	19%
18	California	80	20%
19	Alaska*	3	1%
	Total Number of Plants	395	

Note: Several large plants in Alaska were not included in the FY11 NHAAP summary

e. Number of Conventional Hydro Plants per Ownership Type

Owner Types	Number of CH Plants	Percentage of CH Plants	Number of CH Units	Percentage of CH Units	CH Capacity (MW)	Percentage of CH Capacity
1. Federal	110	31%	508	35%	30,657	49%
2. Public/Municipal	63	18%	214	15%	11,527	18%
3. Private/Corp	179	51%	736	50%	20,356	33%
Sum	352	100%	1,458	100%	62,540	100%

Notes: 1. The info in NHAAP database is not so detailed and complete yet.
2. The difference between Public (Type 2) and Private (Type 3) ownerships is made by judging if the organization is nonprofit or profit oriented.

4.2 RATIONALE OF SAMPLE SIZE FOR NATIONWIDE ASSESSMENTS

The number of assessments is the issue of sample size determination, which is important for economic reason: an under-sized study can lead to incapability to produce useful results, while over-sized one uses more resources than are necessary. The 50 facilities (or around 200–220 units) would be the minimum required sample size for supporting expansion of the assessment results to characterize and estimate the status and improvement opportunities in the entire fleet of large conventional hydropower.

From the theory of statistics, for a certain confidence level (i.e., how sure you can be for the statistic results) and confidence interval (i.e., the margin of error), the needed number of random samples can be calculated:

a. The sample size for an infinitely large population:

$$n_0 = \frac{z^2 p(1-p)}{c^2}$$

Here, Z= Z value (1.645 for 90% confidence level; 1.96 for 95% confidence level)

p = percentage (50% for unknown participation level prior to sampling)

c = the confidence interval (margin of error, plus-or-minus of precision), expressed as decimal (e.g., 0.05 for 5% confidence interval)

The sample size needed for a finite population:

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}}$$

Here, N = the population size.

Considering the 357 facilities as the population size of large hydro, the 154 facilities assessments (random sampling) would be required to gain 90% of confidence level and plus-or-minus 5% of precision level for assessment results. While for a given 90% of confidence level, 11% plus-or-minus of precision levels can be expected from 50 facilities assessments.

Considering the 198 facilities built before 1960 as the population size of large hydro, the 115 facilities assessments (i.e., random sampling from the group of 50-year-old plants) would be required to gain 90% of confidence level and plus-or-minus 5% of precision level. While for a given 90% of confidence level, 10% plus-or-minus of precision levels can be expected from 50 facilities assessments. This indicates the reduction in population size won't significantly help to reduce the effort of assessments.

However, considering the unit-level of population size, that is, the total 1,521 units at the fleet of large conventional hydro, the 230 units' assessments (i.e., random sampling) would be required to gain 90% of confidence level and plus-or-minus 5% of precision level. Furthermore, when the units at the 198 facilities built before 1960 (i.e., around 840 units) is considered as the population, the 205 units' assessments (i.e., random sampling from the 50-year-old units) would be required to gain 90% of confidence level and plus-or-minus 5% of precision level. Therefore, the assessment efforts at the unit-level for the 50 facilities (i.e., 200–220 units) will be quite sufficient in terms of the validity of sample assessments. It is true that HAP condition assessment is both unit and plant levels, but performance assessment is at plant level only.

4.3 SAMPLING TECHNIQUES

To validate the 50 assessment results at the facility level, the assessment sites must be selected carefully with consideration to cover different technologies, ownerships, geographical regions, power markets, ages and sizes of the projects. Firstly, the HAP is a nationwide project effort, aimed to provide a fact-based quantitative estimate of additional energy available through improvements and expansions of hydro plants. This objective of HAP has determined the assessed facilities need to be good representative for the nationwide hydro fleet. Moreover, the hydro facilities are nationwide populated, distributed in all major river basins and 18 UDGS regions in 50 States. A more representative geographical distribution of assessments would indicate more states and congressional districts will be positively affected by the HAP. In addition, there are six classes of hydro plant ownerships in the US: federal, municipal and other non-federal public, private utility, private non-utility, industrial and cooperative. Different ownerships may represent for different power markets and O&M philosophies. All the hydro population and engineering features call for the diversity in the sample assessments. Therefore, the concept and techniques of "Stratified Sampling" will be applied during the process of nationwide facility selection and assessment. This sampling technique can decrease variances of sample estimates and use partly non-random method to sample individual facilities where easily accessible. For example, more facilities will be selected from the regions with dense hydro plant populations; and also at least half of selected facilities should have Francis turbine installed based on the proportion percentages of turbine types in the US large hydro fleet.

5. CONDITION ASSESSMENT SCOPE AND PROCESS

The scope of work for the effort of a hydropower facility assessment will include Facility Selection, Assessment Planning, Site Visit, and Analysis and Reporting. The technical scope, information needs, and required expertise are summarized in Table 6. Workshops will be organized for selected assessment teams to attend to ensure complete understanding of interpretation and use of the BPC and Assessment Manual.

Facility Selection: It is anticipated that diversity of facilities will be selected for HAP assessment in Phase II, which consider:

- The geographic regions (across the United States);
- The project purposes (e.g., power generation, flood control, water supply);
- Turbine technology types (Francis, Kaplan, Propeller, Pelton, Bulb);
- The project sizes (MWs) and components (from intake to tailrace);
- The project types (water storage, run-of-river);
- Water conveyance types (open channel, pressurized tunnel, fabricated penstock);
- Facility ages.

The assessment facilities will have been determined for each assessment team at the time of contracting. The BPC and Assessment Manual will be available publically to provide guidance in the data and resources that will be required to assess facilities.

Assessment Planning: The work will begin well in advance of site visits to solicit, collect, and analyze configuration and operation data to understand how the facility functions. The objective of this effort is to estimate the IPL, CPL, and PPL to the greatest extent possible in advance of the site visit. There should be a shared understanding by the assessment team and the facility staff as to what facility information will be made available to the team, including condition monitoring data, layout and design drawings, equipment specifications, O&M manuals, operation logs, maintenance records, and previous/historic condition assessment reports. Assessment team will also conduct interviews with O&M staff. The Performance Assessment portion of the effort will require multiple years of hourly generation, flow, and water surface elevation data for the facility and units. However, absence of such data does not necessarily eliminate a facility from eligibility, since it is older facilities with limited data that may benefit most from assessment and upgrades. The collected data will be reviewed and studied to determine the focus of on-site assessment for the specific plant, and that the planned level of effort and personnel are adequate for the on-site assessment. This phase of the effort will require focus and insight from the Assessment Team Leader (Table 6), who must possess experience in hydropower design, operation, and inspection.

Table 6. Scope of assessment and personnel requirement

Role	Qualifications	Scope of Assessment (Major Components to be Assessed)	Required Condition Inspection and Data Collection	Preparation (hours)	On-site Assessment (hours)	Post-Assessment (hours)
Assessment Lead	ME, EE, CE with 15+ years of hydropower design or operations experience	Systems coordination, main POC with asset owner, scheduling master, safety analysis	Basic and general info regarding facility and major equipment (e.g., ages, layout and design drawings, major problems experienced and maintenance/upgrade records, historic/previous assessment reports)	40	8–24	80
Power Train & Balance of Plant Expert	ME with 5+ years of hydropower experience	Turbine, shaft, bearings, seals, lubrication, governor, cooling water system, drainage system, SCADA	Turbine model, design parameters and characteristic curves; cavitations inspection and measurement data, gaps in the seal rings; WG/blade angle settings; index tests or other testing data records; any water or oil leakage inspection & measurement data, and so on.	16–40	8–24	24
Electrical Expert	EE with 5+ years of utility experience	Generator, exciter, transformers, switchgear, circuit breakers, relays, SCADA, and so on.	Generator model, design parameters and efficiency curves; Regular tests and EL CID tests data for condition assessment of generators insulation; oil testing data for transformer condition assessment; inspection/data required for efficiency assessment of other components.	16–40	8–24	24
Civil Structures	CE with 5+ years of hydraulic structure experience	Trash racks, intakes, gates and interfacing surface, stoplogs, tunnels/canals, penstocks, draft tubes, tailrace, valves, dams, reservoirs and buildings	Observed corrosion, blockage & other physical conditions, quantified head losses for each component of water conveyance system; measured flow through turbine & released to downstream; leakage, seepages, sedimentation and condition check for reservoir and other civil works. Visional, ROV, dewatered or diving inspections required if no recent records available.	16–40	8–24	24
Performance Specialist	Specialist with experience in hydropower plant efficiency analysis and optimization	Scoring efficiency-related data and processes (availability & soundness), unit and plant controls, operational simulations	Unit performance characteristics, unit operation logs, generation scheduling/dispatch, historic testing data including head water elevation, tailwater elevation, power, flow rate, water temperature, gate opening (blade angle), and so on.	40–80	8–16	40
Clerical Staff				40		24
SUB-TOTAL (hours)				**168–280**	**40–112**	**216**

Note: The on-site assessment hours include traveling time.

Site Visit: The site visit is a critical component of the overall assessment process because it (a) allows the assessment team to validate, through direct observation, their understanding of how the facility operates and performs; and (b) allows the assessment team to address any remaining information needs (e.g., data gaps, quality assurance, anomalies) directly with facility staff. Preparation for the site visit will be extensive and will begin and end with ensuring the health and safety of the team and facility staff. The assessment team must establish a common understanding with facility staff of the schedule for assessment, support functions the facility staff will be expected to perform during the assessment, and any disruptions to normal operations that the assessment may produce. Senior and junior members of the assessment team will arrive at the facility with a site-specific understanding of the design and layout of major components of the powertrain, balance of plant equipment, water conveyances, structures, and interconnection equipment so that on-site interactions can focus on condition and performance assessment rather than explanation of design and basic operations. The assessment team leader will oversee the development of a site-specific assessment work plan, to be provided to the facility staff and ORNL in advance of each site visit. The work plan will include detailed schedules; environmental health, and safety requirements; and the roles, responsibilities, authorities, and accountabilities (R2A2s) of team members and facility staff involved in the assessment. A detailed site visit report will be required to provide to the facility owner and to DOE within two weeks of the conclusion of the site visit.

An example of on-site activities and sequence is as follows: introductory meeting with health and safety briefings; confirm schedule and support staff requirements; discuss remaining information needs; confirm or adjust estimates of IPL, CPL, and PPL; examine plant systems and discuss conditions with facility staff; prepare interim report; and conduct exit meeting to discuss preliminary findings with facility staff. The need for engineers with deep theoretical and practical understanding and experience in hydropower design and operation to lead the on-site efforts cannot be overstated.

Analysis and Reporting: For each facility assessment there are four deliverables:

- Site Visit Report
- Non-public Assessment Data Report
- Draft/Final HAP Assessment Report
- Public Assessment Report

A Site Visit Report will be submitted within two weeks of the conclusion of the site visit. The assessment team will compile and document information obtained prior to and during the site visit into a Non-public Assessment Data Report. This report will not be made public without specific approval from the Facility owners/operators.

The team will complete the analyses required to document the IPL, CPL, and PPL for the facility and will produce a Draft HAP Assessment Report that prioritizes:

- Process (primarily related to performance monitoring, unit commitment, and load allocation) upgrades that move the CPL toward the PPL and

- Equipment improvements and design changes that align the IPL with the PPL.

The report will include estimates for the potentially increased energy and other benefits, the order of magnitude cost estimate to implement, the recommendations for additional studies to resolve uncertainties in prioritization, costs, and benefits of improvement activities. The report will also include a description of the facility and the site-specific environmental and operating constraints that impact the IPL, CPL, and PPL.

Examples of improvement activities that could be recommended include:

- Advanced instrumentation and control upgrades, online condition and performance monitoring
- Runner replacement or turbine upgrade (e.g., propeller upgrading to Kaplan),
- Generator re-winding and up-rating,
- Wicket gate adjustments to minimize leakage,
- Tuning of blade and gate cams in double-regulated machines,
- Intake and trash rack upgrades, online fouling monitors, and optimized cleaning schedules
- Water conductor system from intake to tailrace upgrades and modifications that could improve the plant performance (such as reduction in conveyance losses)
- Spillway gate sealing upgrades for leakage control,
- Dam and reservoir remediation for seepage control,
- Repair and recoating of water conveyances to minimize leakage and friction losses,
- Incorporation of environmental mitigation-induced efficiency losses in unit commitment and load allocation,
- Adding small generating units to use minimum flow releases and maximize plant efficiency,
- Remediation for major safety and reliability issues if any observed, and
- Rehabilitation for prolonged generation years.

6. CONDITION ASSESSMENT OUTCOME

The condition assessment results will be used to analyze three impact indices: Reliability Impact Index, Efficiency Impact Index, and Cost Impact Index. The Reliability Impact Index represents the risk level of an asset (the asset could be a part, a component, a unit, or a plant). Bad condition of an asset means high reliability impact (i.e., more likely to fail and cause more severe impact once it fails). This index can be purely correlated to the asset *Condition Indicators*.

The second outcome from the condition assessment is the Efficiency Impact Index, representing the potential of generating performance improvement. Bad condition usually implies the great potential for efficiency improvement. The analysis of Efficiency Impact Index at a facility will combine the results from both Condition Assessment and Performance Analysis, which could be based on the incremental power production pertaining to a year or long-term timeline.

The third outcome from the condition assessment is the Cost Impact Index, representing the level of dollar cost for upgrading the process or asset in terms of \$/kW or \$/kWh. Usually, bad condition indicates high cost level for the same type of asset. A preliminary cost estimate will be combined with the condition rating results to obtain the Cost Impact Index.

These three impact indices will be analyzed when the condition and performance assessment reports have been generated for 50–60 facilities, so they can be evaluated consistently for all the facilities. The impact analysis results will be assembled to provide a baseline condition and trend the improvement opportunities within the nationwide existing US hydropower fleet.

For an individual facility, the three Impact Indices can collectively provide a base for the decision-making on further assessment or studies and for prioritizing the investment opportunities. Meanwhile, the individual index (Reliability Impact, Efficiency Impact, or Cost Impact) would also make sense individually—for example, if an asset owner concerns of reliability issue more than efficiency potential, the owner may focus on the reliability impacts and even look into the reliability impacts from the most-concerned parts or components of a generating unit.

7. PLANT GENERAL DATA COLLECTION

7.1 PLANT GENERAL ASSESSMENT

Plant general information includes the Name, Location/Coordinates, River name, Ages, Purposes of project, Type of project, histories of project design, construction, operation, maintenance and rehabilitation. This part of data collection should include any information may not be covered in the Inspection Form and Check List for each individual component. The Plant General Inspection Form and Check List is provided as in a separate document.

7.2 DATA LIST FOR PERFORMANCE ANALYSIS

Data can be obtained from plant personnel, central engineering staff (if any), and load control personnel (if applicable):

1. <u>Operating Data</u>: Do a data survey; find out what is measured (and how well); and find out what archival data are available.

    a. Get snapshot data not averages

    b. Hourly sampling frequency

    c. For most cases, a few years' data is plenty to capture operating patterns. However, for others, more years may be appropriate to capture longer term events (e.g., market effects on dispatch, excessive outages due to reliability problems, hydrology-related patterns).

    d. Essential items for schedule analyses and operational efficiency analyses

        i. Unit power
        ii. Head Water Level
        iii. Tail Water Level
        iv. Air on or off for aerating units

    e. Other important data

        i. Winter-Kennedy Differential, Acoustic Flow Meter Output, or Other Unit Flow Rate
        ii. Spill flows
        iii. Wicket gate opening
        iv. Trash rack differential (if available)

v. Blade angle for Kaplan units
vi. Air flow rates
vii. Reservoir bathymetry (for pumped storage plants)
viii. Unit status (available/unavailable)
ix. Environmental flows (e.g., sluice flows)

2. Test Results: Get unit index test results and/or efficiency test information

    a. With aerating units, unit characteristics while aerating are very important
    b. Winter-Kennedy (or other) flow rates are very important

3. Determine how units are dispatched (e.g., generation, ancillary services, both)

4. Determine environmental constraints

5. Determine unit operating constraints

    a. Minimum flow
    b. Cavitation and vibration constraints
    c. Generator constraints

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APPENDIX A. PLANT GENERAL INSPECTION FORM AND CHECKLIST

REVISION 1.0, 12/08/2011

PLANT GENERAL INSPECTION FORM AND CHECK LIST

Plant Name: ____

Utility: ___________________________

Number of units: ____________

Location: ______________________

Coordinates:______________________

River name:________________

Date of Inspection: ___________

Design and Construction History:

Date of Commissioning: _______________

General Construction Description: ____

____

____

Are original design documents available? [Yes/No]: __________

If Yes, list available documents (e.g., calculations, design criteria, geotechnical reports):

____

____

____

For equipment, are the manufacturer’s manuals and drawings available? [Yes/No]: __________

If Yes, list available documents: ____

____

____

____

Design Capacity [MWh]: _______________

Water Storage Type [Reservoir, pumped storage, run of river, other]: ____________________

Operational History:

Inflow [ft^3/s]: _______________ Spill [ft^3/s]: _______________ Outflow [ft^3/s]: _______________

Turbine Discharge [ft^3/s]: _______________ Statutory Release [ft^3/s]: _______________

Monthly Power Generation [MWh]: ________________ (both heavy and light load hours)

Available Power Generation [MWh]: _______________ (less any required statutory releases)

Maximum Power Generation [MWh]:_______________ (assuming unlimited water is available)

Storage Changes [ft^3/s days]: ___________________

Percent use of storage capacity: __________________

Percent operating time per unit [%]: ______________ Number of Outages (Annually): _______________

Causes of Outages and Equipment Involved: ____

____

____

Changes in operation or expected changes [Yes/No]: ______________ (deviations from original design)

If Yes, describe: ____
____
____

Identify any equipment changes: ____
____
____

Additional Information: ____
____
____
____

Inspection and Maintenance History:

Are maintenance reports or inspection records available? [Yes/No]: ____________________

Frequency of Inspections: ____________________ (may vary depending on component)

Identify previous inspection /maintenance issues: ____
____
____

Have there been any major repairs [Yes/No]? If Yes, describe: _________________________________
____
____

Any notable emergency or unscheduled shutdowns [Yes/No]? If Yes, describe:
____
____
____
____

Upgrades [Yes/No]: __________ (deviations from original design or changes in operation)

Description of upgrade and impact on operation: ____
____
____
____

List inspection/data collection techniques used: ____
____
____

Additional Information:

License Status/Description: ____
____
____

Identify any regulatory agencies (such as FERC): ____
____

List applicable restrictions for upgrade/modernization (e.g., federal, local/state, environmental, financial):
____
____
____

Have all accessibility issues been identified, if Yes describe: _________________________________
____
____

List equipment requirements (Lock-out/Tag-out): ______________________________

List testing and measurement techniques: ______________________________

Preliminary upgrade or modernization opportunities: ______________________________

Plant Contacts:

Name	Contact Information:

Major Equipment Vendors:

Name	Contact Information:

General Assessment Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
A. Design and Construction History				
Has the original design criteria been obtained? *[e.g., loadings, design allowances, materials]*				
Are original design calculations available? *[e.g., hydraulic, structural, geotechnical, operational]*				
Are the as-built drawings and specifications available?				
Is there any construction information available? *[e.g., field records, field changes, construction photos]*				
Is there any geotechnical information available? *[e.g., history of seismic activity, geotechnical reports, observations]*				

General Assessment Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
B. Operational History				
Have all pertinent plant records or observations been obtained? *[e.g., leakage, settlement, vertical/horizontal movement, slope stability, geometric changes, equipment changes]*				
Has information regarding steady state flow conditions been obtained?				
Has information regarding transient flow conditions been obtained?				
Have other important operating characteristics been identified? *[e.g., gate closure times, flow restrictions]*				
Are there any future expected modifications to operation?				

General Assessment Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
C. Previous Inspection and Maintenance Reports				
Has information on past inspections been obtained? *[e.g., previous problems or concerns, frequency of inspections, testing methods, data collected, reports]*				
Have previous maintenance items been identified?				
Have any upgrades been implemented? *[Deviations from original design criteria or changes in operation]*				

General Assessment Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
D. Plant Specific Requirements				
Are there any applicable regulatory requirements? *[FERC or other governing agencies]*				
Has all equipment which will need to be Locked-Out/ Tagged-Out been identified?				
Has all the plant personnel involved been identified?				
Have all plant specific restrictions been identified? *[e.g., accessibility issues, environmental restrictions, financial restrictions]*				
Have all other plant specific requirements been identified?				

General Assessment Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
E. Inspection Details				
What is the goal of the inspection? *[e.g., improve efficiency, general maintenance, safety, life extension]*				
Have all components or features which are to be inspected been identified?				
Has proper consideration been given to scheduling? *[e.g., when is the optimal time to perform the inspection; scheduled plant outages, dewatering]*				
How often will the inspection need to take place? *[e.g., yearly, every five years? May vary depending on accessibility, component, function, past maintenance issues]* Have all equipment needs and testing/data collection methods been identified? *[ROVs, divers, NDT testing equipment, other]*				
Has a thorough and comprehensive inspection plan based on plant specific needs been developed?				

APPENDIX B. GUIDE FOR TRASH RACKS AND INTAKES CONDITION ASSESSMENT

REVISION 1.0, 12/13/2011

CONTENTS

1. GENERAL

Unforeseen failure of the trash racks and intake structure can have a devastating impact on a plant. If one of these components failed, extensive outages and equipment repair would be required. Therefore, it is important to maintain a current assessment of the condition of the trash racks and intakes and plan accordingly. Condition assessments for the intakes and trash racks are essential to estimating the economic lifespan, potential risk of failure, and to evaluate the benefits and cost of necessary upgrades.

The following three step analyses are necessary to arrive at a condition indicator for the intakes and trash racks:

1) What parts/items should be included for an intake and trash rack condition assessment and which parts/items are more important than others (parts and their weighting factors)?

2) What metrics/parameters should be investigated for quantitative condition assessment and which ones are more important than others (condition parameters and their weighting factors)?

3) How to assign numerical scores to the intake and trash rack parts (rating criteria)?

This appendix provides guides to answer the above questions, which can be applied to all intakes and trash racks. This condition assessment must be performed for each intake and trash rack. Even if the components appear to be identical, one may have experienced different Operation & Maintenance (O&M) and would arrive at different values for the condition indicators. The guide provided in this appendix cannot quantify all factors that affect the condition of an individual trash rack or intake. Mitigating factors not included in this guide may trigger testing and further evaluation to determine the final score of the component condition.

This appendix is not intended to define intake and trash rack maintenance practices or describe in detail inspections, tests, or measurements.

2. CONSTITUENT PARTS ANALYSIS

A typical trash rack consists of the trash rack structure, trash rake, trash conveyor, and monitoring system. Other common structural items in this location will be the intake structure, stoplogs/bulkhead gates, air vents, and hoisting machinery. These components are listed in Table 1 (references to HAP Taxonomy).

If any component does not exist, this part will be excluded from scoring mechanism by inputting "NA" into the table. The effect of one component exclusion is usually insignificant to the entire system assessment and does not justify an adjustment of the weighting factors for the other components.

3. METRICS FOR TRASH RACK AND INTAKE CONDITION ASSESSMENTS

Table B-1 lists the following five parameters that are considered for condition assessment of trash racks and intakes:

- The Physical Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on previous testing and measurements, historical O&M records, original design drawings, previous rehabilitation feasibility study reports (if conducted), interviews with plant staff and some inspections if possible.

The Data Quality Indicator, shown in Section 6.0 of this report, is an indicator used to determine the quality and confidence of available information and information used for the condition assessment. In some cases, data may be missing, out-of-date or of questionable integrity. Any of these situations could affect the results of condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed component to indicate the data availability, accuracy, and the confidence of the given condition ratings (MWH 2010).

4. WEIGHTING FACTORS

There are two categories of weighting factors in Table B-1. It is recognized that some condition parameters affect the component condition to a greater or lesser degree than other parameters. Also some parts are more or less important to the overall plant generation than others. These weighting factors should be pre-determined by consensus among experienced hydropower engineers and plant O&M experts during the HAP process development. The range of absolute values of weighting factors will not affect the Condition Indicator of a trash rack or intake, which is calculated in Section 6.0 of this report.

Table B-1. Typical condition assessment and scoring

Trash Racks and Intakes for Unit ___	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Trash Racks	3.1.1							2.0
Trash Rake	3.1.2							2.0
Trash Conveyor	3.1.3							1.5
Monitoring System	3.1.4							1.0
Intake Structures/Construction	3.2.1							3.0
Intake Gates	3.2.2							1.5
Bulkhead Gate/Stoplogs	3.2.3							1.0
Hoisting Machinery	3.2.4							1.0
Air Vent and Water Filling Valve	3.2.5							1.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	0.00
							Condition Indicator -->	0.00

5. RATING CRITERIA

Physical Condition: Rating Criteria for Trash Racks and Intakes

Physical Condition of the trash racks refer to those features that are observable or detected through measurement and testing. This includes surface roughness from corrosion, pitting, cracking damage, and hydraulic flow condition at the trash racks and intake. The surface condition of the trash rack is important because of its direct impact on efficiency and potential equipment damage. A wide range of surface deterioration is possible on trash racks. Uneven and restricted flow can be caused by minor surface deterioration and increase as the corrosion worsens. Significant corrosion can lead to substantial section loss and possible failure of trash racks, leaving generating equipment unprotected from reservoir debris. Therefore, the trash racks should have the surface conditions carefully evaluated with reference to the Trash Racks and Intakes Best Practice during the assessment.

For HAP site assessment, it is important to gather as much site specific information as possible regarding the trash rack and intake. This can include but is not limited to technical reports, design drawings, and maintenance history. Interview and discuss trash racks and intakes with the relevant plant personnel to assist in the physical condition scoring of these items. The results of all related information are analyzed and applied to Chart 1 to assign the condition scores.

Chart 1 Trash Rack and Intake Physical Condition Rating Criteria

Physical Condition Description		Physical Condition Score
Excellent	Limited corrosion or cavitation of intake interiors, intake structures, and trash racks and components; limited concrete spalling or cracking of concrete intakes; no significant damage to trash racks and intakes due to debris; intake liner or coating is in good condition; Trash rake, conveyor, and monitoring systems and air valves are regularly tested and functioning properly; gates and hoisting equipment are in good condition and functioning properly; gate seals and slots are in good condition.	**8 – 10**
Good	Moderate corrosion or cavitation of intake interiors, intake structures, and trash racks and components; moderate concrete spalling or cracking of concrete intakes; minor damage to trash racks and intakes due to debris; intake liner or coating is in good condition; Trash rake, conveyor, and monitoring systems and air valves are tested and functioning; gates and hoisting equipment are adequate and functioning; gate seals and slots are adequate.	**5 – 7**
Fair	Large areas of corrosion or cavitation of intake interiors, intake structures, and trash racks and components; large areas of spalling and cracking of concrete intakes; moderate damage to trash racks and intakes due to debris; intake liner or coating is less than adequate; Trash rake, conveyor, and monitoring systems and air valves are not regularly tested but regularly exercised; gates and hoisting equipment are in fair condition; gate seals and slots are less than adequate.	**3 – 4**
Poor	Severe corrosion or cavitation of intake interiors, intake structures, and trash racks and components; severe spalling and cracking of concrete intakes; significant damage to trash racks and intakes due to debris; intake liner or coating is inadequate; Trash rake, conveyor, and monitoring systems and air valves are not regularly exercised; gates and hoisting equipment are in poor condition and are not functioning properly; gate seals and slots are in poor condition.	**0 – 2**

Age: Rating Criteria for Trash Rack and Intake Parts

Age is an important factor to consider when analyzing degradation and potential improvements for the trash racks. All components are subject to a finite life expectancy. The life can be extended and the decline limited in some instances by performing preventative and routine maintenance. However, as the age of the trash racks and intakes increases it will become more susceptible to failure and more likely to negatively affect plant efficiency.

Age scoring is relatively less objective than other condition parameters. The detailed scoring criteria developed in Chart 2 will allow the age score to be automatically generated in the HAP Database by the actual years of the installed part. The trash racks, conveyors, rakes and hoisting machinery usually have an expected lifespan of approximately 30 years. Other parts such as gates and stoplogs have a life expectancy of 80 years. These life expectancies can vary, such as when innovative construction materials or technology is used. For example, the life expectancy for a steel trash rack is typically 15–35 years whereas a plastic or fiberglass trash rack can be expected to past 25–50 years. The age scoring criteria for various parts are shown in Chart 2.

Chart 2 Age Rating Criteria for Trash Rack and Intake Parts

Age of Intake, Intake Structures, Intake Gates, and Stoplogs/Bulkhead Gates	Age Score	Age of Trash Rack, Trash Rake, Trash Conveyor, Air Vents, and Hoisting Machinery
< 30 Years	**8 – 10**	< 10 Years
30-60 Years	**5 – 7**	10 to 20 Years
60-80 Years	**3 – 4**	20 to 30 Years
> 80 years	**0 – 2**	> 30 years

Installed Technology Level: **Rating Criteria for Trash Rack and Intake Parts**

The Installed Technology Level indicates advancement levels of trash rack design, materials, and corrosion protection. Substantial improvements have been made in trash rack designs. The intake angle can be changed or a more hydrodynamic bar shape can be used to reduce head loss. These bars can also be designed such that cleaning is easier and more effective. Improvements in materials used for trash racks include grates constructed of stainless steel, fiber reinforced polymer (FRP), and high density polyethylene (HDPE) to improve corrosion resistance. Another effective method of reducing corrosion is to use cathodic protection systems on the trash rack structure.

Intake improvements are more difficult in most cases to implement because of the larger costs associated with the modifications. Common improvements include installation of turning vanes or splitter walls to improve intake flow and in extreme cases changes can be made to the intake geometry.

Scoring the Installed Technology Level requires historic knowledge of the intakes and trash racks. The material used for construction of the trash rack is a factor to consider for scoring the installed technology level. As discussed above, new innovations have been made using stainless steel, FRP, and HDPE to construct trash racks. See Chart 3 for technology rating criteria.

Chart 3 Trash Rack and Intake Technology Rating Criteria	
Technology Levels of Design and Construction	**Score for Installed Technology Level**
The technology has not been changed significantly since the component was installed; and the installed technology was supplied by brand name companies with great reputation	**8 – 10**
The technology has been more or less advanced but no problem to supply the matching parts in next 5-10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may reduce the cost of replacement). The installed technology was supplied by medium companies with good reputation.	**4 – 7**
The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability of power generation. The installed technology was supplied by small companies with bad reputation.	**0 – 3**

Operating Restrictions: Rating Criteria for Trash Rack and Intake Parts

The trash rack and intake Operating Restrictions refer to the current system limitations such as internal pressures, power capacity, and flow. Operational limitations play a role in determining the serviceability of the unit: the greater the limitations, the greater the generation loss.

Operating restrictions can be caused by to two sources:

1) The trash rack and intake itself. To limit deterioration or to ensure structural safety, the operating ranges of maximum and minimum pressures and flows are constrained due to the limitations of the original design and/or the current deteriorated physical condition.

2) Environmental restrictions due to habitat maintenance, water quality issues (i.e., Dissolved Oxygen), recreational requirements, or fish passage. These restrictions can affect minimum required flows and thus affect the water flows available for power generation. Other environmental restrictions can stem from changes in flow conditions due to climate change.

The operational constraints of trash racks and intakes do not include the constraints from other components within the facility, although they can affect the unit and plant generations. For example, if the water level in the headwater reservoir is limited due to dam safety concerns, then the dam (not the trash rack and intake) will receive a lower score for operating restrictions.

Chart 4 describes the ratings of operating restrictions.

Chart 4 Trash Rack and Intake Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes and the original design has no constraints on the required operation. Tested as Required; no known design and operational inefficiencies.	**8 – 10**
Minimal restraints: Operation range can be expanded with revised component selection and design. No known design and operational inefficiencies.	**5 – 7**
Moderate restraints: The operation range and performance can be significantly improved with revised component design.	**3 – 4**
Severe limitations: The component does not meet the operational criteria, not tested as required, or has a known design and operational deficiency.	**0 – 2**

Maintenance Requirement: **Rating Criteria for Parts**

The amount of corrective and preventative maintenance that has been or must be performed is usually an indication of the component condition. Typically the component condition will be better when more preventative maintenance has been performed. Conversely, when frequent corrective maintenance has been performed this will usually indicate a poorer component condition.

Other factors to consider for maintenance scoring include:

- The reoccurring need of maintenance or problems;
- Previous related failures of parts;
- Failures or problems of parts with similar design.

The results of maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5 to score the intake and trash rack parts.

Chart 5 Trash Rack and Intake Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Condition Score**
Minimum level (normal condition): A small amount of routine preventive maintenance is required. No corrective maintenance.	**9 – 10**
Low level: Small amounts of corrective maintenance. Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis.	**7 – 8**
Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages.	**5 – 6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., corrosion caused leaks).	**3 – 4**
Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required.	**0 – 2**

Data Quality: Rating Criteria for Trash Rack and Intake Parts

The Data Quality scores reflect the quality of the inspection, test, and measurement results to evaluate the condition of trash rack and intake parts. The more current and complete the inspection, testing, and measurement results are the higher the Data Quality scores. The frequency of normal testing is as recommended by the HAP assessment team in conjunction with industry standards.

Reasonable efforts should be made to perform visual inspections and collect data (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports) to aid the current assessment. However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is “Good” or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of trash rack and intake components are shown in Chart 6.

Chart 6 Trash Rack and Intake Data Quality Rating Criteria	
Data Availability, Integrity, and Accuracy	**Data Quality Score**
High - The maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurements were performed within normal frequency in the plant. The required data and information is available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8 – 10**
Medium - One or more of the routine inspections, tests and measurements were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 – 7**
Low - One or more of the routine inspections, tests, and measurements were completed 24-36 months past the normal frequency, or some of the results are not available.	**3 – 4**
Very Low - One or more of the required inspections, tests, and measurements were completed >36 months past the normal frequency, or significant portion of the results are not available.	**0 – 2**

6. TRASH RACK AND INTAKE CONDITION AND DATA QUALITY INDICATORS

In Table B-2, the final condition score called the Condition Indicator (CI) for the trash rack and intake can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J) \times F(K) \times F(J)}{\sum_{K=1,M}^{J=1,5} F(K) \times F(J)} \tag{1}$$

The trash rack and intake Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K) \times F(K)}{\sum_{K=1,M} F(K)} \tag{2}$$

Here, M = the total number of parts/items associated with a trash rack or intake; K = the identification No. of trash rack or intake parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of a part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a trash rack or intake part.

7. REFERENCES

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TRASH RACKS AND INTAKES INSPECTION FORM AND CHECKLIST

REVISION 1.0, 12/12/2011

Trash Rack and Intake: Inspection Form

General Information:

Date of Site Visit: ____________________ Unit No. __________

Plant name: ____________________

Sources of data: ____________________

Manufacturer: ____________________ Age: __________

General Trash Rack Description and Condition: ____________________

General Intake Description and Condition: ____________________

Inspection Objective: ____________________

Previous Inspection History and Maintenance Repairs: ____________________

Method of Cleaning Trash Racks of Debris: ____________________

Method of Removing Debris from Plant: ____________________

Table 1: Trash Racks		
Trash Rack Number	Differential Head (ft)	
	Clean	Clogged

Trash Rack and Intake Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
A. General				
What is the general construction of the trash racks? *[e.g., materials (steel, HDPE, FRP), bar shape, age, type of connections]*				
What is the general intake construction? *[e.g., type of intake (submerged vs. non-submerged and multilevel or single inlet), penstock (buried or exposed), construction materials (steel, concrete, or unlined tunnel)]*				
Are the trash racks and intakes accessible for inspections? *[Can visual assessment of trash racks be performed from the surface? Will divers or ROVs be required? Other limitations on accessibility?]*				
Have all plant records regarding trash rack and intake maintenance, repairs, operating conditions, performance data, etc. been requested/gathered?				
B. Head Differential				
How is head differential monitored at the plant?				
If the plant does not monitor head differential, can measurements be taken during the assessment? *[If yes then record measurements in Table 1 found on page 4]*				
How much head differential is there at various levels of cleanliness? *[Trash racks are clean, partially clogged, or severely clogged]*				
Is head differential data used to schedule/automate trash cleaning? *[i.e., when head differential reaches a certain value the trash racks are cleaned]*				

Trash Rack and Intake Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
C. Design/Damage				
Are the original trash racks still in use?				
If the trash racks have been replaced, what changes were made to their design and why were these changes made? *[e.g., bar shape, bar spacing, material, connections]*				
Has there been any history of severe trash rack degradation or trash rack failure? *[If so, what were the causes?]*				
D. Debris				
What size debris is typically captured on the trash racks? *[e.g., aquatic milfoil, tree trunks]*				
How does debris accumulation vary seasonally? *[Which periods of the year is debris the heaviest? Does the type of debris vary by season?]*				
E. Automation/Mechanization				
What is the history of trash rack cleaning methods? *[What methods were originally used to clear debris? What is the reason for any changes that may have occurred?]*				
How is debris removed from the trash racks? *[Manually or mechanically?]*				
How is debris removed from the plant? *[Manually or conveyor system?]*				
If a mechanical trash raking system is used, how is its cleaning schedule regulated? *[e.g., manually, timed, automated using head differential measurements]*				

Trash Rack and Intake

Assessment Conclusions and Recommendations:

APPENDIX C. GUIDE FOR PRESSURIZED WATER CONVEYANCE SYSTEM CONDITION ASSESSMENT

REVISION 1.0, 12/13/2011

CONTENTS

1. GENERAL

Pressurized water conveyances such as penstocks and tunnels are an important component in the power generation process at a hydropower facility. Penstocks and tunnels are pressurized conduits that transport water to the turbine with maximum hydraulic performance. Since penstocks and tunnels are subject to internal pressures and rapid flow velocities, they are likely to experience several maintenance and reliability issues. These issues can include:

- Deterioration of linings and coatings
- Corrosion/thinning of steel shell and other steel components
- Leakage at joints/couplings
- Erosion or cavitation
- Organic growth on interior surfaces
- Localized buckling
- Air vent blockage or pressure relief valve malfunction
- Foundation settlement
- Slope instabilities
- Sedimentation

Emergency repairs, unscheduled maintenance, or replacement of water conveyance system components can be very costly. Therefore, routine maintenance and condition assessments are important in extending the life expectancy of conveyance components, limiting unscheduled shutdowns, and improving hydraulic performance by minimizing head losses. By performing a condition assessment, plants can estimate the remaining component life expectancy, identify potential failure risks, and evaluate the benefits of component upgrades.

For a water conveyance system, the three following steps are necessary to establish its condition indicator:

1) What parts/items are to be included in the condition assessment and what is their level of importance (parts and their weighting factors)?

2) What metrics/parameters are to be investigated for the quantitative condition assessment and what is their level of importance (condition parameters and their weighting factors)?

3) How to assign numerical scores to the parts (rating criteria)?

This appendix provides guides to help answer the questions above, which can be applied to penstocks, tunnels, and surge tanks. The condition assessment is to be performed on the pressurized water conveyance system for an individual unit. This can include a wide variation in arrangement schemes. Figures 1a, 1b, and 1c represent three separate schemes often found in hydropower facilities. Since plants can have a large variation in the arrangement of water intakes and conveyances, the guides provided in this appendix cannot quantify all factors which can affect individual conveyance conditions. Mitigating factors not included in this Guide may trigger testing and further evaluation to determine the final score of the water conveyance condition and aid in the decision of component replacement or rehabilitation.

This appendix is not intended to define pressurized water conveyance maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2. CONSTITUENT PARTS ANALYSIS

For pressurized water conveyance systems, the constituent parts need to be mapped and determined for a specified unit, as some parts are commonly used by two or more units. Tables C-1, C-2, and C-3, respectively, coincide with the three different system design schemes shown in Figure C-1, C-2, and C-3 for Unit 1.

If any part (e.g., surge tank) does not exist in a particular pressurized conveyance system, this part will be excluded from scoring mechanism by inputting "NA" into the table. The effect of one component exclusion is usually insignificant to the entire system assessment and does not justify an adjustment of the weighting factors for the other components.

Table C-3 can be applied for all three conveyance system schemes by inputting "NA" for the parts that do not exist in the schemes in Figures C-1 and C-2.

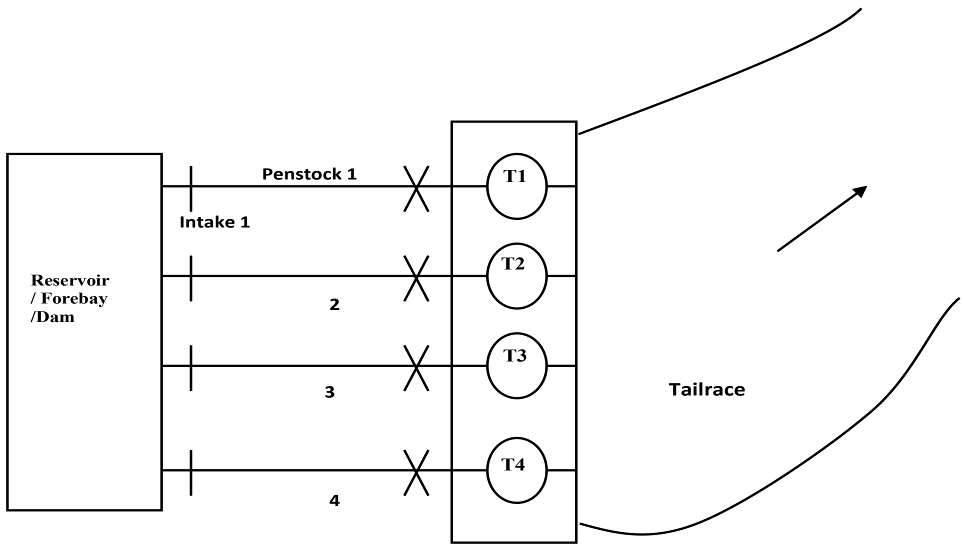

Figure C-1. Scheme A: single unit penstock.

Table C-1. Scheme A pressurized water conveyance condition assessment and scoring: XXX Hydropower Plant (Unit 1)

Parts/Items for Unit 1	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Penstock 1	3.4.1							3.0
Linings and Coatings	3.4.3							1.0
Foundation and Supports	3.4.4							1.0
Air Vent/Pressure Relief Valve	3.4.5							1.0
Joints and Couplings	3.4.6							1.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	0.00
							Condition Indicator -->	0.00

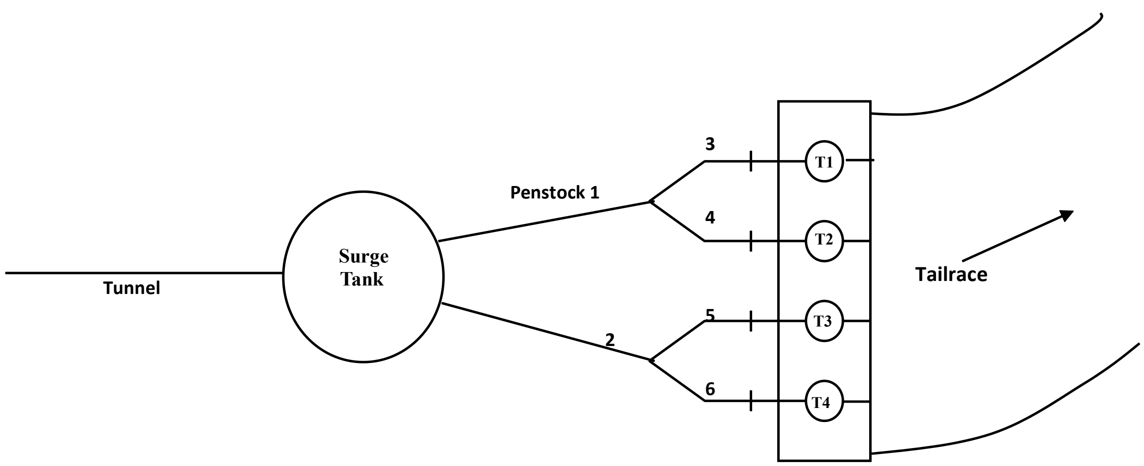

Figure C-2. Scheme B: group shared penstock.

Table C-2. Scheme B pressurized water conveyance condition assessment and scoring: XXX Hydropower Plant (Unit 1)

Parts/Items for Unit 1	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Tunnel	3.3							2.0
Surge Tank	3.6							1.5
Penstock 1	3.4.1							3.0
Penstock 3	3.4.1							2.0
Bifurcation 1	3.4.2							1.0
Linings and Coatings	3.4.3							1.0
Foundation and Supports	3.4.4							1.0
Air Vent/Pressure Relief Valve	3.4.5							1.0
Joints and Couplings	3.4.6							1.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	*0.00*
							Condition Indicator -->	*0.00*

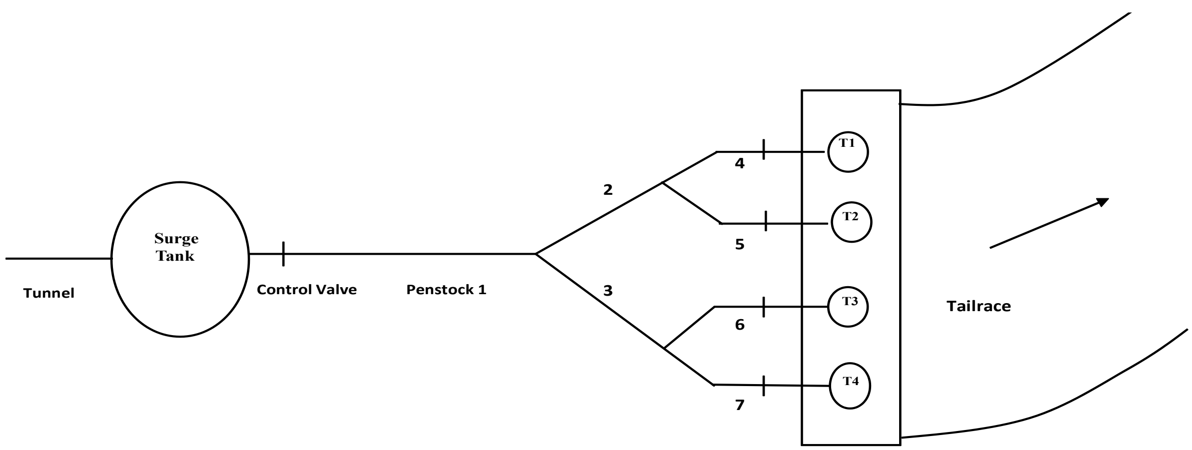

Figure C-3. Scheme C: plant shared penstock.

Table C-3. Scheme C pressurized water conveyance condition assessment and scoring: XXX Hydropower Plant (Unit 1)

Parts/Items for Unit 1	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Tunnel	3.3							2.0
Surge Tank	3.6							1.5
Penstock 1	3.4.1							3.0
Penstock 2	3.4.1							2.0
Penstock 4	3.4.1							2.0
Bifurcation 1	3.4.2							1.0
Bifurcation 2	3.4.2							1.0
Linings and Coatings	3.4.3							1.0
Foundation and Supports	3.4.4							1.0
Air Vent/Pressure Relief Valve	3.4.5							1.0
Joints and Couplings	3.4.6							1.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	*0.00*
							Condition Indicator -->	***0.00***

3. METRICS FOR CONDITION ASSESSMENT

As listed in Tables C-1, C-2, and C-3, the following five condition parameters are considered for the condition assessment of pressurized water conveyances:

- The Physical Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on previous testing and measurements, historical Operation and Maintenance (O&M) records, original design drawings, previous rehabilitation feasibility study reports if available, interviews with plant personnel, and inspections for wherever accessible.

It can be noted that there is a certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmark condition assessment (without specific testing and measurements conducted on site) these five parameters are regarded as providing the basis for assessing the condition of pressurized water conveyance systems and components (i.e., penstocks).

In addition, the Data Quality Indicator, as an independent metrics, is to reflect the quality of the available information and the confidence of the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity. Any of these situations could affect the results of the condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed component to indicate the data availability, integrity, and accuracy; and the confidence of the given condition ratings (MWH 2010).

4. WEIGHTING FACTORS

There are two categories of weighting factors in Table C-1, Table C-2, and Table C-3. It is recognized that some condition parameters affect the condition to a greater degree than other parameters. Also, some parts are more or less important than other parts to the entire conveyance system. These weighting factors should be pre-determined by consensus among experienced hydropower engineers and plant O&M experts. Once they are determined, they should be largely fixed from plant to plant for similar conveyance system arrangements. Depending on the refining process during the demonstration and baseline assessments, the weighting factors for the parts/items of water conveyance system may have to be adjusted for some plants. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors will not affect the Condition Indicator of a conveyance system, which is the weighted summation of all scores assigned to the components and five condition parameters.

5. RATING CRITERIA

Physical Condition: Rating Criteria for Pressurized Water Conveyances

Physical Condition of pressurized water conveyance components refers to those features that are observable or detected through measurement and testing. It includes corrosion or cavitation of shell or tunnel liners, presence of organic growth on interior surfaces, shell thinning, localized buckling of penstock shell, leakage, slope stability, tunnel erosion, hydraulic flow conditions inside the water conveyance system, etc. The surface of the conveyance is important since increased surface roughness can affect efficiency by increasing head losses. Excessive leakage can lead to uncontrolled water losses which can also affect efficiency. In addition to efficiency related issues, evidence of severe corrosion, shell thinning, or localized buckling may indicate a safety issue or potential component failure. Thus, they should be carefully evaluated. The Best Practices for Penstocks, Tunnels and Surge Tanks can assist in evaluating the physical condition. For HAP site assessment, it is important to interview and discuss with plant personnel to score the physical condition of the water conveyance. The results of all related information are analyzed and applied to Chart 1 to assign the condition scores.

Chart 1 Pressurized Water Conveyance Physical Condition Rating Criteria		
Physical Condition Description		Physical Condition Score
Excellent	Limited corrosion or cavitation on the liners of water passage; limited organic growth on interior surfaces; no localized buckling of penstock shell; coating is in good condition; minimum leakage at joints/couplings; the air valve or pressure relief valve is regularly tested and functions well; the foundation and slope of penstock is stable and in good condition.	8 – 10
Good	Moderate corrosion or cavitation on the liners of water passage; moderate organic growth on interior surfaces; slight localized buckling of penstock shell; coating is in good condition; slightly increased leakage at joints/couplings; the air valve or pressure relief valve is tested and functions; the foundation and slope of penstock is stable and in adequate condition (i.e., minimal cracking or signs of erosion).	5 – 7
Fair	Large area of corrosion or cavitation on the liners of water passage; moderate organic growth on interior surfaces; slight localized buckling of penstock shell; coating is less than adequate; seals and seats have some damage with minor leakage at joints/couplings; the air valve or pressure relief valve is regularly exercised; the foundation and slope of penstock is stable and in fair condition (i.e., moderate cracking or erosion).	3 – 4
Poor	Severe corrosion or cavitation on the liners of water passage; severe organic growth on interior surfaces found; localized buckling of penstock shell; coating is inadequate; seals and seats have severe damage with minor leakage at joints/couplings; the air valve or pressure relief valve is not regularly exercised; the foundation and slope of penstock is unstable and in poor condition (i.e., severe cracking or erosion).	0 – 2

Age: Rating Criteria for Pressurized Water Conveyances

Age is an important factor when considering component or system upgrade as it can be an indication of performance degradation. As water conveyances age, they become more susceptible to wear due to vibrations, rapid flow velocities, and varying internal pressures. Not only does increased wear result in operational problems and loss of efficiency, it can also increase the risk of sudden failure.

Age scoring is relatively more objective than other condition parameters. The detailed scoring criteria developed in Chart 2 allow the age score to be automatically generated in the HAP Database by the actual years of the installed part. Liners typically have a maximum life span of 25 to 30 years depending on the type of liner material and application, whereas, water conveyance structural parts (i.e., penstock shell) can last up to 80 years with routine and proper maintenance. Older liners generally have increased surface roughness which can lead to frictional head losses. By replacing liners that are nearing the end of their life span, plants have the opportunity to install a more hydraulically efficient liner. The age scoring criteria for various components are shown in Chart 2.

Chart 2 Age Rating Criteria for Pressurized Water Conveyance Parts		
Age of Penstock, Bifurcation, Surge Tank, Tunnel, Foundation and Supports, and Joints/Couplings	**Age Score**	**Age of Coatings/Linings and Air Vents/Pressure Relief Valves**
< 30 Years	**8 – 10**	< 10 Years
30-60 Years	**5 – 7**	10 to 20 Years
60-80 Years	**3 – 4**	20 to 30 Years
> 80 years	**0 – 2**	> 30 years

Installed Technology Level: Rating Criteria for Pressurized Water Conveyances

The Installed Technology Level indicates advancement in pressurized water conveyance design, installation/construction techniques, liner/coating materials and application process, and other component materials which may affect unit performance. Outdated technology may cause difficulties for supplying replacement parts or performing routine maintenance which can result in prolonged outages.

Scoring the Installed Technology Level requires historic knowledge of water conveyance technology advancement and familiarity with industry standards and materials. For example, penstock lining technology has advanced significantly since the 1980s with the use of silicone and epoxy liners. Therefore, penstocks lined prior to the 1980s or those lined with coal tar enamels would receive a lower score than those lined in the 1990s or later. The overall arrangement and design of the pressurized water conveyance system is another factor to consider for scoring the Installed Technology Level. With advances in computer modeling, designers are able to provide a more hydraulically efficient arrangement while limiting erroneous design inputs. Other factors can include advances in tunneling technology, penstock joints (riveted joints versus bolting or welding), and improved penstock shell materials.

The competence, professionalism, and reputation of the original suppliers could also impact the Installed Technology Levels. As compared to large and well-known manufacturers, the components supplied or installed by small, unknown companies would get lower scores. The installed technology scoring criteria for various components are shown in Chart 3.

Chart 3 Pressurized Water Conveyance Technology Rating Criteria	
Technology Levels of Design and Construction	**Score for Installed Technology Level**
The technology has not been changed significantly since the component was installed; and the installed technology was supplied by brand name companies with great reputation	**8 – 10**
The technology has been more or less advanced but no problem to supply the matching parts in next 5-10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may reduce the cost of replacement). The installed technology was supplied by medium companies with good reputation.	**4 – 7**
The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability of power generation. The installed technology was supplied by small companies with bad reputation.	**0 – 3**

Operating Restrictions: Rating Criteria for Pressurized Water Conveyances

The Operating Restrictions refers to the current limitations on the operating ranges including internal pressures, power capacity, and flow. Either under-sized or under-utilized capacity may reduce the overall operational efficiencies and accelerate the deterioration of the water conveyance physical condition. Operational limitations play a role in determining the serviceability of the unit: the greater the limitations, the greater the generation loss.

Operating restrictions can be caused by to two sources:

1) The conveyance system itself. To limit deterioration or to ensure structural safety, the operating ranges of maximum and minimum pressures and flows are constrained due to the limitations of the original design and/or the current deteriorated physical condition.

2) Environmental restrictions due to habitat maintenance, water quality issues (i.e., Dissolved Oxygen), or fish passage. These restrictions can affect minimum required flows and thus change the current available flow conditions for the existing water conveyance system. Other environmental restrictions can stem from changes in flow conditions due to climate change. However, any constraints from other components within the facility, which may affect the unit and plant generations, will not be included in the constraints of pressurized water conveyances. For example, if the water level in the headwater reservoir is limited due to dam safety concerns, then the dam (not the water conveyance system) will receive a lower score for operating restrictions.

Chart 4 describes the ratings of operating restrictions.

Chart 4 Pressurized Water Conveyance Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes, and the original design has no constraints on the required operation. Tested as Required; no known design and operational inefficiencies.	**8 – 10**
Minimal restraints: Operations to avoid minor rough zones; operation range can be expanded with revised equipment selection and design. No known design and operational inefficiencies.	**5 – 7**
Moderate restraints: Operations to avoid large rough zones with high vibration. The operation range and performance can be significantly improved with revised system design.	**3 – 4**
Severe limitations: The equipment does not meet the operational criteria or not tested as required or has a known design and operational deficiency.	**0 – 2**

Maintenance Requirement: Rating Criteria for Pressurized Water Conveyances

The amount of corrective maintenance that either has been or must be performed is an indication of the water conveyance condition. If the conveyance system has required limited or no maintenance, then that is an indication that the system is in good condition. If a component has required extreme corrective maintenance resulting in unscheduled or forced outages, then the component is considered to be in poor condition.

Other factors to consider for maintenance scoring include:

- Maintenance needs are increasing with time or problems are re-occurring
- Experiencing frequent rough-zone operations
- Previous failures related to pressurized water conveyances
- Failures or problems with pressurized water conveyances of similar design and material

The results of the maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5.

Chart 5 Pressurized Water Conveyance Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum level (normal condition): A small amount of routine preventive maintenance is required. No corrective maintenance.	**9 – 10**
Low level: Small amounts of corrective maintenance. Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis.	**7 – 8**
Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages.	**5 – 6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., corrosion caused leaks).	**3 – 4**
Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required.	**0 – 2**

Data Quality: Rating Criteria for Pressurized Water Conveyance Components

The Data Quality score reflects the quality of the inspection, test, and measurement results used to evaluate the pressurized water conveyance system. The more current and complete the inspection, tests, and measurement results are, the higher the Data Quality scores. The frequency of normal testing is as recommended by the HAP assessment team in conjunction with industry standards.

Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality are developed in Chart 6.

Chart 6 Pressurized Water Conveyance Data Quality Rating Criteria	
Data Availability, Integrity and Accuracy	**Data Quality Score**
High – The maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurement were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8 – 10**
Medium – One or more of routine inspections, tests and measurement were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 – 7**
Low – One or more of routine inspections, tests and measurement were completed 24-36 months past the normal frequency, or some of results are not available.	**3 – 4**
Very Low – One or more of required inspections, tests and measurement were completed >36 months past the normal frequency, or significant portion of results are not available.	**0 – 2**

6. CONDITION AND DATA QUALITY INDICATOR

In Table C-1, C-2, or C-3, the final condition score of the pressurized water conveyance (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J) \times F(K) \times F(J)}{\sum_{K=1,M}^{J=1,5} F(K) \times F(J)} \quad (1)$$

The Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts:

$$DI = \frac{\sum_{K=1,M} S_D(K) \times F(K)}{\sum_{K=1,M} F(K)} \quad (2)$$

Here, M = the total number of parts associated with a pressurized water conveyance; K = the identification No. of parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of a part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific testing, such as penstock shell thickness measurements, would more directly reveal the condition of the pressurized water conveyance.

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PRESSURIZED WATER CONVEYANCE INSPECTION FORM AND CHECKLIST

REVISION 1.0, 12/12/2011

Penstocks, Tunnels, & Surge Tanks: Inspection Form

General Information:

Date of Site Visit: ____________________
Plant Name: ____________________
Source(s) of Data: ____________________
Number of Units: ____________________ Unit Inspected: ____________________
Description of General Arrangement (i.e., Group Shared Penstock): ____________________

General Construction Description: ____________________

Age of Conveyance (Tunnels or Penstocks): ____________ Penstock Diameter (ft):____________
Exposed Length (ft):____________ Buried Length (ft): ____________
Accessibility for Visual Inspection: ____________________

Previous Condition Assessment Date(s): ____________________

Chronic Issues or Maintenance (Routine and Corrective): ____________________

Description of Gate Types and Configuration: ____________________

Description of Liners (if applicable): ____________________

Age of Liner [Yrs]: ____________
Liner Material: ____________________
Previous Maintenance Issues with Liner [If yes, describe]:____________________

Estimated Life Remaining for Liner [Yrs]: ____________

Tunnels:

Surge Tanks:

Penstocks:

Bifurcations:

Linings and Coatings:

Foundation and Supports:

Air Vent/Pressure Relief Valve:

Joints and Couplings:

Table 1: Pressurized Water Conveyances						
Intake Number	Shell Thickness (in.)			Diameter: Penstock or Tunnel (in.)		
	Location 1	Location 2	Location 3	Location 1	Location 2	Location 3

Penstocks, Tunnels, & Surge Tanks Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
A. General Information				
What are the plant specific life and serviceability needs for the pressurized water conveyance system?				
Identify the appropriate testing techniques to be used. *[e.g., this will depend on accessibility, construction materials, plant requirements, safety restrictions]*				
Identify any testing techniques or equipment required for the plant walk down. *[e.g., depends on accessibility, plant requirements, safety restrictions, construction materials]*				
Have all plant records regarding maintenance repairs, operating conditions, performance data, etc. been requested/gathered?				

Penstocks, Tunnels, & Surge Tanks Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
B. Interior Condition				
Is there evidence of previous repair work? *[If so, what type of repair and are they listed in previous reports? List any changes in condition and repair effectiveness.]*				
Is material buildup (protrusions) or debris present? If yes, what is the extent and severity of buildup? What is the type and apparent source of debris? *[Buildup could be due to organic growth, calcium deposits, liner degradation, marine organisms, etc. Large amounts of debris could indicate a trash rack failure.]*				
If concrete structure, is cracking visible? If so, create a crack map listing the location, severity, and type of cracking.				
If concrete structure, is spalling, erosion, cavitation, or other deterioration present? If so, list the location, severity, and potential causes. *[e.g., causes can be surface irregularities, high flow at transition areas, high sediment]*				
If steel is present, is there visible damage from cavitation or abrasions to the surface? *[e.g., Causes can be surface irregularities, high flow at transition areas, high sediment]*				
If steel is present, is there evidence of corrosion, rust, shell thinning, or cracking? *[If so, use an ultrasonic thickness measuring device to determine thickness loss and document these results.]*				

Penstocks, Tunnels, & Surge Tanks Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
B. Interior Condition (Continued)				
For unlined tunnels, is rock/debris fallout or cavities in the tunnel walls present? *[If so, to what extent (i.e., localized or widespread) and how severe?]*				
Is there visible leakage occurring at gates? If yes, where and has it been previously documented? What are possible causes? *[e.g., at the seals, guides, gate assembly]*				
Is cracking of the liner visible (deep cracks or mud-cracking) *[Look for surface cracking or deep cracks which extend through the liner to the shell]*				
Is there apparent damage to the surface of the liner? *[Damage to liner may indicate loose debris in penstock or intake from either deteriorated liner/tunnel or issues with the trash racks]*				
Is there evidence of adhesion loss or de-lamination of the liner? *[Look for flaking or lifting of the liner or blistering. If present, it may be necessary to perform adhesion testing]*				

Penstocks, Tunnels, & Surge Tanks Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
B. Interior Condition (Continued)				
Are there any pin-holes, voids in the liner or areas where the liner is missing? [*Is the shell material visible?*]				
Are there any other indications of liner deterioration?				
Is there evidence of localized buckling (circumferential buckling) of the penstock shell? [*Can result from inadequate provisions for expansion and contraction due to thermal changes]*				
C. Geometric Observations (Penstocks)				
Are there signs of ovalization (out-of-roundness), distortions, or flat spots? [*Measure diameter both horizontally and vertically at various increments along the penstock's length]*				
Are there signs of misalignment? [*Look for cracks in thrust blocks, cracks in the surrounding earth, ovalling, misalignments at joints/connections*]				

Penstocks, Tunnels, & Surge Tanks Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
D. Exterior Condition				
Is there evidence of previous repair work? *[If so, what type of repair and are they listed in previous reports? List any changes in condition and repair effectiveness.]*				
If concrete structure, is cracking visible? If so, create a crack map listing the location, severity, and type of cracking.				
Is the penstock under hydrostatic pressure and has all debris or slides covering the penstock been removed? [*This is the preferred method for exterior inspections of penstocks*]				
Are there areas of distress in the penstock coating? *[Look for stretching, cracking, or broken areas. This could indicate hidden problems in the base materials.]*				
Are there any signs of leakage or coating degradation?				

Penstocks, Tunnels, & Surge Tanks Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
D. Exterior Coating/Surface Condition				
Are there any rust blisters, stains or other signs which could indicate corrosion of the steel base material?				
For bolted/riveted joints or connections, is there evidence of corrosion or rust, movement, missing or loose fasteners or leakage?				
For concrete penstocks, do the waterstops or gaskets at the joints show signs of deterioration or leakage?				
For welded joints, are the welds cracked or flawed and are there signs of leakage?				
Is there evidence of movement or settlement of the supports or excessive vibrations? *[Look for deformation or leaning of the supports]*				
Is there eroded soil or displaced rock at the bottom of the slopes near the penstock? *[Could indicate slope stability issues]*				
Is there concrete damage or deterioration of supports/foundations? *[e.g., concrete spalling, cracking, erosion of supporting soil]*				

Penstocks, Tunnels, & Surge Tanks

Assessment Conclusions and Recommendations:

APPENDIX D. GUIDE FOR CONTROL/SHUT-OFF VALVE CONDITION ASSESSMENT

REVISION 1.0, 1/11/2012

CONTENTS

1.0 GENERAL

This Guide is for condition assessment of the major valves along with their operating system at a hydropower plant, which are installed in penstocks or large conduits to cut off or control the turbine generating flow. Unforeseen failure of the control/shut-off valves can have a substantial impact on power generation and revenues due to an extended forced outage; under emergency situation of load rejection coincidence with wicket gate malfunction, the failure of shut-off valve could cause catastrophic threats of human lives and asset damages resulting from penstock rapture and plant flooding (reference to the Shut-Off Valve Best Practices). Therefore, it is important to maintain an updated condition assessment of the control/shut-off valves and plan accordingly. A control/shut-off valve condition assessment is essential to estimate the economic lifespan and potential risk of failure, and to evaluate the benefits and cost of control/shut-off valve upgrading.

For any type of plant major valve system, the following three step analyses are necessary to arrive at a control/shut-off valve condition indicator:

1) What parts should be included for control/shut-off valve condition assessment and which parts are more important than others (parts and their weighting factors)?

2) What metrics/parameters should be investigated for quantitative condition assessment and which ones are more important than others (condition parameters and their weighting factors)?

3) How to assign numerical scores to the control/shut-off valves (rating criteria)?

This appendix provides guides to answer the above questions, which can be applied to all control/shut-off valves. The condition assessment is performed on individual control/shut-off valves in a plant, because even the originally identical control/shut-off valves may have experienced different Operation & Maintenance (O&M) histories and would arrive at different values of condition indicators. Due to the uniqueness of each individual control/shut-off valve, the guides provided in this appendix cannot quantify all factors that affect individual control/shut-off valve condition. Mitigating factors not included in this guide may trigger testing and further evaluation to determine the final score of the control/shut-off valve condition and to make the decision of control/shut-off valve replacement or rehabilitation.

This appendix is not intended to define valve maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2.0 CONSTITUENT PARTS ANALYSIS

The components of a control/shut-off valve system include the valve body and internals, valve operator which may include electric and/or hydraulic power, and structural supports. If any part does not exist in a particular control/shut-off valve, this part will be excluded from scoring mechanism by inputting "NA" into the table. The effect of one part exclusion is usually insignificant to justify any adjustment for the weighting factors of other control/shut-off valve parts.

3.0 METRICS FOR CONTROL/SHUT-OFF VALVE CONDITION ASSESSMENT

As listed in Table 1, the following five condition parameters are considered for condition assessment of control/shut-off valve parts:

- The Physical Condition

- The Age
- The Installed Technology Level
- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on the previous testing and measurements, historical O&M records, original design drawings, previous rehabilitation feasibility study reports if conducted, interviews with plant staff and some limited inspections. It is noticed that there is a certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmarking condition assessment without specific testing and measurements conducted on site, these five parameters are regarded as providing the basis for assessing the condition of control/shut-off valve parts.

In addition, the Data Quality Indicator, as an independent metric, is to reflect the quality of available information and the confidence on the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity, and any of these situations could affect the results of condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part/item to indicate the information and data availability, integrity and accuracy, and the confidence on the given condition ratings (MWH 2010).

4.0 WEIGHTING FACTORS

There are two categories of weighting factors in Table D-1. It is recognized that some condition parameters affect the control/shut-off valve condition to a greater or lesser degree than other parameters; also some parts are more or less important than other parts to an entire control/shut-off valve. These weighting factors should be pre-determined by consensus among experienced hydropower mechanical engineers and plant O&M experts. Once they are determined for each type of control/shut-off valve, they should be largely fixed from plant to plant for the same type of control/shut-off valve, except for special designs found in a control/shut-off valve where the weighting factors have to be adjusted. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors won't affect the Condition Indicator of a control/shut-off valve, which is the weighted summation of all scores assigned to the control/shut-off valve parts and five condition parameters.

Table D-1. Typical control/shut-off valve condition assessment and scoring: XXX Hydropower Plant

Control/Shut-off Valve for Unit ___	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Valve	3.5.1							2.0
Valve Operator Equipment	3.5.2							2.0
Structural/Supports	3.5.3							1.0
Electric/Hydraulic Power System	3.5.4							1.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	*0.00*
							Condition Indicator -->	***0.00***

5.0 RATING CRITERIA

Physical Condition: Rating Criteria for Control/shut-off valve Parts

Physical Condition of control/shut-off valve parts refers to those features that are observable or detected through measurement and testing, including some observed performance. It includes the observation of the valve body exterior and interior, the disc, rotor, plug, or gate, the valve operator, the valve connection to the penstock, and valve support. The Best Practices of Control/shut-off valve Condition Assessment can assist in evaluating the control/shut-off valve condition.

For HAP site assessment, it is important to conduct interviews and discussions with plant personnel to score the physical condition of control/shut-off valve parts. The results of all related information are analyzed and applied to Charts 1a, 1b and 1c to assign the condition scores of control/shut-off valve parts.

Chart 1a Control/Shut-off Valve Physical Condition Rating Criteria

Physical Condition Description	Physical Condition Score
Limited corrosion on disk/plug and water passage; coating is in good condition; seals and seats are in good condition and properly adjusted with no or minimal leakage, bearing/pivot point lubrication is in good condition; the bypass is in good condition; valve is regularly exercised.	**8 – 10**
Moderate corrosion on disk/plug and water passage; coating is in adequate condition; seals and seats are in adequate condition with minimal leakage; bearing/pivot point lubrication is in good condition; the bypass is in good condition; valve is regularly exercised.	**5 – 7**
Large areas of corrosion on disk/plug and water passage; coating is less than adequate; seals and seats have some damage with minor leakage; bearing/pivot point lubrication is in adequate condition; the bypass has moderate corrosion; valve is regularly exercised.	**3 – 4**
Severe corrosion on disk/plug and water passage; coating is poor; seals and seats are damaged allowing excessive leakage; bearing/pivot point lubrication is not functioning properly; the bypass has excessive corrosion; there is severe chattering, vibration, or binding during operation; the valve is either rarely exercised or is excessively exercised (i.e., ≥ 50 cycles per year).	**0 – 2**

Chart 1b Control/Shut-Off Valve Operator, Electric/Hydraulic Power System Physical Condition Rating Criteria	
Physical Condition Description	**Physical Condition Score**
Seals, stems, cylinders, hydraulic system, position indicators, and controls are in good condition; backup power is available and tested regularly; slow-down mode has been tested and verified; pressure differential indicators up/downstream are operational and tested; operational testing performed on annual basis; the system is exercised frequently.	**8–10**
Seals, stems, cylinders, hydraulic system, position indicators, and controls are updated or in good condition; backup power is available; slow-down mode functions but needs a minor adjustment; pressure differential indicators up/downstream are operational but not calibrated; the system is exercised frequently.	**5–7**
Seals, stems, cylinders, hydraulic system, position indicators, and controls are in fair condition; backup power is not regularly tested; slow-down mode functions but needs a minor adjustment; pressure differential indicators up/downstream are operational and tested; the cycle of operation time has changed slightly; the system is exercised rarely.	**3–4**
Seals, stems, cylinders, hydraulic system, gate position indicators, and controls are in poor condition; backup power is not available or not reliable; slow-down mode and limit switches are out of adjustment; pressure differential indicators up/downstream are not functioning; the cycle of operation time has changed significantly; the system is never exercised.	**0–2**

Chart 1c Control/Shut-off Valve Structural/Supports Physical Condition Rating Criteria	
Physical Condition Description	**Physical Condition Score**
Coating is intact with little or no evidence of corrosion. Fasteners in excellent condition. Concrete in excellent condition.	**8 – 10**
Coatings is mostly intact with minor corrosion. Fasteners intact with some corrosion. Concrete intact with minor cracking.	**5 – 7**
Coating is more than 50% missing and moderate corrosion on most steel parts. Fastners corroded. Concrete cracked and small areas spalled.	**3 – 4**
Coating is severely compromised and corrosion is severe on all steel parts. Fasteners are severely corroded and one or more is missing. Concrete appears severely compromised by cracks and deterioration.	**0 – 2**

Age: Rating Criteria for Control/shut-off valve Parts

Age scoring is relatively more objective than other condition parameters. The detailed scoring criteria developed in Chart 2 allow the age score to be automatically generated in the HAP Database by the actual years of the installed part.

Chart 2 Age Rating Criteria for Control/Shut-off Valve Parts

Age of Equipment	Age Score
< 20 Years	**8 – 10**
20-35 Years	**5 – 7**
35-60 Years	**3 – 4**
> 60 Years	**0 – 2**

Installed Technology Level: Rating Criteria for Control/shut-off valve Parts

The Installed Technology Level indicates advancement levels of designing, machining, installation and materials, which may affect the unit and plant performance. Outdated technology may bring difficulties for spare parts supply and become a prolonged outage when it fails.

Scoring the Installed Technology Level requires historic knowledge of control/shut-off valve technology advancement and familiarity with the current control/shut-off valve manufacturing industry. High head valves of pre-1940 construction with cast one piece bodies may be susceptible to cracking of the body if the valve is subjected to very high loads. Valves of modern design (post-1950) generally have an expected service life in excess of 75 years subjected to proper and routine maintenance. Wearing of seals or bearings, which was a serious maintenance problem for pre-1950s valves, has been mitigated through the development of corrosion and wear resistant materials. Even modern valves that are infrequently operated will have a greater occurrence and frequency of problems. With the use of computers to model stresses and deflections in valves, they have become lighter with thinner walls, resulting in ultimate factors of safety that are not as high as with valves fabricated before the 1970s (ASCE 2007).

In addition, the competence, professionalism and reputation of the original suppliers could also imply the installed technology levels. Compared to those from large and well-known manufacturers, the valve parts supplied by small and unnamed companies would get lower scores.

Chart 3 Control/Shut-off Valve Technology Rating Criteria	
Technology Levels of the Parts/Items	**Score for Installed Technology Level**
The technology has not been changed significantly since the valve was installed; and the installed technology was supplied by brand name companies with great reputation.	**8 – 10**
The technology has been advanced but no problem to supply the matching parts in next 5-10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may reduce the cost of replacement). The installed technology was supplied by medium companies with good reputation.	**4 – 7**
The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability of power generation. The installed technology was supplied by small companies with bad reputation.	**0 – 3**

Operating Restrictions: Rating Criteria for Control/shut-off valve Parts

Operational limitations play a role in determining the serviceability of control/shut-off valve. The control/shut-off valve operating restrictions may be sourced from the original design and current condition of control/shut-off valve parts. The operating ranges may be constrained due to the limited original design ranges for the flow and head, and/or currently deteriorated control/shut-off valve physical condition (e.g., severe vibrations or cavitation noise).

Chart 4 describes the ratings of control/shut-off valve operating restrictions.

Chart 4 Control/Shut-off Valve Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes, and the original design has no constraints on the required operation. Tested as Required; no known design or operational deficiencies.	**8 – 10**
Minimal restraints: Operations to avoid minor rough zones; operation range can be expanded with revised equipment selection and design. No known design and operational deficiencies.	**5 – 7**
Moderate restraints: Operations to avoid large rough zones with high vibration. The operation range and performance can be significantly improved with revised equipment selection and design.	**3 – 4**
Severe limitations: The equipment does not meet the operational criteria or not tested as required or has a known design and operational deficiency.	**0 – 2**

Maintenance Requirement: Rating Criteria for Control/Shut-Off Valve Parts

The amount of corrective maintenance that either has been or must be performed is an indication of the control/shut-off valve condition. No corrective maintenance is an indication that the control/shut-off valve is in good shape. Severe corrective maintenance requires scheduled or forced outages to perform.

Other factors to consider for maintenance scoring include:

- The need of maintenance is increasing with time or problems are reoccurring;
- Previous failures related to the control/shut-off valve parts;
- Failures and problems of control/shut-off valve parts with similar design.

The results of control/shut-off valve maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5 to score the control/shut-off valve parts.

Chart 5 Control/Shut-off Valve Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum level (normal condition): A small amount of routine preventive maintenance is required. No corrective maintenance.	**9 – 10**
Low level: Small amounts of corrective maintenance. Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis.	**7 – 8**
Moderate level: Some corrective maintenance that causes extensions of unit preventive maintenance outages.	**5 – 6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., corrosion caused leaks).	**3 – 4**
Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required.	**0 – 2**

Data Quality: Rating Criteria for Control/Shut-Off Valve Parts

The Data quality scores reflect the quality of the inspection, test, and measurement results to evaluate the condition of control/shut-off valve parts. The more current and complete inspection, testing, and measurement results, the higher the Data Quality scores. The frequency of normal testing is as recommended by the organization. Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of control/shut-off valve parts are developed in Chart 6.

Chart 6 Control/Shut-off Valve Data Quality Rating Criteria	
Years Since Last Condition Assessment	**Data Quality Score**
<8 years	**8 – 10**
8-17 years	**5 – 7**
17-25 years	**3 – 4**
>25 years	**0 – 2**

6.0 CONTROL/SHUT-OFF VALVE SYSTEM AND DATA QUALITY INDICATORS

In Table D-1, the final condition score of the control/shut-off valves (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J) \times F(K) \times F(J)}{\sum_{K=1,M}^{J=1,5} F(K) \times F(J)} \quad (1)$$

The control/shut-off valves Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K) \times F(K)}{\sum_{K=1,M} F(K)} \quad (2)$$

Here, M = the total number of parts/items associated with the control/shut-off valves; K = the identification No. of control/shut-off valve parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of the control/shut-off valves part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for control/shut-off valve.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific control/shut-off valve testing would more directly reveal the condition of the control/shut-off valve.

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SHUT-OFF VALVE INSPECTION FORM AND CHECKLIST

REVISION 1.0, 1/20/2012

Shut-Off Valve: Inspection Form

General Information:

Date of Site Visit: ______________________________ Unit No.____________

Plant Name: ______________________________

Source/s of data: ______________________________

Valve Manufacturer: ______________________________Age of Valve:____________

Size of Valve:____________ Size of Penstock ______________________________

System Pressure (PSI):______________________________

Control/Shut-Off Valve Description:______________________________

Maintenance History / Major Repairs Description:

Control/Shut-Off Valve:

Valve Manufacturer/Model: ______________________________

Rated Operating Pressure: ______________________________

Addition specification data:

Valve Operator:
Make:_______________________________________ Model:_________________________________
Addition specification data:

Control/Shut-Off Valve Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History				
Are there plant preventive maintenance procedures for the control/shut-off valve? Are they routinely carried out?				
Has there been any valve and/or penstock repair?				
Has the Valve been rebuilt?				
Has the valve operator been rebuilt?				
If parts of valve require lubrication, are there records of lubricant application?				
Have all plant records regarding valve repairs, operating conditions, etc. been requested/gathered?				

Control/Shut-Off Valve Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment				
What is condition of the exterior of the valve?				
Can the interior of the Valve be accessed?				
What is the condition of the interior of the valve?				
What is the condition of the valve operator?				
Are differential pressure indicators or transmitters present?				
Are differential pressure indicators or transmitters operational?				

Control/Shut-Off Valve Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment (Continued)				
Is there a valve position indicator?				
Does the valve position indicator function correctly? Local and/or remote?				
Have valve malfunctions been noted as the cause of unit outages or unit deratings? If so, how many megawatt hours lost (MWHL) have been attributed to valves?				
Does the valve have packing leaks?				
Does the valve have flange gasket leaks?				
Is the valve insulated? If so, does the insulation contain asbestos fiber?				

Control/Shutoff Valve Data Collection Sheet	
Topic	Data Input

APPENDIX E. GUIDE FOR FLUMES & OPEN CHANNELS CONDITION ASSESSMENT

REVISION 1.0, 12/20/2011

CONTENTS

1. GENERAL

Free-flow water conveyances such as flumes and open channels are an important component in the power generation process at a hydropower facility. Free-flow water conveyances operate under the laws of open channel flow and are primarily used to divert flow from the upstream reservoir or forebay to the dam intake. Since flumes and open channels are periodically exposed to severe service conditions such as turbulent water and severe weather, they are likely to experience several maintenance and reliability issues. These issues can include:

- Erosion
- Structural deterioration (e.g., concrete spalling, steel corrosion, cracking)
- Aquatic growth
- Sedimentation
- Seepage
- Ice and debris build-up
- Lining deterioration
- Instability of adjacent slopes

Emergency repairs, unscheduled maintenance, or replacement of flume and open channel parts can be very costly. Therefore, routine maintenance and condition assessments are important in extending the life expectancy of conveyance parts, limiting unscheduled shutdowns, and improving hydraulic performance by minimizing seepage and head losses. By performing a condition assessment, plants can estimate the remaining life expectancy, identify potential failure risks, and evaluate the benefits of upgrades.

For flumes and open channels, the three following steps are necessary to establish a condition indicator:

1) What parts are to be included in the condition assessment and what is their level of importance (parts and their weighting factors)?

2) What metrics/parameters are to be investigated for the quantitative condition assessment and what is their level of importance (condition parameters and their weighting factors)?

3) How to assign numerical scores to the parts (rating criteria)?

This appendix provides guides to help answer the questions above, which can be applied to flumes and open channels. Flumes and open channels can serve varied roles in a hydropower facility such as intake canals and tailrace channels. There are also variations in conveyance general arrangements, construction materials, and accessibility for maintenance. Therefore, separate water conveyances at a single facility may have different Operating and Maintenance (O&M) histories and will have different rating criteria. This condition assessment is to be performed on a single water conveyance. For example, separate assessments will be performed on intake canals and tailrace channels. Since plants can have a large variation in the arrangement of water conveyances, the guides provided in this appendix cannot quantify all factors which can affect individual conveyance conditions. Mitigating factors not included in this Guide may trigger testing and further evaluation to determine the final score of the water conveyance condition and aid in the decision of part replacement or rehabilitation.

This appendix is not intended to define flume and open channel maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2. CONSTITUENT PARTS ANALYSIS

For flumes and open channels, the constituent parts are analyzed and listed in Table E-1 (references to HAP Taxonomy).

If any part (e.g., de-silting chamber) does not exist in a particular conveyance system, this part will be excluded from scoring mechanism by inputting "NA" into the table. The effect of one part exclusion is usually insignificant to the entire system assessment and does not justify an adjustment of the weighting factors for the other parts.

3. METRICS FOR CONDITION ASSESSMENT

As listed in Table E-1, the following five condition parameters are considered for the condition assessment of flumes and open channels:

- The Physical Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on previous testing and measurements, historical Operation and Maintenance (O&M) records, original design drawings, previous rehabilitation feasibility study reports if available, interviews with plant personnel, and inspections when accessible.

It can be noted that there is a certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmark condition assessment (without specific testing and measurements conducted on site) the five parameters are regarded as providing the basis for assessing the condition of flumes and open channels.

In addition, the Data Quality Indicator, as an independent metrics, is to reflect the quality of the available information and the confidence of the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity. Any of these situations could affect the results of the condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part to indicate the data availability, integrity, and accuracy; and the confidence of the given condition ratings (MWH 2010).

4. WEIGHTING FACTORS

There are two categories of weighting factors in Table E-1. It is recognized that some condition parameters affect the condition to a greater degree than others. The weighting factors for different condition parameters should be pre-determined by consensus among experienced hydraulic and hydropower engineers. Also, some parts are more or less important than other parts to the entire conveyance system, particularly due to the overall facility layout and length of open channels/flumes varying from plant to plant. The weighting factors for constituent parts are hard to be pre-determined; the values filled in Table E-1 and in workbook are an example only; they should be adjusted accordingly during the demonstrations and baseline assessments by HAP core process development team with consensus among experienced hydraulic and hydropower engineers. . Then, the weighting factors can be used for the plants with similar open channel/flume arrangement. The range of absolute values of weighting factors will not affect the Condition Indicator of a conveyance system, which is the weighted summation of all scores assigned to the parts and five condition parameters.

Table E-1. Typical flumes/open channels condition assessment and scoring

Flumes / Open Channels	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Flumes	3.7.1							5.0
Open Channels	3.7.2							5.0
Forebay Structure	3.7.3							5.0
Desilting Chamber	3.7.4							2.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	*0.00*
							Condition Indicator -->	*0.00*

5. RATING CRITERIA

Physical Condition: Rating Criteria for Flumes/Open Channels

Physical Condition of flume and open channel parts refers to those features that are observable or detected through measurement and testing. It includes lining deterioration, channel blockage (e.g., due to debris, ice, eroded materials), structural deterioration, seepage, foundation/slope instabilities, hydraulic conditions etc. The surface or liner of channels is important since increased surface roughness can affect efficiency by increasing head losses. Excessive seepage can lead to uncontrolled water losses which can also affect efficiency. In addition to efficiency related issues, evidence of adjacent or supporting slope instabilities, severe structural deterioration, severe vibrations, and flow blockage may be an indication of impending failure or safety issues. Therefore, flumes and open channels should be carefully evaluated. The Best Practices for Flumes & Open Channels can assist in evaluating the physical condition. For HAP site assessment, it is important to interview and discuss with plant personnel to help score the physical condition. The results of all related information are analyzed and applied to Chart 1.

Chart 1 Flumes/Open Channels Physical Condition Rating Criteria		
Physical Condition Rating Scale		**Physical Condition Score**
Excellent	Limited deterioration or damage to liners of water conveyances; no evidence of foundation settlement or deterioration; minimal leakage at joints; no evidence of erosion or instabilities of embankments or adjacent slopes; no significant build-up of eroded materials, debris, or sedimentation; no organic growth on interior surfaces; minimal signs of seepage through unlined channels; limited corrosion, cavitation, or spalling of steel and concrete surfaces. Part/item is functioning optimally.	**8–10**
Good	Moderate deterioration or damage to liners of water conveyances; evidence of minor foundation settlement or deterioration; moderate leakage at joints; evidence of minor erosion or instabilities of embankments or adjacent slopes; slight build-up of eroded materials, debris, or sedimentation; minor organic growth on interior surfaces; signs of seepage through unlined channels; moderate corrosion, cavitation, or spalling of steel and concrete surfaces. Part/item function is not significantly affected however minor repairs may be necessary.	**5–7**
Fair	Large areas of deterioration or damage to liners of water conveyances; evidence of foundation settlement or deterioration; considerable leakage at joints; evidence of significant erosion or instabilities of embankments or adjacent slopes; significant build-up of eroded materials, debris, or sedimentation; build-up of organic growth on interior surfaces; moderate seepage through unlined channels; large areas of corrosion, cavitation, or spalling of steel and concrete surfaces. Part/item function is adequate, however, efficiency and reliability may be affected. Moderate repairs may be necessary.	**3–4**
Poor	Severe deterioration or damage to liners of water conveyances; extensive foundation settlement or deterioration; excessive leakage at joints; significant erosion or instabilities of embankments or adjacent slopes; limited flow or complete blockage due to build-up of eroded materials, debris, or sedimentation; severe organic growth on interior surfaces; excessive seepage through unlined channels; severe corrosion, cavitation, or spalling of steel and concrete surfaces. Part/item no longer functions properly or there is a risk of failure. Replacement or repairs are necessary.	**0–2**

Age: Rating Criteria for Flumes/Open Channels

Age is an important factor when considering part or system upgrade as it can be an indication of performance degradation. As water conveyances age, they become more susceptible to wear due to vibrations, turbulent flow, and severe weather. Not only does increased wear result in operational problems and loss of efficiency, it can also increase the risk of sudden failure.

Age scoring is relatively more objective than other condition parameters. The detailed scoring criterion developed in Chart 2 allows the age score to be automatically generated in the HAP Database by the actual years of the installed part. Channel liners typically have a maximum life span of 25 to 30 years depending on the type of liner material and application process; whereas, structural components (i.e., flume structure) or excavated channel formation can last up to 80 years with routine and proper maintenance. The Age scoring criteria for various parts are shown in Chart 2.

Chart 2 Age Rating Criteria for Flumes/Open Channels

Age of Flume Structure, Open Channel, Forebay Structure, Desilting Chamber, Foundation or Supports, and Joints	Age Score	Age of Liners
<30 years	**8–10**	<10 years
30–60 years	**5–7**	10–20 years
60–80 years	**3–4**	20–30 years
>80 years	**0–2**	>30 years

Installed Technology: Rating Criteria for Flume/Open Channels

The Installed Technology indicates advancement in flume and open channel design, installation/construction techniques, liner/coating materials and application process, and other materials which may affect the hydraulic, maintenance and reliability performance of water conveyance system. Outdated technology may cause difficulties for supplying replacement parts or performing routine maintenance which can result in prolonged outages.

Scoring the Installed Technology requires historic knowledge of flume and open channel technology advancement and familiarity with industry standards and materials. For example, historically, open channels have been unlined or lined with erodible materials such as sand or gravel. This can lead to a multitude of maintenance issues over time such as severe erosion, water loss due to seepage, buildup of organic material (i.e., weeds), and increased surface roughness. Therefore, channels with liners such as concrete or geomembranes will receive a higher score than unlined channels. The hydraulic modeling and design tool for open flow conveyance systems is another factor to consider for scoring the Installed Technology. With advances in computer modeling, designers are able to provide a more hydraulically efficient arrangement while limiting erroneous design inputs. Other factors to consider are advances in excavation and construction techniques.

The competence, professionalism, and reputation of the original suppliers could also impact the Installed Technology. As compared to large and well-known manufacturers, the parts supplied or installed by small, unknown companies would get lower scores. The Installed Technology scoring criteria for various parts are shown in Chart 3.

Chart 3 Flumes/Open Channels Technology Rating Criteria	
Technology Levels of the Design and Construction	**Score for Installed Technology Level**
The technology has not been changed significantly since the part/item was installed; and the installed technology was supplied by brand name companies with a great reputation	**8 – 10**
The technology has been more or less advanced but no problem to supply the matching parts in next 5-10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may reduce the cost of replacement). The installed technology was supplied by medium companies with good reputation.	**4 – 7**
The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability of power generation. The installed technology was supplied by small companies with bad reputation.	**0 – 3**

Operating Restrictions: Rating Criteria for Flumes/Open Channels

The Operating Restrictions refers to the current limitations on the operating ranges including flow, head and power capacity. Either under-sized or under-utilized capacity may reduce the overall operational efficiencies and accelerate the deterioration of the water conveyance physical condition. Operational limitations play a role in determining the serviceability of the unit: the greater the limitations, the greater the generation loss.

Operating restrictions can be caused by to two sources:

1) The conveyance system itself. To limit deterioration or to ensure structural safety, the operating flows are constrained due to the limitations of the original design and/or the current deteriorated physical condition. Flow can also be impacted by obstructions in the channels (due to debris or ice) or a reduction of hydraulic area (due to sedimentation or organic material buildup).

2) Environmental restrictions due to habitat maintenance, water quality issues (i.e., Dissolved Oxygen), or fish passage. These restrictions can affect minimum required flows and thus affect the available plant flows. Other environmental restrictions can stem from changes in flow conditions due to climate change or changes in the Probable Maximum Flood (PMF). However, any constraint from other

components within the facility, which may affect unit and plant generation, will not be included in the constraints for flume and open channels. For example, if the water in the headwater reservoir is limited due to dam safety concerns, then the dam (not the water conveyance) will receive a lower score for Operating Restrictions.

Chart 4 describes the ratings for Operating Restrictions.

Chart 4 Flumes/Open Channels Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes, and the original design has no constraints on the required operation.	**8 – 10**
Minimal restraints: Operations to avoid minor rough zones; operation range can be expanded with revised equipment selection or design.	**5 – 7**
Moderate restraints: Operations to avoid large rough zones and high vibrations. The operation range and performance can be significantly improved with revised system design.	**3 – 4**
Severe limitations: The part/item does not meet the operational criteria, performance and reliability are significantly limited if it operates under current environment/requirement.	**0 – 2**

Maintenance Requirement: Rating Criteria for Flumes/Open Channels

The amount of corrective maintenance that either has been or must be performed is an indication of the water conveyance condition. If the conveyance system has required limited or no maintenance, then that is an indication that the system is in good condition. If a part has required extreme corrective maintenance resulting in unscheduled or forced outages, then the part is considered to be in poor condition.

Other factors to consider for maintenance scoring include:

- Maintenance needs are increasing with time or problems are re-occurring
- Previous failures or issues related to flumes and open channels
- Failures or problems with flumes or open channels of similar design and material

The results of the maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5.

Chart 5 Flumes/Open Channels Maintenance Requirement Rating Criteria

Amounts of Corrective Maintenance	Maintenance Requirement Score
Minimum level (normal condition): A small amount of routine preventive maintenance is required. No corrective maintenance.	**9–10**
Low level: Small amounts of corrective maintenance (e.g., less than 3 staff days per part/item per year). Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis.	**7–8**
Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages.	**5–6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems.	**3–4**
Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to parts/items, and/or labor-intensive maintenance is required.	**0–2**

Data Quality: Rating Criteria for Flumes/Open Channels

The Data Quality score reflects the quality of the inspection, test, and measurement results used to evaluate flumes and open channels. The more current and complete the inspection, tests, and measurement results are, the higher the Data Quality scores. The frequency of normal testing is as recommended by industry standards.

Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination of the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality are developed in Chart 6.

Chart 6 Flumes/Open Channels Data Quality Rating Criteria	
Data Availability, Integrity and Accuracy	**Data Quality Score**
High – The maintenance policies and procedures were followed by the plant and the routine inspections, tests, and measurements were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8 – 10**
Medium – One or more of routine inspections, tests, and measurements were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 – 7**
Low – One or more of routine inspections, tests, and measurements were completed 24-36 months past the normal frequency, or some of results are not available.	**3 – 4**
Very Low – One or more of required inspections, tests, and measurements were completed >36 months past the normal frequency, or significant portion of results are not available.	**0 – 2**

6. CONDITION AND DATA QUALITY INDICATOR

In Table E-1, the final condition score for flumes and open channels (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J) \times F(K) \times F(J)}{\sum_{K=1,M}^{J=1,5} F(K) \times F(J)} \quad (1)$$

The Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts:

$$DI = \frac{\sum_{K=1,M} S_D(K) \times F(K)}{\sum_{K=1,M} F(K)} \quad (2)$$

Here, M = the total number of parts associated with a flume or open channel; K = the identification No. of parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of a part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific testing would more directly reveal the condition of the water conveyance.

7. REFERENCES

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FLUMES & OPEN CHANNELS INSPECTION FORM AND CHECKLIST

REVISION 1.0, 12/20/2011

Flumes/Open Channels: Inspection Form

General Information:

Date of Site Visit: ______________________________

Plant Name: ______________________________

Source(s) of Data: ______________________________

Channel or Flume Inspected: ______________________________

Description of General Arrangement: ______________________________

____

____

General Construction Description: ______________________________

____

____

Age of Conveyance: ____________

Length of Conveyance (ft):____________

Accessibility for Visual Inspection: ______________________________

____

____

Previous Condition Assessment Date(s): ______________________________

____

Chronic Issues or Maintenance (Routine and Corrective): ______________________________

____

____

Description of Liners (if applicable): ______________________________

____

____

Age of Liner [Yrs]: ____________

Liner Material: ______________________________

Liner Application Process: ______________________________

____

____

Previous Maintenance Issues with Liners [If yes, describe]:______________________________

____

____

Estimated Life Remaining for Liner [Yrs]: ____________

Flumes:

____

____

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____

Open Channels:

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Forebay Structure:

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____

____

____

De-Silting Chamber:

____

____

____

Channel Liner:

Foundation and Supports:

Joints and Couplings:

Flumes/Open Channels Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
A. General Information				
What are the plant specific life and serviceability needs for the water conveyance? *[How long will the conveyance system be required, are there any future plans for facility decommissioning, are there future plans for part/item replacement or upgrade, etc.?]*				
Have all accessibility issues been addressed and discussed with plant personnel prior site visit? *[Determine which parts/items require access for inspection, which parts/items will not be available for visual inspection, alternative means of collecting data (i.e. interviews with plant personnel), etc.]*				
Identify the appropriate testing techniques to be used. *[Depends on accessibility, construction materials, plant requirements, safety restrictions, etc.]*				
Identify any special equipment required for the plant walk down. *[Depends on accessibility, construction materials, plant requirements, safety restrictions, etc.]*				
Have all plant records regarding maintenance, repairs, operating conditions, performance data, etc. been gathered or requested?				

Flumes/Open Channels Check List - Continued				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
B. Liner Condition				
Is the water conveyance (flumes or channels) lined? If yes, describe the liner material and application process. *[If unlined, describe the natural liner (i.e., rock, sand, excavated soil, etc) or interior surface]*				
Is the liner or interior surface accessible for visual inspection? *[Is the conveyance currently dewatered? If no, then interview operating staff, review maintenance records, review previous repair records, etc., to determine the liner condition.]*				
Is there evidence of any previous liner repair work (visual observation or maintenance records)? *[If so, document type of repair, location, reason for repairs, when repair was done, and effectiveness of repair work.]*				
Is there evidence of liner damage or deterioration? *[Look for buildup of eroded materials, concrete spalling, steel corrosion, vegetation (i.e., weeds) perforating the liner, significant water loss due to seepage, puncturing or tearing of geomembranes, adhesion loss, debris damage, etc.]*				
Is material buildup or debris present? If yes, what is the extent and severity of the problem? *[What is the type and apparent source of the buildup (ice accumulation, tree limbs, organic growth, liner degradation, sedimentation).]*				

Flumes/Open Channels Check List - Continued				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
C. Structural Integrity				
For structural concrete, is there evidence of deterioration or damage? If so, record location, severity, and apparent cause. *[Look for concrete cracking, spalling, erosion, cavitation, exposed rebar, etc.]*				
For structural steel, is the evidence of deterioration or damage? Is so, record location, severity, and apparent cause. *[Look for corrosion or rust stains, fatigue, warping, cavitation or abrasions, displacement, etc.]*				
Is there evidence of foundation movement? *[Possible causes can include settlement, erosion of supporting soil, slope instabilities, or errors in the original design. Look for cracking, eroded soil or displaced rock at base of slope, deformation or leaning of supports, misalignment, etc.]*				
Is there evidence of joint deterioration? *[Look for soil fines seeping through joints, vegetation in joints, leakage or seepage, missing or damaged sealant, missing or loose fasteners, etc.]*				
Has the facility experienced any slope stability issues in the past (i.e. mudslides) of both supporting and adjacent slopes? *[If yes, when and what repair was done to remedy the problem? If no, is there evidence that slope stability might be an issue in the future (i.e. displaced rock or movement)?]*				

Flumes/Open Channels Check List - Continued				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
D. Miscellaneous				
Has ice, debris, or sedimentation buildup been an issue in water conveyances at the facility? If yes, are there any measures in place to control the accumulations and are these measures effective? *[Examples include trash/ice booms, desilting chambers, routine dredging, vacuum extraction, etc.]*				
Is there apparent erosion of channel embankment slopes? *[Look for accumulations of eroded material in channel.]*				
Is the facility experiencing significant water loss due to seepage or leakage in water conveyances such as flumes or open channels. *[What is the apparent cause of the leakage or seepage? Have any attempts to limit the water loss been implemented, if so what has been done and has it been successful?]*				
Does the facility have a routine inspection and maintenance plan for flumes and open channels currently in place? *[If yes, what is the frequency and extent of inspections? What type of maintenance is routinely performed and how often?]*				
Have there been any operational changes to the original design? *[This can include changes in the Probable Maximum Flood (PMF), flow requirements due to unit upgrades, seismic criteria, operational regimes, limitations due to severe degradation, etc.]*				

Flumes/Open Channels

Assessment Conclusions and Recommendations:

APPENDIX F. GUIDE FOR DRAFT TUBE GATES CONDITION ASSESSMENT

REVISION 1.0, 12/20/2011

CONTENTS

1. GENERAL

The primary purpose of draft tube gates is to protect the interior equipment and power generation components such as turbines by providing a barrier and blocking water flow during dewatering and unit shut down for maintenance and inspection activities. Since draft tube gates spend the majority of their life cycle in storage or moist conditions, they are likely to experience several maintenance and reliability issues such as

- Corroded, bent, or damaged structural gate members and gate parts.
- Debris jamming gates
- Seal deterioration
- Misalignment of gate slots
- Concrete support deterioration, damage, or concrete growth
- Failure of crane and lifting parts

Gate replacement or gate slot repair can be very costly. Therefore, routine maintenance and condition assessments are very important in extending the life expectancy of gates and associated parts. By performing condition assessments, plants can estimate the remaining part life expectancy, identify any potential failure risks, and evaluate the benefits of part upgrade.

For draft tube gate systems, the three following steps are necessary to establish a condition indicator:

1) What parts are to be included in the condition assessment and what is their level of importance (parts and their weighting factors)?

2) What metrics/parameters are to be investigated for the quantitative condition assessment and what is their level of importance (condition parameters and their weighting units)?

3) How to assign numerical scores to the parts (rating criteria)?

This appendix provides a guide to help answer the questions above, which can be applied to draft tube gates. The condition assessment is to be performed on a single gate system since even identical gate systems may have experienced different Operation & Maintenance (O&M) histories and would receive different value for condition indicators. Due to the uniqueness of each gate system (e.g., gate configuration, supports/slots, seals), the guides provided in this appendix cannot quantify all factors that affect individual gate condition. Mitigating factors not included in this Guide may trigger testing and further evaluation to determine the final score of the draft tube gate condition and to make the decision of replacement or rehabilitation.

This appendix is not intended to define draft tube gate maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2. CONSTITUENT PARTS ANALYSIS

For draft tube gates, the constituent parts are analyzed and listed in Table F-1 (references to HAP Taxonomy).

If any part does not exist in a particular gate configuration, this part will be excluded from scoring mechanism by inputting “NA” into the table. The effect of one part exclusion is usually insignificant to the entire system assessment and does not justify an adjustment of the weighting factors for the other parts.

3. METRICS FOR CONDITION ASSESSMENT

As listed in Table F-1, the following five condition parameters are considered for the assessment of draft tube gates:

- The Physical Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on previous testing and measurements, historical Operation and Maintenance (O&M) records, original design drawings, previous rehabilitation feasibility study reports if available, interviews with plant personnel, and inspections where possible.

It can be noted that there is a certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmark condition assessment (without specific testing and measurements conducted on site) these five parameters are regarded as providing the basis for assessing the condition of draft tube gates.

In addition, the Data Quality Indicator, as an independent metric, is intended to reflect the quality of the available information and the confidence of the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity. Any of these situations could affect the results of the condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part to indicate the data availability, integrity, and accuracy; and the confidence of the given condition ratings (MWH 2010).

4. WEIGHTING FACTORS

There are two categories of weighting factors in Table F-1. It is recognized that some condition parameters affect the condition to a greater degree than other parameters. Also, some parts are more or less important than other parts to the entire gate system. These weighting factors should be pre-determined by consensus among experienced hydropower engineers and plant O&M experts. Once they are determined for each part, they should be largely fixed from plant to plant for similar arrangements. Depending on the refining process during the demonstration and baseline assessments, the weighting factors for the parts/items associated with draft tube gates may have to be adjusted for some plants. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors will not affect the Condition Indicator of the gate system, which is the weighted summation of all scores assigned to the parts and five condition parameters.

Table F-1. Typical draft tube gates condition assessment and scoring

Draft Tube Gates for Unit ____	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Draft Tube Gates	3.8.1							3.0
Gate Operating Equipment	3.8.2							2.0
Gate Seals	3.8.3							1.0
Gate Slots/Supports	3.8.4							1.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	0.00
							Condition Indicator -->	0.00

5. RATING CRITERIA

Physical Condition: Rating Criteria for Draft Tube Gates

Physical Condition of draft tube gates refers to those features that are observable or detected through measurement and testing. It includes gate seal deterioration, corrosion or damage of gate parts, presence of debris, damage or deterioration of gate slots and supporting piers, misalignment of gate slots due to concrete growth, etc. It is important that draft tube gates function properly since they are used in dewatering and the failure of a gate could have severe consequences. Therefore, draft tube gates should be carefully evaluated to ensure proper and safe functionality. The Best Practices for Draft Tube Gates can assist in evaluating the physical condition. For HAP site assessment, it is important to interview and discuss with plant personnel to help score the physical condition. The results of all related information are analyzed and applied to Chart 1.

Chart 1 Draft Tube Gates Physical Condition Rating Criteria		
Physical Condition Rating Scale		**Physical Condition Score**
Excellent	Limited or no deterioration or damage to gates; minimal leakage at gate seals; no deterioration, damage, or defects of gate seals; gate slots are in alignment and show not sign of movement; no deterioration or damage of concrete slots/supports; hoisting equipment is functioning properly and shows no sign of motor overload; hoisting equipments parts are in excellent condition. Gate system is functioning optimally and requires no repairs.	**8–10**
Good	Minor deterioration or damage to gates; moderate leakage at gate seals; minor deterioration, damage, or defects of gate seals; gate slots are in alignment and show signs of slight movement; minor deterioration or damage of concrete slots/supports; gates are functioning with minor binding during installation and removal; hoisting equipment is functioning and shows minimal signs of motor overload; hoisting equipments parts are in adequate condition. Gate system is functioning however minor repairs may be necessary.	**5–7**
Fair	Moderate deterioration or damage to gates; significant leakage at gate seals; moderate deterioration, damage, or defects of gate seals; gate slots misaligned and show sign of movement; moderate deterioration or damage of concrete slots/supports; hoisting equipment is functioning but shows moderate signs of motor overload; hoisting equipments parts are in fair condition. Gate system is functioning however moderate repairs may be necessary.	**3–4**
Poor	Severe deterioration or damage to gates; extensive leakage at gate seals; severe deterioration, damage, or defects of gate seals; gate slots are extremely misaligned; severe deterioration or damage of concrete slots/supports; hoisting equipment is functioning poorly with severe motor overload; hoisting equipments parts are in poor condition. Gate system no longer functions properly and replacement or extensive repairs are necessary.	**0–2**

Age: Rating Criteria for Draft Tube Gates

Age is an important factor when considering part upgrade as it can be an indication of performance degradation. As gate systems age, they become more susceptible to deterioration due prolonged exposure to moisture when in use and the elements when in storage. Not only does increased wear result in operational problems and loss of efficiency, it can also increase the risk of failure.

Age scoring is relatively more objective than other condition parameters. The detailed scoring criterion developed in Chart 2 allows the age score to be automatically generated in the HAP Database by the actual years of the installed part. The age scoring criteria for various parts are shown in Chart 2.

Chart 2 Age Rating Criteria for Draft Tube Gates

Age of Gate or Hoist Structural Parts and Supports	Age Score	Age of Seals	Age of Operating Equipment
<30 years	**8–10**	<10 years	<15 years
30–60 years	**5–7**	10–15 years	15–25 years
60–80 years	**3–4**	15–20 years	25–35 years
>80 years	**0–2**	>20 years	>35 years

Installed Technology: Rating Criteria for Draft Tube Gates

The Installed Technology indicates advancement in draft tube gate design, installation/construction techniques, hoisting techniques, corrosion protection, and gate seal configuration and material which may affect maintenance and reliability performance of the gates. Outdated technology may cause difficulties for supplying replacement parts or performing routine maintenance.

Scoring the Installed Technology requires historic knowledge of draft tube gate technology advancement and familiarity with industry standards and materials. For example, gate seal geometry and seal attachment have advanced in recent years. The use of rubber gate seals with a J-bulb shape have been more commonly used in the past 40 years. Recently, the use of stainless steel for gates and seal parts has been used with the advantage of providing corrosion protection.

The competence, professionalism, and reputation of the original suppliers could also impact the Installed Technology. As compared to highly reputable manufacturers with a good service record, the parts supplied or installed by unknown or disreputable companies would get lower scores. The Installed Technology scoring criteria for various parts are shown in Chart 3.

Chart 3 Draft Tube Gates Technology Rating Criteria	
Technology Levels of the Design and Construction	**Score for Installed Technology Level**
The technology has not been changed significantly since the part was installed; and the installed technology was supplied by brand name companies with a great reputation	**8 – 10**
The technology has been more or less advanced but no problem to supply the matching parts in next 5-10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may reduce the cost of replacement). The installed technology was supplied by medium companies with good reputation.	**4 – 7**
The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability. The installed technology was supplied by small companies with bad reputation.	**0 – 3**

Operating Restrictions: Rating Criteria for Draft Tube Gates

The Operating Restrictions refers to the current limitations on the operating ranges. Draft tube gates are not part of normal plant operations and are primarily used only for plant maintenance and dewatering activities. Therefore, any restriction based on the condition of draft tube gates does not directly impact plant operations. Indirectly, issues with draft tube gates (i.e., gate binding or failure) can impact the length of unit shutdown during dewatering which consequently affects plant operations. Chart 4 describes the rating for operating restrictions.

Chart 4 Draft Tube Gates Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes, and the original design has no constraints on the required operation.	**8 – 10**
Minimal restraints: Dewatering activities are affected by gate and hoisting equipment selection or design.	**5 – 7**
Moderate restraints: Dewatering activities are limited. The performance can be significantly improved with revised system design.	**3 – 4**
Severe limitations: The component does not meet the operational criteria, dewatering capabilities and reliability are significantly limited if it operates under current system design.	**0 – 2**

Maintenance Requirement: Rating Criteria for Draft Tube Gates

The amount of corrective maintenance that either has been or must be performed is an indication of the gate system condition. If draft tube gate or associated parts have required limited or no maintenance, then that is an indication that the system is in good condition. If a part has required extreme corrective maintenance, then the part is considered to be in poor condition.

Other factors to consider for maintenance scoring include:

- Maintenance needs are increasing with time or problems are re-occurring
- Previous failures or issues related to draft tube gates
- Failures or problems with draft tube gates of similar design and material

The results of the maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5.

Chart 5 Draft Tube Gates Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum level (normal condition): A small amount of routine preventive maintenance is required. No corrective maintenance.	**9–10**
Low level: Small amounts of corrective maintenance (e.g., less than 3 staff days per component per year). Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis.	**7–8**
Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages.	**5–6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems.	**3–4**
Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required.	**0–2**

Data Quality: Rating Criteria for Draft Tube Gates

The Data Quality score reflects the quality of the inspection, test, and measurement results used to evaluate draft tube gates. The more current and complete the inspection, tests, and measurement results are, the higher the Data Quality scores. The frequency of normal testing is as recommended by the HAP assessment team in conjunction with industry standards.

Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination of the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality are developed in Chart 6.

Chart 6 Draft Tube Gates Data Quality Rating Criteria	
Data Availability, Integrity and Accuracy	**Data Quality Score**
High – The maintenance policies and procedures were followed by the plant and the routine inspections, tests, and measurements were performed within normal frequency in the plant. The required data and information are available to the assessment team through means of site visits, possible visual inspections, and interviews with experienced plant staff.	**8 – 10**
Medium – One or more of routine inspections, tests, and measurements were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 – 7**
Low – One or more of routine inspections, tests, and measurements were completed 24-36 months past the normal frequency, or some of results are not available.	**3 – 4**
Very Low – One or more of required inspections, tests and measurement were completed >36 months past the normal frequency, or significant portion of results are not available.	**0 – 2**

6. CONDITION AND DATA QUALITY INDICATOR

In Table F-1, the final condition score for flumes and open channels (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J) \times F(K) \times F(J)}{\sum_{K=1,M}^{J=1,5} F(K) \times F(J)} \quad (1)$$

The Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts:

$$DI = \frac{\sum_{K=1,M} S_D(K) \times F(K)}{\sum_{K=1,M} F(K)} \quad (2)$$

Here, M = the total number of parts associated with draft tube gates; K = the identification No. of parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of a part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific testing would more directly reveal the condition of the draft tube gate system.

7. REFERENCES

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4. MWH (2010). *Final Report of Hydropower Modernization Initiative Asset Investment Planning Program*, Prepared for US Army Corps of Engineers Northwest Division, Hydroelectric Design Center, 2010.

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DRAFT TUBE GATES INSPECTION FORM AND CHECKLIST

REVISION 1.0, 12/20/2011

Draft Tube Gates: Inspection Form

General Information:

Date of Site Visit: ______________________________

Plant Name: ______________________________

Source(s) of Data: ______________________________

Gate System Inspected: ______________________________

Description of General Arrangement: ______________________________

____

____

General Construction Description: ______________________________

____

____

Typical Storage Conditions: ______________________________

____

____

Age of Gate and Associated Parts: ______________________________

Accessibility for Visual Inspection: ______________________________

____

____

Previous Condition Assessment Date(s): ______________________________

____

Estimated Life Remaining [Yrs]: ____________________

Gates:

____

____

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____

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Gate Seals:

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Hoists and Lifting Equipment:

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____

____

____

Bearing Structure:

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____

____

Draft Tube Gates Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
A. General Information				
What are the plant specific life and serviceability needs for the draft tube gate system? *[How long will the gate system be required, are there future plans for facility decommissioning, are there any plans for replacement or major upgrades, etc.?]*				
Have all accessibility issues been addressed and discussed with plant personnel prior to the site visit? *[Determine which parts require special access for inspection, which parts will not be available for visual inspection, alternative means of collecting data (i.e. interviews with plant personnel), etc.]*				
Identify the appropriate testing techniques to be used. *[Depends on accessibility, construction materials, plant requirements, safety restrictions, etc.]*				
Identify any special equipment required for the plant walk down. *[Depends on accessibility, construction materials, plant requirements, safety restrictions, etc.]*				
Have all plant records regarding maintenance, repairs, operating conditions, performance data, etc. been gathered or requested?				

Draft Tube Gates Check List - Continued				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
B. Gate, Seals, and Gate Slots				
Are the gates original or have they been replaced/upgraded since facility commissioning? *[If replaced, why were they replaced and what changes (if any) were made to the original design?]*				
Is there evidence of steel corrosion of gate parts? If yes, how severe is the corrosion and what is the extent? *[Look for pitting, surface rust, section loss, etc.]*				
Are the gate seals intact and functioning properly? *[Look for seal deterioration (i.e. cracks or chips), damage, or irregularities. Check for any debris trapped between seal and sealing surface. Are the seals leaking?]*				
Is there evidence of gate slot movement or misalignment which could result in gate binding? *[Slot misalignment could be a result of concrete growth (AAR). Other causes of irregularities can include local deterioration or concrete spalling. If possible, collect precise measurements to determine if movement has occurred.]*				
Is there evidence of gate member deterioration, damage, or overstress? *[Look for loose/missing bolts or rivets, weld cracks or gouges, member warping, loose or misaligned exterior plates, excessive deformations, etc. Could result in twisting of gate when being lifted.]*				

Draft Tube Gates Check List - Continued				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
C. Hoists and Lifting Equipment				
Are hoists and lifting equipment working properly? *[Are moving parts properly lubricated, is oil free of contaminants, gears and bearings do not have excessive wear, hoist ropes have no broken strands or deformation, etc. Are there any unusual sounds or excessive vibrations propagating from the gearbox?]*				
Is excessive debris present near hoisting equipment? *[May cause blockage of gate lifting lugs and result in malfunction of lifting beam sheaves or lift lug engagement device.]*				
Is there evidence (records or visual inspection) of hoisting equipment motor overload (either currently or previously) and what is the apparent cause? *[May be due to motor under-sizing, additional frictional and resisting gate loads (i.e. gate binding), drive shaft misalignment, old age, and deterioration of motor windings.]*				
Are hoisting mechanisms regularly inspected? If yes, how often and how extensive is the inspection.				
Is there any evidence of deterioration or damage of hoisting equipment? *[Corrosion of lifting beam and lugs, member deformations, etc.]*				

Draft Tube Gates Check List - Continued				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
D. Miscellaneous				
Are gates stored in a dry environment and not exposed to weather when not in operation? *[Storage conditions can impact gate condition and life expectancy (i.e. poor storage conditions might accelerate gate deterioration).]*				
Does the facility have a routine inspection and maintenance plan for draft tube gates currently in place? *[If yes, what is the frequency and extent of inspections? What type of maintenance is routinely performed and how often?]*				
Have there been any changes to the original design? *[Gate materials, coatings, seal configurations and materials, gate slots configuration, hoisting/lifting equipment].*				

Draft Tube Gates

Assessment Conclusions and Recommendations:

APPENDIX G. GUIDE FOR LEAKAGE AND RELEASES CONDITION ASSESSMENT

REVISION 1.0, 12/20/2011

CONTENTS

1. GENERAL

Unregulated or excessive leakage and releases can negatively impact power generation at a hydropower facility since any significant water loss is a loss in potential generation. This condition assessment addresses leakage and releases issues as they relate to spillways, sluiceways, and dam structure. The two primary sources of leakage considered within this assessment are seepage at foundations or dam abutments and inadequate sealing at spillway and sluiceway gate seals. Releases are the excess spillage of water from spillways and sluiceways due to either excess storage (i.e., regulate reservoir level) or maintenance of minimum downstream flow requirements (i.e., dissolved oxygen).

For leakage and releases, the three following steps are necessary to establish a condition indicator:

1) What parts/items are to be included in the condition assessment and what is their level of importance (parts and their weighting factors)?

2) What metrics/parameters are to be investigated for the quantitative condition assessment and what is their level of importance (condition parameters and their weighting factors)?

3) How to assign numerical scores to the parts/items (rating criteria)?

This appendix provides guides to help answer the questions above, which can be applied to the leakage and releases through spillways, sluiceways, and dams. The condition assessment of leakage and releases is not as tangible as other facility parts/items such as penstocks or turbines. Table G-1 includes three systems (spillways, sluiceways, and dam structure) which are often sources of leakage or used to regulate releases. Due to the variation in sources of leakage and basis for releases, the guides provided in this appendix cannot quantify all contributing factors. Mitigating factors not included in this Guide may trigger testing and further evaluation to determine the final condition score and determine the feasibility of replacement or repair.

This appendix is not intended to define maintenance practices associated with leakage or releases or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2. CONSTITUENT PARTS ANALYSIS

For the scoped leakage and releases assessment, the constituent parts/items are analyzed and listed in Table G-1 (references to HAP Taxonomy).

If any part (e.g., flashboard) does not exist in a particular system, this part will be excluded from scoring mechanism by inputting "NA" into the table. The effect of one part exclusion is usually insignificant to the entire system assessment and does not justify an adjustment of the weighting factors for the other parts.

3. METRICS FOR CONDITION ASSESSMENT

As listed in Table G-1, the following five condition parameters are considered for the condition assessment of leakage and releases:

- The Physical Condition
- The Age
- The Installed Technology Level

- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on previous testing and measurements (i.e., flow measurements), historical Operation and Maintenance (O&M) records, original design drawings, previous rehabilitation feasibility study reports if available, interviews with plant personnel, and inspections where available.

It can be noted that there is a certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmark condition assessment (without specific testing and measurements conducted on site) the five parameters are regarded as providing the basis for assessing the condition of leakage and releases.

In addition, the Data Quality Indicator, as an independent metric, is intended to reflect the quality of the available information and the confidence of the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity. Any of these situations could affect the results of the condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part/item to indicate the data availability, integrity, and accuracy; and the confidence of the given condition ratings (MWH 2010).

4. WEIGHTING FACTORS

There are two categories of weighting factors in Table G-1. It is recognized that some condition parameters affect the condition to a greater degree than others. Also, some parts are more or less important than other parts to the system. These weighting factors should be pre-determined by consensus among experienced hydropower engineers and plant O&M experts. Once they are determined for each part/item, they should be largely fixed from plant to plant for similar arrangements. In some plants the weighting factors will have to be adjusted for specific arrangements. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors will not affect the Condition Indicator, which is the weighted summation of all scores assigned to the parts/items and five condition parameters.

Table G-1. Typical spillways/sluiceways/dams condition assessment and scoring for leakage and releases

Leakage & Releases through Spillways/Sluiceways/ Dams	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Concrete Structure	2.1.1							5.0
Spillway Gates	2.1.2							3.0
Spillway Gates Hoisting Machinery	2.1.3							2.0
Flashboard	2.1.4							2.0
Bulkhead Gates/Stoplogs	2.1.5							2.0
Spillway Caisson	2.1.6							3.0
Sluiceway Gates	2.2.1							3.0
Sluiceway Gate Operating Equipment	2.2.2							2.0
Sluiceway Trash Racks	2.2.3							2.0
Sluiceway Inlet Structure	2.2.4							3.0
Sluiceway Outlet Structure	2.2.5							3.0
Main Dam	2.3.1							5.0
Embankment	2.3.2							3.0
Retaining Walls	2.3.3							3.0
Drainage Galleries	2.3.4							1.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	*0.00*
							Condition Indicator -->	*0.00*

5. RATING CRITERIA

Physical Condition: Rating Criteria for Leakage and Releases

Physical Condition refers to those features that are observable or detected through measurement and testing. It includes leakage at gate seals, gate seal deterioration, seepage, structural deterioration (i.e., concrete cracking), functionality of operating equipment, excess release, etc. In addition to efficiency related issues, severe leakage or seepage may be an indication of compromised structural integrity or safety issues. Therefore, leakage and releases should be carefully evaluated. The Best Practices for Leakage and Releases can assist in evaluating the physical condition. For HAP site assessment, it is important to interview and discuss with plant personnel to help score the physical condition. The results of all related information are analyzed and applied to Chart 1.

Chart 1 Leakage and Releases Physical Condition Rating Criteria		
Physical Condition Rating Scale		Physical Condition Score
Excellent	Limited leakage from gate seals; no sign of gate seal deterioration; tailwater flows are clean; limited or no downstream leakage or seepage at dam abutments; spillway and sluiceway gates are working properly and have been recently calibrated; limited concrete deterioration of structures. Parts/items are functioning properly and there are no significant water losses due to leakage and releases.	8 – 10
Good	Moderate leakage from gate seals; minimal gate seal deterioration; tailwater flows fairly are clean and free of debris; minimal downstream leakage or seepage at dam abutments; spillway and sluiceway gates are functioning but have not been recently calibrated; minimal concrete deterioration of structures. Parts/items are functioning and there are only minimal water losses due to leakage and releases. Minor repairs may be necessary.	5 – 7
Fair	Significant leakage from gate seals; moderate gate seal deterioration; muddy tailwater flows are common; significant downstream leakage or seepage at dam abutments; spillway and sluiceway gates are working but are rarely calibrated or monitored; moderate concrete deterioration structures. Parts/items are functioning however there are significant water losses due to leakage and releases. Moderate repairs may be necessary.	3 – 4
Poor	Severe leakage from gate seals; severe gate seal deterioration or failure of seals; tailwater flows are muddy; severe downstream leakage or seepage at dam abutments; spillway and sluiceways gates are not functioning; severe concrete deterioration of structures. Parts/items are not functioning and there is excessive water losses due to leakage and releases. Replacement or repairs are necessary.	0 – 2

Age: Rating Criteria for Leakage and Releases

Age is an important factor when considering part or system upgrade as it can be an indication of performance degradation. As structures age, they become more susceptible to deterioration due to turbulent flow and severe weather. Also gate systems become less reliable with age due to infrequent calibration, poor equipment maintenance, and seal deterioration. Not only does increased wear result in operational problems (i.e., water loss) and loss of efficiency, it can also increase the safety concerns.

Age scoring is relatively more objective than other condition parameters. The detailed scoring criterion developed in Chart 2 allows the age score to be automatically generated in the HAP Database by the actual years of the installed part. The Age scoring criteria for various parts are shown in Chart 2.

Chart 2 Age Rating Criteria for Leakage and Releases			
Age of Structures and Gates	**Age Score**	**Age of Gate Seals**	**Age of Operating Equipment**
<30 years	**8 – 10**	<10 years	<15 years
30-60 years	**5 – 7**	10-15 years	15-25 years
60-80 years	**3 – 4**	15-20 years	25-35 years
>80 years	**0 – 2**	>20 years	>35 years

Installed Technology Level: Rating Criteria for Leakage and Releases

The Installed Technology indicates advancement in design, installation/construction techniques, gate calibration, instrumentation, and gate seal technology which may affect performance. Outdated technology may cause difficulties for supplying replacement parts or performing routine maintenance which can result in prolonged outages.

Scoring the Installed Technology requires historic knowledge of spillway and sluiceway technology advancement and familiarity with industry standards and materials. For example, historically wood and steel were used for gate seals; however, most modern facilities use rubber seals which significantly reduce leakage. Therefore, spillway and sluiceway gates utilizing rubber seals will receive a higher score than those using other materials. With advances in instrumentation and software analysis, releases can be better regulated and losses due to leakage more easily quantified. Systems utilizing state of the art instrumentation and analysis software will also receive a higher score than plant utilizing antiquated calibration techniques.

The competence, professionalism, and reputation of the original suppliers could also impact the Installed Technology. As compared to highly reputable manufacturers with a good service record, the parts supplied or installed by unknown or disreputable companies would get lower scores. The Installed Technology scoring criteria for various parts are shown in Chart 3.

Chart 3 Leakage and Releases Technology Rating Criteria	
Technology Levels of the Parts/Items	**Score for Installed Technology Level**
The technology has not been changed significantly since the part/item was installed; and the installed technology was supplied by brand name companies with a great reputation	**8 – 10**
The technology has been more or less advanced but no problem to supply the matching parts in next 5-10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may reduce the cost of replacement). The installed technology was supplied by medium companies with good reputation.	**4 – 7**
The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability of power generation. The installed technology was supplied by small companies with bad reputation.	**0 – 3**

Operating Restrictions: Rating Criteria for Leakage and Releases

The Operating Restrictions refers to the current limitations on the operating ranges including flow and power capacity. Either under-sized or under-utilized capacity may reduce the overall operational performance and accelerate the deterioration of the physical condition. Operational limitations play a role in determining the serviceability of the unit: the greater the limitations, the greater the generation loss.

Operating restrictions can be caused by to two sources:

1) Excessive water loss due to unregulated release from spillways and sluiceways (poor gate calibration), or loss of generation due to required minimum release amounts which in some cases can be avoided. For example, minimum releases are sometimes required to improve dissolved oxygen levels which can also be met with the installation of aeration weirs or aerating turbines. Also, some plants have installed generating equipment to utilize previously unused generation potential from environmental releases.

2) Increase outages due to deterioration or reliability of gate systems.

Chart 4 describes the ratings of Operating Restrictions.

Chart 4 Leakage and Releases Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes, and the original design has no constraints on the required operation.	**8 – 10**
Minimal restraints: Operation range can be expanded with revised equipment selection or design.	**5 – 7**
Moderate restraints: The operation range and performance can be significantly improved with revised system design.	**3 – 4**
Severe limitations: The part/item does not meet the operational criteria, performance and reliability are significantly limited if it operates under current environment/requirement.	**0 – 2**

Maintenance Requirement: Rating Criteria for Leakage and Releases

The amount of corrective maintenance that either has been or must be performed is an indication of the part/item condition. If the part/item has required limited or no maintenance, then that is an indication that the system is in good condition. If it has required extreme corrective maintenance resulting in unscheduled or forced outages, then the part/item is considered to be in poor condition.

Other factors to consider for maintenance scoring include:

- Maintenance needs are increasing with time or problems are re-occurring
- Previous failures or issues related to parts/items
- Failures or problems with parts/items of similar design and material

The results of the maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5.

Chart 5 Leakage and Releases Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum level (normal condition): A small amount of routine preventive maintenance is required. No corrective maintenance.	**9–10**
Low level: Small amounts of corrective maintenance (e.g., less than 3 staff days per component per year). Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis.	**7–8**
Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages.	**5–6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems.	**3–4**
Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required.	**0–2**

Data Quality: Rating Criteria for Leakage and Releases

The Data Quality score reflects the quality of the inspection, test, and measurement results used to evaluate leakage and releases. The more current and complete the inspection, tests, and measurement results are, the higher the Data Quality scores. The frequency of normal testing is as recommended by the HAP assessment team in conjunction with industry standards.

Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination of the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality are developed in Chart 6.

Chart 6 Leakage and Releases Data Quality Rating Criteria	
Data Availability, Integrity and Accuracy	**Data Quality Score**
High – The maintenance policies and procedures were followed by the plant and the routine inspections, tests, and measurements were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8 – 10**
Medium – One or more of routine inspections, tests, and measurements were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 – 7**
Low – One or more of routine inspections, tests, and measurements were completed 24-36 months past the normal frequency, or some of results are not available.	**3 – 4**
Very Low – One or more of required inspections, tests, and measurements were completed >36 months past the normal frequency, or significant portion of results are not available.	**0 – 2**

6. CONDITION AND DATA QUALITY INDICATOR

In Table G-1, the final condition score for flumes and open channels (i.e., the Condition Indicator, *CI*), can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J)\times F(K)\times F(J)}{\sum_{K=1,M}^{J=1,5} F(K)\times F(J)} \quad (1)$$

The Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K)\times F(K)}{\sum_{K=1,M} F(K)} \quad (2)$$

Here, M = the total number of parts associated with leakage and releases; K = the identification No. of parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of a part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific testing would more directly reveal the condition of the pressurized water conveyance.

7. REFERENCES

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LEAKAGE AND RELEASES INSPECTION FORM AND CHECKLIST

REVISION 1.0, 12/20/2011

Leakage and Releases: Inspection Form

General Information:

Date of Site Visit: ____
Number of Spillways: __________________ Spillway[s] Inspected: _________________________
Number of Sluiceways: ___________________ Sluiceway[s] Inspected: ______________________
Previous Inspection Issues or Repairs: ____
____
____
Description of Current Flow Measurement and Gate Calibration Techniques: _______________________
____
____
Estimated Loss Due to Seepage or Leakage [%]: ____________________
Previous History of Seepage or Leakage: ____
____
____
Minimum Downstream Flow Requirements [ft^3/s]: ____________________ (Average)
Actual Release Discharge [ft^3/s]: ____________________ (Average)
Additional Observations or Considerations: ____
____
____
____

Spillways:

Sluiceways:

Dam Abutments:

Gate and Seals:

Leakage:

Releases:

Leakage and Releases Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
A. General Information				
What are the plant specific life and serviceability needs for spillways and sluiceways? *[How long will the spillways and sluiceways be required (i.e. are there future plans for plant decommissioning or major upgrade)?]*				
Have all accessibility issue been addressed and discussed with plant personnel prior to site visit? *[Determine which parts/items will require access for visual inspection, which parts/items will not be accessible, and alternative means of collecting date (previous records, interviews with plant personnel, etc.)]*				
Will any testing be permitted during the site visit? If yes, what testing techniques will be used and is any special equipment required? *[Will depend on accessibility, plant requirements, safety restrictions, etc.]*				
Have all plant records regarding spillway and sluiceway maintenance, repairs, operating conditions, performance data, etc. been gathered or requested?				

Leakage and Releases Check List - Continued				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
B. Leakage - Spillways and Sluiceways				
Is there visible leakage occurring at spillway and sluiceway gates when closed? *[If sluiceways are not visible, then leakage can be observed at their outlets.]*				
Is there evidence of gate seal deterioration? *[Look for excessive leakage past gate seals, missing seals, degradation or damage, etc.]*				
Are gates in good condition and functioning properly? *[Look for steel corrosion, loss of material/section, warping of members, etc.]*				
Has the plant reported any prior issues with leakage at gates? If yes, have any repair techniques been implemented? *[List any repair technique, location of leakage, causes, effectiveness of repair, etc.]*				
If leakage is present, is it possible to measure or quantify the flow rate? *[Record measurements or observations for future comparison (i.e., Are conditions worsening?)]*				

Leakage and Releases Check List - Continued				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
C. Leakage - Seepage				
Has the plant had any previous issues with seepage and is seepage currently visible downstream of the reservoir? *[If yes, observe previous seepage locations, document current condition, and quantify severity of seepage (i.e. minimal, moderate, severe). Have conditions worsened, improved, or remained the same?]*				
If the plant has experience previous issues with seepage, were any techniques or repairs implemented to reduce or prevent the seepage? *[Indicated whether repair methods were successful]*				
Is there appearance of sinkholes downstream of the reservoir? *[Indicate size and location of sinkholes. May indicate seepage issues.]*				
Have there been any muddy tailwater flow previously observed or recorded? *[Indicate when the flow occurred and how long it lasted. May indicate seepage issues.]*				

Leakage and Releases List - Continued				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
D. Releases				
Does the plant have a minimum downstream flow requirement? *[If yes, what is the requirement, source of requirement (i.e. dissolved oxygen levels), how is the plant currently meeting the requirement (time and method of release), etc.?]*				
Is the plant currently releasing water from spillways and sluiceways exceeding the minimum requirement? *[If yes, what is the reason for the excess release (i.e. poor gate calibration)? Is the amount of release measured and regularly documented?]*				
How is the flow rate of spillway and sluiceways releases calculated? *[Charts, formulas, computer programs]*				
Are spillways and sluiceways routinely inspected and calibrated? *[If yes, how are they calibrated and what is the frequency of inspection?]*				

Leakage and Releases

Assessment Conclusions and Recommendations:

APPENDIX H. GUIDE FOR FRANCIS TURBINE, KAPLAN/PROPELLER TURBINE AND PELTON TURBINE CONDITION ASSESSMENT

REVISION 1.0, 12/08/2011

HAP
HYDROPOWER ADVANCEMENT PROJECT

CONTENTS

1. GENERAL

The hydraulic turbine is the most critical component in the powertrain of a hydropower plant. Unlike the generators and transformers, catastrophic failure is rare to happen on turbines, but a turbine does have an economic lifespan. Contributed by (a) the surface damages from cavitation, erosion and corrosion; (b) the cracks from fatigue and "rough zone" operations; and (c) the off-design contours accumulated from welding repairs, the turbine efficiency and capacity decline with time while the annual cost of repairs and maintenance increases with time. Thus, rehabilitation and replacement of an aging turbine may become more economical and less risky than maintaining the original turbine, especially considering the potential efficiency improvement from the state-of-art turbine design and from the turbine material and fabrication technology advancement achieved during past decades. Yet, turbine condition assessment is essential to estimate the economic lifespan and potential risk of failure, and to evaluate the benefits and cost of turbine upgrading.

For any type of turbine, the following three step analyses are necessary to arrive at a turbine condition indicator:

1) What parts should be included for a turbine condition assessment and which parts are more important than others (parts and their weighting factors)?

2) What metrics/parameters should be investigated for quantitative condition assessment and which ones are more important than others (condition parameters and their weighting factors)?

3) How to assign numerical scores to the turbine parts (rating criteria)?

This appendix provides guides to answer the above questions, which can be applied to Francis, Propeller/Kaplan and Pelton turbines. The condition assessment is performed on individual turbines in a plant, because even the originally identical turbines may have experienced different Operation & Maintenance (O&M) stories and would arrive at different values of condition indicators. Due to the uniqueness of each individual turbine, the guides provided in this appendix cannot quantify all factors that affect individual turbine condition. Mitigating factors not included in this Guide may trigger testing and further evaluation to determine the final score of the turbine condition and to make the decision of turbine replacement or rehabilitation.

This appendix is not intended to define turbine maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2. CONSTITUENT PARTS ANALYSIS

For three major types of turbines (i.e., Francis, Propeller/Kaplan and Pelton), their constituent parts are analyzed and listed in Tables H-1, H-2, and H-3, respectively (references to HAP Taxonomy). Among all the turbine parts, the runner is the most critical part for a turbine. If any part (e.g., draft tube) does not exist in a particular turbine unit, this part will be excluded from scoring mechanism by inputting "NA" into the table. The effect of one part exclusion is usually insignificant to the entire turbine assessment, which usually does not justify any adjustment of the weighting factors for other parts of the turbine.

3. METRICS FOR TURBINE CONDITION ASSESSMENT

As listed in Tables H-1, H-2, and H-3, the following five condition parameters are considered for condition assessment of turbine and turbine parts:

- The Physical Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on the previous testing and measurements, historical O&M records, original design drawings, previous rehabilitation feasibility study reports if conducted, interviews with plant staff and some limited inspections. It is noticed that there are certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmarking condition assessment without specific testing and measurements conducted on site, these five parameters are regarded as providing the basis for assessing the condition of turbine parts and entire turbine.

In addition, the Data Quality Indicator, as an independent metrics, is to reflect the quality of available information and the confidence on the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity, and any of these situations could affect the results of condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part/item to indicate the data availability, integrity and accuracy and the confidence on the given condition ratings (MWH 2010).

4. WEIGHTING FACTORS

There are two categories of weighting factors in Table H-1, H-2, and H-3. It is recognized that some condition parameters affect the turbine condition to a greater or lesser degree than other parameters; also some parts are more or less important than other parts to an entire turbine. These weighting factors should be pre-determined by consensus among experienced hydropower mechanical engineers and plant O&M experts. Once they are determined for each type of turbines, they should be largely fixed from plant to plant for the same type of turbines, except for special designs found in a turbine where the weighting factors have to be adjusted. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors won't affect the Condition Indicator of a turbine, which is the weighted summation of all scores that assigned to the turbine parts and five condition parameters.

Table H-1. Typical Francis turbine condition assessment and scoring: XXX Hydropower Plant (Unit #)

Francis Turbine Unit ____	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Spiral/Scroll Case	4.1.1.1							1.5
Stay Ring/Vanes	4.1.1.2							1.5
Wicket Gates Mechanism/Servomotors	4.1.1.3							3.0
Runner	4.1.1.4							5.0
Draft Tube	4.1.1.5							2.0
Main Shaft	4.1.1.6							1.0
Guide Bearings	4.1.1.7							1.5
Mechanical Seal/Packing	4.1.1.8							1.0
Head Cover	4.1.1.9							1.5
Vacuum Breaker/PRV	4.1.1.10							1.5
Aeration Devices	4.1.1.11							2.0
Bottom Ring	4.1.1.12							1.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	0.00
							Condition Indicator -->	0.00

Table H-2. Typical propeller/Kaplan turbine condition assessment and scoring: XXX Hydropower Plant (Unit #)

Kaplan or Propeller Turbine Unit_____	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Spiral Case	4.1.1.1							1.5
Stay Ring/Vanes	4.1.1.2							1.5
Wicket Gates Mechanism/Servomotors	4.1.1.3							3.0
Runner	4.1.1.4							5.0
Draft Tube	4.1.1.5							2.0
Main Shaft	4.1.1.6							1.0
Guide Bearings	4.1.1.7							1.5
Mechanical Seal/Packing	4.1.1.8							1.0
Head Cover	4.1.1.9							1.5
Bottom Ring	4.1.1.12							1.0
Discharge/Throat Ring	4.1.1.13							1.5
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	0.00
							Condition Indicator -->	0.00

Table H-3. Typical Pelton turbine condition assessment and scoring: XXX Hydropower Plant (Unit #)

Pelton Turbine Unit _____	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Distributor/Manifold	4.1.1.14							1.5
Housing	4.1.1.15							1.5
Needle Valves/Nozzles	4.1.1.16							2.0
Runner	4.1.1.4							5.0
Discharge Chamber	4.1.1.17							1.0
Deflectors	4.1.1.18							1.0
Main Shaft	4.1.1.6							1.0
Guide Bearings	4.1.1.7							1.5
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	0.00
							Condition Indicator -->	0.00

5. RATING CRITERIA

Physical Condition: Rating Criteria for Turbine Parts

Physical Condition of turbine parts refers to those features that are observable or detected through measurement and testing. It includes surface roughness from erosion, corrosion or cavitation, cavitation pitting, cracking damage, clearances and leakage, vibrations and noises, oil loss, shaft runout, etc. The surface condition of waterway is important since it affects the efficiency and capacity of the turbine. The excessive clearance and leakage will lead to uncontrolled water losses, vibration and shaft runout may lead to safety issues of turbine operation, and the oil loss may affect water environment. Thus, they should be carefully evaluated. The Best Practices of Francis Turbine, Propeller Turbine and Pelton Turbine can assist in evaluating the physical conditions.

For HAP site assessment, it is important to interview and discuss with plant personnel to score the physical condition of turbine parts. The results of all related information are analyzed and applied to Chart 1 to assign the condition scores of turbine parts.

Chart 1 Turbine Physical Condition Rating Criteria		
Physical Condition Rating Scale		**Physical Condition Score**
Excellent	No noticeable defects. Some aging or wear may be noticeable.	**9–10**
Very good	Only minor deterioration or defects are evident, and function is full.	**7–8**
Good	Some deterioration or defects are evident, but function is not significantly affected.	**5–6**
Fair	Moderate deterioration, function is still adequate, but the unit efficiency may be affected.	**3–4**
Poor	Serious deterioration in at least some portions, function is inadequate, unit efficiency or availability significantly affected.	**2**
Very poor	Extensive deterioration. Barely functional.	**1**
Failed	No longer functions, may cause failure of a major component.	**0**

Age: Rating Criteria for Turbine Parts

Age is an important factor to consider turbine upgrading and also to indicate performance degradation. When turbine ages, it becomes more susceptible to cracks from fatigue and cumulative weld repairs, and increases the likelihood of physical failure. Meanwhile, an older turbine usually has greater potential to gain efficiency and capacity by replacing and using the state-of-the-art turbine design and materials.

Age scoring is relatively more objective than other condition parameters. The detailed scoring criteria developed in Chart 2 allows the age score be automatically generated in the HAP Database by the actual years of the installed part. The turbine parts usually have expected lifespan of 40–45 years, but the seal rings and bearings are considered 20 years between the overhauls or rehabilitations, and a water-lubricated guide bearing has 10 years of expected lifespan. Their scoring criteria will be changed accordingly as shown in Chart 2.

Chart 2 Age Rating Criteria for Turbine Parts			
Ages of the turbine major Parts/Items	**Age Score**	**Ages of Oil Bearings and Seal Rings**	**Age of Water-Lubricated Guide Bearing**
<5 years	**10**	<2 years	<1 years
5–10 years	**9**	2–5 years	1–2 years
10–15 years	**8**	5–7 years	2–3 years
15–20 years	**7**	7–10 years	3–5 years
20–25 years	**6**	10–12 years	5–6 years
25–35 years	**5**	12–17 years	6–8 years
35–40 years	**4**	17–20 years	8–10 years
40–45 years	**3**	20–22 years	10–12 years
45–50 years	**2**	22–25 years	12–13 years
50–60 years	**1**	25–30 years	13–15 years

Installed Technology Level: Rating Criteria for Turbine Parts

The Installed Technology Level indicates advancement levels of designing, machining, installation and materials, which may effect on the unit and plant performance. The outdated technology may bring difficulties for spare parts supply and prolonged outage when it fails.

Scoring the Installed Technology Level requires historic knowledge of turbine technology advancement and familiarity with turbine manufacturing industry. With the computerization of turbine design (CFD) and manufacturing (CNC), the production accuracy and turbine efficiency have been significantly improved since 1970s to 1980s, particularly for the water passage parts. Thus, the turbine parts installed before 1970 would get lower scores than those in 1990. The material of turbine parts is another factor to consider for scoring the installed technology level. Very old runners in the early 1900s or before, could have been cast from cast iron, later to be replaced with cast carbon steel, and today either cast or fabricated from carbon steel or stainless steel. The most common material being used in is ASTM A743 CA6NM stainless steel. It is cavitation resistant, fairly easy to cast and fabricate, and can usually be weld repaired without post heat treatment. The same is true for wicket gates materials.

The competence, professionalism and reputation of the original suppliers could also imply the installed technology levels. Compared those from large and well-known manufacturers, the turbine parts supplied by small and unnamed companies would get lower scores.

Chart 3 Turbine Technology Rating Criteria	
Technology Levels of the Parts/Items	**Score for Installed Technology Level**
The technology has not been changed significantly since the part was installed; and the installed technology was supplied by brand name companies with great reputation	**8 – 10**
The technology has been more or less advanced but no problem to supply the matching parts in next 5-10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may reduce the cost of replacement). The installed technology was supplied by medium companies with good reputation.	**4 – 7**
The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability of power generation. The installed technology was supplied by small companies with bad reputation.	**0 – 3**

Operating Restrictions: Rating Criteria for Turbine Parts

The turbine operating restrictions refer to the current limitations on the operating ranges of head, flow and power capacity, as well as on the required load ramp speeds, based on the original design and current condition of turbine parts. Either under-sized or under-utilized turbine capacity may reduce the turbine operational efficiencies and accelerate the deterioration of turbine physical condition (e.g., cavitation, vibrations). Operational limitations play a role in determining the serviceability of turbine unit: the greater the limitations, the greater the generation loss and sometimes water spilling.

The operating restrictions may be sourced from two aspects:

1) Turbine itself. To limit the severe cavitation or for the structural safety consideration, the operating ranges of maximum/minimum flows and heads are constrained due to the original design and/or currently deteriorated turbine physical condition (e.g., insufficient main shaft strength, hot bearings, and severe vibrations).

2) Environmental and market changes, including the role change in power grid (e.g., the unit assumed more peaking power with the nuclear and wind capacity added in the grid) and the site flow condition changes due to the climate change or required minimum instream flow change. The environmental constraints do not refer to any limitation from other components in the facility—for example, if the highest water level in headwater reservoir is limited by the safety concern of dam, then the dam, not the turbine, would get lower score for the operating restrictions.

Another example of turbine design constraint is that many low-head sites with great flow were designed and installed Propeller or Francis turbines before 1956 to 1960. However, today Kaplan turbines with adjustable blades become more economically feasible, which could improve unit efficiencies within wider range of flow/head.

Chart 4 describes the ratings of turbine operating restrictions.

Chart 4 Turbine Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes, and the original turbine design has no constraints on the required operation.	**8–10**
Minimal restraints: Operations to avoid minor rough zones; operation range can be expanded with revised turbine selection and design.	**5–7**
Moderate restraints: Operations to avoid large rough zones, high vibrations, and hot bearings. The operation range and performance can be significantly improved with revised turbine selection and design.	**3–4**
Severe limitations: The turbine is undesirable to operate anymore; the original design has significantly limited the performance and reliability if it operates under current environment/requirement.	**0–2**

Maintenance Requirement: Rating Criteria for Turbine Parts

The amount of corrective maintenance that either has been or must be performed is an indication that how the turbine condition is. No corrective maintenance is an indication that the turbine is in good shape. Severe corrective maintenance requires for scheduled or forced outages to perform.

Other factors to consider for maintenance scoring include:

- The need of maintenance is increasing with time or problems are reoccurring;
- Experience of frequent rough-zone operations;
- Previous failures related to the turbine parts;
- Failures and problems of the turbine parts with similar design.

The results of turbine maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5 to score the turbine parts.

Chart 5 Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum level (normal condition): A small amount of routine preventive maintenance is required (e.g., Runner blade surface cleaning and re-coating). No corrective maintenance.	**9 – 10**
Low level: Small amounts of corrective maintenance (e.g., less than 3 staff days per unit per year). Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis.	**7 – 8**
Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages (e.g., runner blade pit welding, seal ring replacement).	**5 – 6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., corrosion caused leaks; re-profiling and machining to OEM specifications is required).	**3 – 4**
Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required.	**0 – 2**

Data Quality: Rating Criteria for Turbine Parts

The Data quality scores reflect the quality of the inspection, test, and measurement results to evaluate the condition of turbine parts. The more current and complete the inspection, tests, and measurement results are, the higher the Data Quality scores. The frequency of normal testing is as recommended by industry standards.

Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of turbine parts are developed in Chart 6.

Chart 6 Turbine Data Quality Rating Criteria	
Data Availability, Integrity, and Accuracy	**Data Quality Score**
High: The turbine maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurement were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8–10**
Medium: One or more of routine inspections, tests and measurement were completed 6–24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5–7**
Low: One or more of routine inspections, tests and measurement were completed 24–36 months past the normal frequency, or some of results are not available.	**3–4**
Very Low: One or more of required inspections, tests and measurement were completed >36 months past the normal frequency, or significant portion of results are not available.	**0–2**

6. TURBINE CONDITION AND DATA QUALITY INDICATORS

In Table H-1, H-2, or H-3, the final condition score of the turbine (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J) \times F(K) \times F(J)}{\sum_{K=1,M}^{J=1,5} F(K) \times F(J)} \quad (1)$$

The turbine Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K) \times F(K)}{\sum_{K=1,M} F(K)} \quad (2)$$

Here, M = the total number of parts/items associated with a turbine; K = the identification No. of turbine Parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of a turbine part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a turbine part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific turbine testing, such as the efficiency/index test and paint film quality test, would more directly reveal the condition of turbine.

7. REFERENCES

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FRANCIS TURBINE INSPECTION FORM AND CHECK LIST

REVISION 1.0, 12/08/2011

HYDROPOWER ADVANCEMENT PROJECT

Francis Turbine: Inspection Form

General Information:

Date of Site Visit: ____ Unit No.________

Plant name: ____

Source/s of data:____

Manufacturer: ____Age:______________

Rated Output (MW):_________Max. Output (MW):__________Rated Speed (rpm):____________________

Rated net head (ft) __________ Max. net head (ft):__________Max. Efficiency (%):____________________

General Turbine Description:____

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Maintenance History / Major Repairs Description:

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Runner:

Diameter, intake: ___________________________ Diameter, discharge:_____________________________

Main Shaft Size (At runner connection):__________________________ Shaft Orientation:______________

Centerline to bottom: ________________________

Centerline to top: ___________________________

Material: ____

Addition specification data:

____

____

____

____

____

Wicket Gates:
Material: ___________________________

Addition specification data:

____
____
____
____

Stay Vanes:
Material: _________________________

Addition specification data:

____
____
____
____

Spiral Case (see Turbine Common Sub-Section):
Material: ________________________

Addition specification data:

____
____
____
____

Draft Tube:
Material: _________________________ Net Area at outlet opening (per unit):_________________________

Horizontal length (centerline of turbine to downstream face):_______________________________________

Vertical distance (distributor centerline to draft tube floor):____

Addition specification data:

____
____
____

Vacuum Breaker:
Material: _________________________

Addition specification data:

____
____
____
____

Francis Turbine Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History				
Runner cavitation repair? *[welding labor h/year]*				
Runner erosion repair? *[welding labor h/year]*				
Runner crack repair? *[welding labor h/year]*				
Runner re-coating with different material? *[Very hard metals, polymeric coatings, ceramics]*				
Any Runner modifications to reduce cavitation?				
Has the Runner wear ring been replacement?				
Has Runner been replaced with like original runner or new runner design?				
Is the Runner accessible for visual inspections? [*Identify if de-watering is an option for interior inspection.]*				
Have all plant records regarding runner maintenance, repairs, operating conditions and performance data been requested/gathered?				

Francis Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Has there been a refurbishment or replacement of the wicket gates?				
Has there been a replacement of wicket gate bushings? *[greased to greaseless]*				
Has there been a change of bushing type/design?				
Has there been change of wicket gate seal type or replacement of seals due to excessive leakage or rubbing.?				
Has there been change of inter-gate seal type?				
Has there been change of head cover seal type?				
Has there been change of bottom ring seal type? *[high density polyurethane]*				
Has there been a replacement of V packing on lower headcover bearings?				

Francis Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Has there been an improvement to wicker gate failure mechanism to increase reliability?				
Has there been a rehabilitation of operating ring, links, levers and servomotor connecting rods?				
Has there been an implementation of an automatic greasing system?				
Have there been any modifications/repairs to vacuum breaker?				

Francis Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment				
Is there evidence of runner surface corrosion?				
Is there evidence of erosion on the runner surface?				
Is there evidence of cavitation on the runner surface?				
Is there cracking in runner bucket root area?				
Can measurement to engineering drawings be made for the runner seal or blade tip clearance (gap)?				
Can the structural integrity of stay vane fillets be assessed?				

Francis Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment (Continued)				
Can end clearances be assessed?				
Is there history of failure mechanism- shear pin failures?				
Is there evidence of surface wear on wicket gate links, levers and connecting rods?				
Can WG servomotor leakage rate be assessed?				
Can Servomotor pressure be assessed?				
Can internal surface condition of spiral case (coating) be assessed?				
Can surface condition of baffle plates be assessed?				
Is annual welding cost known ($/year, labor h/year)?				

Francis Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment (Continued)				
Is there evidence of inter-gate leakage?				
Can surface finish of wicket gates be inspected for pitting?				
What is level of cracking on the wicket gates?				
Can wicket gates bushings/bearings condition be assessed?				
Can wicket gates radial clearance of bearings be assessed?				
Can wicket gates seal condition be assessed?				
Can nose to tail seal clearances be assessed?				

Francis Turbine Data Collection Sheet	
Topic	Data Input

KAPLAN/PROPELLER TURBINE INSPECTION FORM AND CHECK LIST

REVISION 1.0, 12/08/2011

Kaplan/Propeller Turbine: Inspection Form

General Information:

Date of Site Visit: ____ Unit No.________

Plant name: ____

Source/s of data:____

Manufacturer: ____Age:______________

Rated Output (MW):________Max. Output (MW):_________Rated Speed (rpm):_______________

Rated net head (ft) _________Max. net head (ft):_________Max. Efficiency (%):______________

General Turbine Description:____

____

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____

Maintenance History / Major Repairs Description:

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Runner:

Diameter, intake: __________________________ Diameter, discharge: ____________________________

Main Shaft Size (At runner connection):_________________________ Shaft Orientation: ______________

Centerline to bottom: _______________________

Centerline to top: __________________________

Material: ____

Addition specification data:

____

____

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____

____

Wicket Gates:
Material: ___________________________

Addition specification data:

___

___

___

___

Stay Vanes:
Material: _________________________

Addition specification data:

___

___

___

___

Spiral Case (see Turbine Common Sub-Section):
Material: ________________________

Addition specification data:

___

___

___

___

Draft Tube:
Material: _________________________ Net Area at outlet opening (per unit):_________________________

Horizontal length (centerline of turbine to downstream face):_______________________________________

Vertical distance (distributor centerline to draft tube floor):____

Addition specification data:

___

___

___

Kaplan/Propeller Turbine Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History				
Runner cavitation repair? *[welding labor h/year]*				
Runner erosion repair? *[welding labor h/year]*				
Runner crack repair? *[welding labor h/year]*				
Runner re-coating with different material? *[Very hard metals, polymeric coatings, ceramics]*				
Any runner modifications to reduce cavitation?				
Has the Runner wear ring been replacement?				
Has Runner been replaced with like original runner or new runner design?				
Is the Runner accessible for visual inspections? [*Identify if de-watering is an option for interior inspection.]*				
Have all plant records regarding runner maintenance, repairs, operating conditions and performance data been requested/gathered?				

Kaplan/Propeller Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Has there been a refurbishment or replacement of the wicket gates?				
Has there been a replacement of wicket gate bushings? *[greased to greaseless]*				
Has there been a change of bushing type/design?				
Has there been change of wicket gate seal type or replacement of seals due to excessive leakage or rubbing.?				
Has there been change of inter-gate seal type?				
Has there been change of head cover seal type?				
Has there been change of bottom ring seal type? *[high density polyurethane]*				
Has there been a replacement of V packing on lower headcover bearings?				

Kaplan/Propeller Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Has there been an improvement to wicker gate failure mechanism to increase reliability?				
Has there been a rehabilitation of operating ring, links, levers and servomotor connecting rods?				
Has there been an implementation of an automatic greasing system?				
Have there been any modifications/repairs to vacuum breaker?				

Kaplan/Propeller Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment				
Is there evidence of runner surface corrosion?				
Is there evidence of erosion on the runner surface?				
Is there evidence of cavitation on the runner surface?				
Is there cracking in runner bucket root area?				
Can measurement to engineering drawings be made for the runner seal or blade tip clearance (gap)?				
Can the structural integrity of stay vane fillets be assessed?				

Kaplan/Propeller Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment (Continued)				
Is there evidence of inter-gate leakage?				
Can surface finish of wicket gates be inspected for pitting?				
What is level of cracking on the wicket gates?				
Can wicket gates bushings/bearings condition be assessed?				
Can wicket gates radial clearance of bearings be assessed?				
Can wicket gates seal condition be assessed?				
Can nose to tail seal clearances be assessed?				

Kaplan/Propeller Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**

Equipment Condition Assessment (Continued)				
Can end clearances be assessed?				
Is there history of failure mechanism- shear pin failures?				
Is there evidence of surface wear on wicket gate links, levers and connecting rods?				
Can WG servomotor leakage rate be assessed?				
Can Servomotor pressure be assessed?				
Can internal surface condition of spiral case (coating) be assessed?				
Can surface condition of baffle plates be assessed?				
Is annual welding cost known ($/year, labor h/year)?				

Kaplan Turbine Data Collection Sheet	
Topic	**Data Input**

PELTON TURBINE INSPECTION FORM AND CHECK LIST

REVISION 1.0, 12/08/2011

Pelton Turbine: Inspection Form

General Information:
Date of Site Visit:______________ Unit No.________
Source/s of data:__________________ ____
Plant Name:____
Manufacturer:____Age:______________
Rated Output (MW):________Max. Output (MW):_________Rated Speed (rpm):_______
Rated net head (ft)_________Max. net head (ft):_________Max. Efficiency (%):________
General Turbine Description:____

Maintenance History / Major Repairs Description:

Runner:
Size (Diameter):___________________ Weight:_________________ Shaft Orientation:______________
Main Shaft Size (At runner connection):__________________________ Shaft Material:_______________
Number of Buckets:______________________ Surface Finish:_________________________________
Disc Material:___________________________ Bucket Material:________________________________
Bucket Bolt Connection [Yes/No]: ________________________ Bolt Material:____________________
Bucket Grind Profile Template available:____
Addition specification data:

Housing/Pit Size:
Housing Size (H × L × W):______________________________
Pit Size (H × L × W):______________________________
Housing Material:______________ Pit Material:______________
Addition specification data:
____
____
____
____
____
____
____

Nozzle Assemblies:
Number of Jets:__________ Seat Size (Diameter):__________
Design type of Nozzle (internal/external):______________________________
Seat Material:__________ Housing Material:__________ Needle Material:__________
Nominal Discharge Rate:______________________________
Addition specification data:
____
____
____
____
____
____

Distributor/Manifold:
Number of Outlets:______________________________
Pipe Size (Diameter):______________________________
Pipe Material:______________ Internal Surface Finish:______________
Addition specification data:
____
____
____
____
____
____

Pelton Turbine Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History				
Bucket cavitation repair?				
Bucket erosion repair?				
Bucket crack repair?				
Bucket re-coating with different material? *[Very hard metals, polymeric coatings, ceramics]*				
Have original bucket contour templates been used on any repair? *[Repair weld ground to original geometry]*				
Has Runner been replaced with like original runner or new runner design?				
Is the Runner accessible for visual inspections? [*Identify if de-watering is an option for interior inspection.]*				
Have all plant records regarding Runner maintenance, repairs, operating conditions, performance data, etc. been requested/gathered?				

Pelton Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Is there evidence of previous housing repair work? *[If so, when were the repairs done and for what reason? Are previous maintenance reports available?]*				
Is there evidence of previous pit modifications? *[If so, when were the modifications done and for what reason? Are previous maintenance reports available?]*				
Is the housing/pit accessible for visual inspections? *[Identify if de-watering is an option for interior inspection.]*				
Have all plant records regarding housing/pit maintenance, repairs, operating conditions, performance data, etc. been requested/gathered?				
Has there been replacement of nozzles or needle tips?				
Has there been replacement or repair of deflectors?				

Pelton Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment				
Is there evidence of bucket surface corrosion?				
Is there evidence of erosion or cavitation on the bucket surface?				
Is there cracking in bucket root area?				
Can measurement to engineering drawings be made for the minimum bucket thickness?				
Can measurement to engineering drawings be made for the bucket splitter width?				
What is the condition of the bucket bolts?				
Can servomotor (needle) leakage rate be assessed?				

Pelton Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Has there been repair of nozzles or needle tips?				
Has there been replacement of needle servomotors?				
Has there been repair of needle servomotors?				
Is the housing/pit accessible for visual inspections? *[Identify if de-watering is an option for interior inspection.]*				
Have all plant records regarding nozzles assemblies' maintenance, repairs, operating conditions, performance data, etc. been requested/gathered?				
Have all plant records regarding distributor/manifold maintenance, repairs, operating conditions, performance data, etc. been requested/gathered?				

Pelton Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment -Continued				
Can servomotor (needle) pressure (as % governor pressure) be assessed?				
Is there evidence of surface finish or erosion damage to needle tip?				
Is there evidence of surface finish or erosion damage to nozzle?				
Is there evidence of surface finish or erosion damage to nozzle seat needle?				
Is there evidence leakage when nozzle closed?				

Pelton Turbine Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment -Continued				
What is the condition of bushings on deflectors?				
What is the surface condition of deflectors?				
What is the condition of deflector servomotor?				
What is the annual maintenance/service on nozzle ($/year)?				

Pelton Turbine Data Collection Sheet	
Topic	**Data Input**

APPENDIX I. GUIDE FOR GOVERNOR CONDITION ASSESSMENT

REVISION 1.0, 12/09/2011

CONTENTS

1. GENERAL

Unforeseen failure of the governor can have a substantial impact on power generation and revenues due to a extended forced outage. Therefore, it is important to maintain a current assessment of the condition of the governor and plan accordingly. A governor condition assessment is essential to estimate the economic lifespan and potential risk of failure, and to evaluate the benefits and cost of governor upgrading.

For any type of governor, the following three step analyses are necessary to arrive at a governor condition indicator:

1) What parts should be included for a governor condition assessment and which parts are more important than others (parts and their weighting factors)?

2) What metrics/parameters should be investigated for quantitative condition assessment and which ones are more important than others (condition parameters and their weighting factors)?

3) How to assign numerical scores to the governor parts (rating criteria)?

This appendix provides guides to answer the above questions, which can be applied to all governors. The condition assessment is performed on individual governors in a plant, because even the originally identical governors may have experienced different Operation & Maintenance (O&M) histories and would arrive at different values of condition indicators. Due to the uniqueness of each individual governor, the guides provided in this appendix cannot quantify all factors that affect individual governor condition. Mitigating factors not included in this guide may trigger testing and further evaluation to determine the final score of the governor condition and to make the decision of governor replacement or rehabilitation.

This appendix is not intended to define governor maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2. CONSTITUENT PARTS ANALYSIS

For the four major types of governors (i.e., mechanical, mechanical-hydraulic, analog, and digital), their constituent parts are analyzed and listed in Table I-1 (references to HAP Taxonomy). If any part (e.g., Double Regulating Device) does not exist in a particular governor, this part will be excluded from scoring mechanism by inputting “NA” into the table. The effect of one part exclusion is usually insignificant to justify any adjustment for the weighting factors of other governor parts.

3. METRICS FOR GOVERNOR CONDITION ASSESSMENT

As listed in Table I-1, the following five condition parameters are considered for condition assessment of turbine and turbine parts:

- The Physical Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on the previous testing and measurements, historical O&M records, original design drawings, previous rehabilitation feasibility study reports if conducted, interviews with plant staff and some limited inspections. It is noticed that there is a certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmarking condition assessment without specific testing and measurements conducted on site, these five parameters are regarded as providing the basis for assessing the condition of governor parts.

In addition, the Data Quality Indicator, as an independent metrics, is to reflect the quality of available information and the confidence on the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity, and any of these situations could affect the results of condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part/item to indicate the information and data availability, integrity and accuracy and the confidence on the given condition ratings (MWH 2010).

4. WEIGHTING FACTORS

There are two categories of weighting factors in Table I-1. It is recognized that some condition parameters affect the governor condition to a greater or lesser degree than other parameters; also some parts are more or less important than other parts to an entire governor. These weighting factors should be pre-determined by consensus among experienced hydropower mechanical engineers and plant O&M experts. Once they are determined for each type of governor, they should be largely fixed from plant to plant for the same type of governor, except for special designs found in a governor where the weighting factors have to be adjusted. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors won't affect the Condition Indicator of a governor, which is the weighted summation of all scores that assigned to the governor parts and five condition parameters.

Table I-1. Typical governor condition assessment and scoring: XXX Hydropower Plant (Unit #)

Governor for Unit ___	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Oil Pressure System	4.1.2.1							3.0
Flow Distributing Valves	4.1.2.2							4.0
Control System	4.1.2.3							5.0
Speed Sensing Device	4.1.2.4							2.0
Feedback Device	4.1.2.5							1.0
Double Regulating Device	4.1.2.6							2.0
Weighting Factors for Condition Parameters		2.0	1.0	1.5	1.0	1.0	Data Quality -->	0.00
							Condition Indicator -->	0.00

5. RATING CRITERIA

Physical Condition: Rating Criteria for Governor Parts

Physical Condition of governor parts refers to those features that are observable or detected through measurement and testing, including some observed performance. It includes pump vibration and noise, oil loss, looseness of pins and linkages, and sticking of valves. The Best Practices of Governor Condition Assesment can assist in evaluating the governor condition.

For HAP site assessment, it is important to conduct interviews and discussions with plant personnel to score the physical condition of governor parts. The results of all related information are analyzed and applied to Chart 1 to assign the condition scores of governor parts.

Chart 1 Governor Physical Condition Rating Criteria	
Observation and Inspection Results	**Physical Condition Score**
No damaged or significantly worn parts have even been found by previous disassembly physical inspection. No significant increase on leakage rate from original value. Off-line and on-line response and stability normal, governor free from hunting, accuracy of frequency within < 0.2 Hz, synchronization time within norm, and able to remote start.	**8–10**
Damaged or worn parts found and replaced. Small increase in the leakage rate. Off-line and on-line response and stability fair, occasional hunting problems, accuracy of frequency and synchronization time outside the norm, or remote start is difficult.	**4–7**
Damaged or worn parts found and not replaced as appropriate. Leakage rate has doubled (or more). Off-line and on-line response and stability poor, reoccurring hunting problems, difficulty in synchronization or unable to remote start.	**0–3**

Age: Rating Criteria for Governor Parts

Age scoring is relatively more objective than other condition parameters. The detailed scoring criteria developed in Chart 2 allows the age score be automatically generated in the HAP Database by the actual years of the installed part.

Chart 2 Age Rating Criteria for Governor Parts			
Age for Mechanical-hydraulic Governor System	Age for Analog Governor System	Age for Digital Governor System	Age Score
< 25 Years	< 20 Years	< 10 Years	8 – 10
25-40 Years	20 to 30 Years	10 to 15 Years	4 – 7
> 40 Years	> 30 Years	> 15 Years	0 – 3

Installed Technology Level: Rating Criteria for Governor Parts

The Installed Technology Level indicates advancement levels of designing, machining, installation and materials, which may effect on the unit and plant performance. The outdated technology may bring difficulties for spare parts supply and come a prolonged outage when it fails.

Scoring the Installed Technology Level requires historic knowledge of governor technology advancement and familiarity with the current governor manufacturing industry. The competence, professionalism and reputation of the original suppliers could also imply the installed technology levels. Compared to those from large and well-known manufacturers, the governor parts supplied by small and unnamed companies would get lower scores.

Chart 3 Governor Technology Rating Criteria	
Technology Levels of the Parts/Items	Score for Installed Technology Level
The technology has not been changed significantly since the governor was installed; all necessary mechanical and electronic parts are available from original supplier; and the original supplier is a brand name company with great professional reputation.	8 – 10
The mechanical and electronic parts are no longer available from original supplier and must be obtained from alternative suppliers.	5 – 7
The electronic and mechanical parts are not available at all and/or some mechanical parts must be reverse-engineered and manufactured by alternative suppliers.	3 – 4
The mechanical and electronic parts are not available at all and there are significant obstacles to successful reverse-engineering of the mechanical parts.	0 – 2

Operating Restrictions: Rating Criteria for Governor Parts

The governor operating restrictions refer to the limitations on normal operation caused by the tendency of the governor to hunt. Hunting is an unstable condition in which the governor can't maintain frequency at an acceptable level when operating off line. Off-line hunting is usually the first and possibly the only sign of a problem with a governor. But, off-line hunting can also be a symptom of a variety of problems. The most common cause of off-line hunting is misadjustment of the dashpot. If the dashpot needle is too far open, there is not enough compensation and the governor will hunt. Excessive friction in the governor mechanism or the turbine wicket gate mechanism can also cause hunting. The on-line hunting is not common, it is the result of bad signal from PMG or hydraulic problem. In sum, if the automatic synchronizer will not synchronize the unit because of excessive hunting then that is a problem, but further check is needed to find if it is the governor caused this operating restriction.

Chart 4 describes the ratings of governor operating restrictions.

Chart 4 Governor Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes, and the original design has no constraints on the required operation. Tested as Required; no known design and operational efficiencies.	**8 – 10**
Minimal restraints: Special operational requirements are needed to avoid minor maintenance issues. The operation range can be expanded with revised equipment selection and design. No known design and operational efficiencies.	**5 – 7**
Moderate restraints: Special operational requirements are needed to avoid major maintenance issues. The operation range and performance can be significantly improved with revised equipment selection and design.	**3 – 4**
Severe limitations: The equipment do not meet the operational criteria or not tested as required or has a known design and operational deficiency.	**0 – 2**

Maintenance Requirement: Rating Criteria for Turbine Parts

The amount of corrective maintenance that either has been or must be performed is an indication of the governor condition. No corrective maintenance is an indication that the governor is in good shape. Severe corrective maintenance requires scheduled or forced outages to perform.

Other factors to consider for maintenance scoring include:

- The need of maintenance is increasing with time or problems are reoccurring;

- Previous failures related to the governor parts;
- Failures and problems of governor parts with similar design.

The results of governor maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5 to score the governor parts.

Chart 5 Governor Maintenance Requirement Rating Criteria	
Historical Maintenance Records	**Maintenance Requirement Score**
Normal preventative and corrective maintenance (<50 hours/year/unit) or no significant increase in preventive and corrective maintenance (less than 1.5 times of baseline, as established by maintenance records).	**8 – 10**
Significant increase (over 1.5 times of baseline) in preventative maintenance, but no significant increase in corrective maintenance.	**5 – 7**
Significant increase (over 1.5 times of baseline) in corrective maintenance, otherwise operational constraints would occur.	**3 – 4**
Repeated corrective maintenance to avoid operational constraints.	**0 – 2**

Data Quality: Rating Criteria for Governor Parts

The Data quality scores reflect the quality of the inspection, test, and measurement results to evaluate the condition of governor parts. The more current and complete inspection, testing and measurement results, the higher the Data Quality scores. The frequency of normal testing is as recommended by the organization. Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is “Good” or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of governor parts are developed in Chart 6.

Chart 6 Governor Data Quality Rating Criteria	
Data Availability, Integrity and Accuracy	**Data Quality Score**
High: The maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurement were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8 – 10**
Medium: One or more of routine inspections, tests and measurement were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 – 7**
Low: One or more of routine inspections, tests and measurement were completed 24-36 months past the normal frequency, or some of results are not available.	**3 – 4**
Very Low: One or more of required inspections, tests and measurement were completed >36 months past the normal frequency, or significant portion of results are not available.	**0 – 2**

6. GOVERNOR CONDITION AND DATA QUALITY INDICATORS

In Table I-1, the final condition score of the governor (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J)\times F(K)\times F(J)}{\sum_{K=1,M}^{J=1,5} F(K)\times F(J)} \tag{1}$$

The governor Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K)\times F(K)}{\sum_{K=1,M} F(K)} \tag{2}$$

Here, M = the total number of parts/items associated with a governor; K = the identification No. of governor parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of a governor part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a governor part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific governor testing, such as the efficiency/index test and paint film quality test, would more directly reveal the condition of the governor.

7. REFERENCES

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GOVERNOR INSPECTION FORM AND CHECKLIST

REVISION 1.0, 12/12/2011

Governor: Inspection Form

General Information:

Date of Site Visit: ____ Unit No.________

Plant name: ____

Source/s of data:____

Manufacturer: ____Age:_____________

Rated Output (MW):________Max. Output (MW):_________Rated Speed (rpm):____________________

Rated net head (ft) _________ Max. net head (ft):_________Max. Efficiency (%):___________________

Governor Type:

☐ Mechanical -Hydraulic

☐ Analog

☐ Digital

General Governor Description:____

____

____

____

Maintenance History / Major Repairs Description:

____

____

____

____

____

____

Oil Pressure System:

Flow Distributing Valves:

Control System:

Speed Sensing Devices:

Feedback Device:

Double Regulating Device:

Governor Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History				
Is the governor mechanically adjusted per OEM specification?				
Does the Ball Head have any unusual vibration?				
Is the oil motor vibrator turning at 400 to 600 rpm? And oscillating between 0.006 and 0.007 in.?				
Does the oil supply main valve plunger move feely?				
Does the pilot valve plunger move feely?				
Is the dashpot oil level correct?				
Does the dashpot plunger take more than 50 s to re-center after being pushed down all the way with the bypass and needle valves closed? More than 50 s to travel 0.125 in. is OK. Less is sign of leakage.				
Are links and pins worn?				
Are Restoring Cable sheaves and cables worn?				
Is the hydraulic system oil level correct?				

Governor Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Is the hydraulic system oil clean?				
Is there any oil foaming in sump tank?				
Is the float valve operating correctly?				
Are the pump unloader valves operating correctly?				
Are the pressure and level switches calibrated?				
Is the pump taking longer to reach full pressure than previously?				
Are speed changer and gate limit switches operating correctly?				
Do shutdown solenoids operate without binding and sticking?				
Do speed changer motor operate smoothly?				

APPENDIX J. GUIDE FOR GENERATOR CONDITION ASSESSMENT

REVISION 1.0, 12/20/2011

CONTENTS

1. GENERAL

The generator is a critical component in the powertrain of a hydropower plant. A failure of the generator stator can result in an extended outage and extensive repairs. Failure or degradation of other generator components may result in operation at reduced output or may result in catastrophic failure. While operation with a degraded condition such as aged insulation, cooler leaks or cracked structural components may continue undetected, a thorough condition assessment may avert a costly forced outage and can be used to justify upgrades and improvements. Generator reliability can decline with time while the annual cost of repairs and maintenance increases with time. Thus, rehabilitation and replacement of aging generator (or generator components) may become more economical and less risky than maintaining the original generator, especially considering the potential reliability improvements from the state-of-art generator design and from the generator material and fabrication technology advancements achieved during past decades. Yet, generator condition assessment is essential to estimate the economic lifespan and potential risk of failure, and to evaluate the benefits and cost of generator upgrading.

For any generator, the following three step analyses are necessary to arrive at a generator condition indicator:

1) What parts should be included for a generator condition assessment and which parts are more important than others (parts and their weighting factors)?

2) What metrics/parameters should be investigated for quantitative condition assessment and which ones are more important than others (condition parameters and their weighting factors)?

3) How to assign numerical scores to the turbine parts (rating criteria)?

This appendix provides guides to answer the above questions, which can be applied to the generator and it's various subcomponents. The condition assessment is performed on individual generators in a plant, because even the originally identical generators may have experienced different Operation & Maintenance (O&M) stories and would arrive at different values of condition indicators. Due to the uniqueness of each individual generator, the guides provided in this appendix cannot quantify all factors that affect individual generator condition. Mitigating factors not included in this Guide may trigger testing and further evaluation to determine the final score of the generator condition and to make the decision of generator replacement or rehabilitation.

This appendix is not intended to define generator maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2. CONSTITUENT PARTS ANALYSIS

Generators and their constituent parts are analyzed and listed in Table J-1 (references to HAP Taxonomy). Among all the generator parts, the stator is the most critical part for a generator. If any part (e.g., the common shaft being assessed with the turbine assemly) does not exist in a particular generator unit, this part will be excluded from scoring mechanism by inputting "NA" into the table. The effect of one part exclusion is usually insignificant to the entire generator assessment, which may not justify any adjustment of the weighting factors for other parts of the generator.

3. METRICS FOR GENERATOR CONDITION ASSESSMENT

For generator condition assessment, it is recognized that the physical condition cannot be properly and sufficiently evulated based on the visual inspections only while the results from some routine or available tests are more critical as indication of generator condition. Although these testing results can be catergorize into the Physical Condition, they are listed separately in adiition to the visual condition to emphazie the importances of these meterics. Thus, as listed in Table J-1, the following eight condition parameters are considered for condition assessment of generator and generator parts:

- The Visual Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- Stator Electrical Tests
- Rotor Electrical Tests
- Stator Core Tests
- The Maintenance Requirement

These eight condition parameters are scored based on the previous testing and measurements, historical O&M records, original design drawings, previous rehabilitation feasibility study reports if conducted, interviews with plant staff, and some limited inspections or previous inspections. It is noticed that there are certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmarking condition assessment without specific new testing and measurements conducted on site, these eight parameters are regarded as providing the basis for assessing the condition of generator parts and entire generator. If any type of tests or metrics are not applicable for some parts (e.g., the Stator Eletrcial Tests are only applicable to the Stator), input “NA” into the cells of irrelevant parts for this metrics.

In addition, the Data Quality Indicator, as an independent metrics, is to reflect the quality of available information and the confidence on the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity, and any of these situations could affect the results of condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part/item to indicate the data availability, integrity and accuracy and the confidence on the given condition ratings (MWH 2010).

4. WEIGHTING FACTORS

There are two categories of weighting factors in Table J-1. It is recognized that some condition parameters affect the generator condition to a greater or lesser degree than other parameters; also some parts are more or less important than other parts to an entire generator. These weighting factors should be pre-determined by consensus among experienced hydropower mechanical and electrical engineers and plant O&M experts. Once they are determined for each generator, they should be largely fixed from plant to plant except for special designs found in a generator where the weighting factors have to be adjusted. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors won’t affect the Condition Indicator of a generator which is the weighted summation of all scores that assigned to the generator parts and eight condition parameters.

Table J-1. Typical generator condition assessment and scoring: XXX Hydropower Plant (Unit #)

Generator for Unit___	Taxonomy ID	Visual Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Stator Electrical Tests	Rotor Electrical Tests	Stator Core Tests	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Stator Windings	4.1.3.1						NA	NA			3.0
Stator Core	4.1.3.1					NA	NA				1.5
Rotor	4.1.3.2					NA		NA			2.5
Ventilation & Cooling	4.1.3.3					NA	NA	NA			2.0
Neutral Grounding	4.1.3.4					NA	NA	NA			0.5
Thrust Bearings	4.1.3.5					NA	NA	NA			1.0
Guide Bearings	4.1.3.6					NA	NA	NA			1.0
Generator Shaft	4.1.3.7					NA	NA	NA			1.5
Weighting Factors for Condition Parameters		1.0	2.0	1.0	1.0	3.0	2.5	1.0	1.5	Data Quality -->	0.00
										Generator Condition Indicator -->	0.00

5. RATING CRITERIA

Visual Condition: Rating Criteria for Generator Parts

Visual Condition of generator parts refers to those features that are observable or detected through visual inspections. Stator winding insulation and its condition is a significant factor in determining reliability of the unit. Previous visual inspections for loose components, evidence of corona, evidence of overheating, and fouled heat exchangers can provide valuable insight into the overall generator condition.

For HAP site assessment, it is important to review previous inspection records and interview and discuss with plant personnel to score the visual condition of the generator. The results of all related information are analyzed and applied to Chart 1 to assign the condition scores of generator parts.

Chart 1 Generator Visual Condition Rating Criteria		
Visual Condition Rating Scale		**Physical Condition Score**
Excellent	No noticeable defects. Some aging or wear may be noticeable.	**9–10**
Very good	Only minor deterioration or defects are evident, and function is full.	**7–8**
Good	Some deterioration or defects are evident, but function is not significantly affected. Isolated evidence of corona, loose winding components or dirty coolers.	**5–6**
Fair	Moderate deterioration, function is still adequate, but the unit efficiency may be affected. Some areas exhibiting corona discharge, loose winding components or cooler fouling.	**3–4**
Poor	Serious deterioration in at least some portions, function is inadequate, unit efficiency or availability significantly affected. Widespread corona, greasing, loose components or hardware, fouled coolers or cooler defects. Girth cracking evident.	**2**
Very poor	Extensive deterioration. Barely functional. Loose or displaced winding components, extensive girth cracking, extensive corona, extensive greasing, mechanical damage to insulation.	**1**
Failed	No longer functions, may cause failure of a major component.	**0**

Age: Rating Criteria for Generator Parts

Age is an important factor to consider for generator reliability and upgrade potential. The most critical part, the stator, will irreversibly age and its remaining life will be a function of the original design and operating and maintenance history. When the generator ages, the electrical insulation is more likely to develop turn to turn shorts and is more susceptible to failure from electrical transients. Heat transfer characteristics degrade as coolers and cooling passages become fouled. Raw Cooling Water (RCW) flow for coolers and bearings will degrade due to internal build-up. Meanwhile, an older generator usually has greater potential to gain efficiency and capacity by replacing and using the state-of-the-art generator design and materials.

Age scoring is relatively more objective than other condition parameters. The detailed scoring criteria developed in Chart 2 allows the age score be automatically generated in the HAP Database by the actual years of the installed part. The generator parts usually have expected lifespan of 40–45 years, highly dependent on operating conditions. Bearings and cooling component ages are based on the time since their last overhaul or replacement.

Chart 2 Age Rating Criteria for Generator Parts				
Age of the Generator Stator/Insulation	Age of the Generator Rotor/Insulation	Age of the Generator Stator Core	Age of Major Generator Components (Cooling, Bearings)	Age Score
<5 years	<5 years	<10 years	<5 years	**10**
5–10 years	5–10 years	10–25 years	5–10 years	**9**
10–15 years	10–15 years	25–40 years	10–15 years	**8**
15–20 years	15–20 years	>40 years	15–20 years	**7**
20–25 years	20–25 years		20–25 years	**6**
25–35 years	25–35 years		25–35 years	**5**
35–40 years	35–40 years		35–40 years	**4**
40–45 years	40–45 years		40–45 years	**3**
45–50 years	45–50 years		45–50 years	**2**
>50 years	>50 years		>50 years	**1**

Installed Technology Level: Rating Criteria for Generator Parts

The Installed Technology Level indicates advancement levels of designing, insulation and materials, which may effect on the generator performance. The outdated technology may bring difficulties for spare parts supply and prolonged outage when it fails.

Scoring the Installed Technology Level requires historic knowledge of generator technology advancement and familiarity with generator material advancements for electrical insulation, core steel, and heat exchangers. With the computerization of generator winding design and manufacturing (CNC), the production accuracy and overall efficiency (reduction of losses) have been improved over the original design particularly for I^2R and core losses. Generator and rotor windings with class B (NEMA class) insulation get lower scores than those with class F. The competence, professionalism and reputation of the original suppliers could also imply the installed technology levels. Compared with those from large and well-known manufacturers, the generator parts supplied by small and unnamed companies whose industry track record shows history of reliability issues due to their design would get lower scores.

Chart 3 Generator Technology Rating Criteria	
Technology Levels of the Parts/Items	**Score for Installed Technology Level**
Both stator and rotor have Class F (or greater) insulation. Core has been restacked with low hysteresis steel and / or retorqued.	**10**
Both stator and rotor have Class F (or greater) insulation. Core has not been restacked with low hysteresis steel and / or retorqued.	**9**
Either the stator or rotor have been rewound with Class F or greater insulation and the core has been restacked with low hysteresis steel.	**8**
Either the stator or rotor have been rewound with Class F or greater insulation and the core has not been restacked with low hysteresis steel.	**7**
Both the stator and the rotor have been rewound with Class B insulation system and the core has been restacked with low hysteresis steel.	**6**
Both the stator and the rotor have been rewound with Class B insulation system and the core has not been restacked with low hysteresis steel.	**5**
Either the stator or rotor have been rewound with Class B insulation and the core has been restacked with low hysteresis steel.	**4**
Either the stator or rotor have been rewound with Class B or greater insulation and the core has not been restacked with low hysteresis steel.	**3**
Stator, rotor and core are original equipment installed prior to 1970.	**0–3**
Add indicated points for any and each of the following installed condition monitoring devices; Partial Discharge Analyzer (PDA), Rotor Shorted Turns (Flux Probe), Rotor Air Gap Probe.	**0.5**

Operating Restrictions: Rating Criteria for Generator Parts

The generator operating restrictions refer to any limitations on the output of MW or MVAR. Operational limitations play a role in determining the serviceability of generator unit: the greater the limitations, obviously the greater the generation loss.

> To prevent overheating or due concerns for structural integrity due to a currently deteriorated generator physical condition (e.g., cut out coils, shorted rotor turns, degraded cooling system performance, structural (frame) concerns, hot bearings, and severe vibrations). Generator constraints do not refer to any limitation from other components in the system—for example, if the excitation system is limiting reactive power then the excitation system rather than the generator would get lower score for the operating restrictions.

Chart 4 describes the ratings of generator operating restrictions.

Chart 4 Generator Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes, and the original generator design has no constraints on the required operation.	**8–10**
Minimal restraints: Temperature resistrictions, vibration issues, cooler leaks	**5–7**
Moderate restraints: Cut out stator coils, shorted rotor turns, grounded rotor, structural defects	**3–4**
Severe limitations: The generator is undesirable to operate anymore; the original design has significantly degraded and limited the performance and reliability if it operates under current requirement.	**0–2**

Stator Electrical Tests

In conjunction with a thorough visual inspection electrical testing will reveal the most information about the health of the winding. Basic tests include the insulation resistance (IR) test, polarization index (PI) test, and a bridge test for winding resistance. Hi potential test, either AC or DC or very low frequency AC test may be performed. The hi potential test may be performed as a proof type test where the objective is simply that the winding withstand the imposed test voltage or a stepped or ramped voltage test offering some insight into winding condition. Partial discharge analysis (PDA), if available, offers on-line diagnostic ability to assess winding insulation condition. Engineering judgement will be required to assign a score based on available test data and weighing of comparative test results.

Chart 5 Stator Electrical Test Scoring	
Test Results	**Score for Electrical Condition**
Insulation resistance (IR) > 100 megohms, polarization index (PI) >2.0, withstood AC/DC or VLF hipot, low partial discharge levels (or no significant increase from previous) all as indicated by most recent test, stator winding resistance within 5% of design value and balanced.	**10**

Chart 5 Stator Electrical Test Scoring	
Test Results	**Score for Electrical Condition**
Insulation resistance (IR) > 100 megohms, polarization index (PI) >2.0, withstood AC/DC or VLF hipot, low partial discharge levels (or no significant increase from previous) all as indicated by most recent test, stator winding resistance within 5% of design value and balanced. 4 of 5 criteria met.	**8–9**
Insulation resistance (IR) > 100 megohms, polarization index (PI) >2.0, withstood AC/DC or VLF hipot, low partial discharge levels (or no significant increase from previous) all as indicated by most recent test, stator winding resistance within 5% of design value and balanced. 3 of 5 criteria met.	**5–7**
Insulation resistance (IR) > 100 megohms, polarization index (PI) >2.0, withstood AC/DC or VLF hipot, low partial discharge levels (or no significant increase from previous) all as indicated by most recent test, stator winding resistance within 5% of design value and balanced. 2 of 5 criteria met.	**2–4**
Insulation resistance (IR) > 100 megohms, polarization index (PI) >2.0, withstood AC/DC or VLF hipot, low partial discharge levels (or no significant increase from previous) all as indicated by most recent test, stator winding resistance within 5% of design value and balanced. 1 of 5 criteria met.	**1**
None of the above criteria met.	**0**

Rotor Electrical Tests

IR, PI, bridge resistance and an electrical test for pole shorted turns usually provide adequate indication of the electrical health of the rotor windings. Hi potential test for the rotor are not usually performed as a routine test. With rotor electrical tests some engineering judgement will be required to assign scores based on available data.

Chart 6 Rotor Electrical Test Scoring	
Test Results	**Score for Electrical Condition**
No rotor turn faults (shorts), insulation resistance > 100 megohms, polarization index (PI) >2.0, all as indicated by most recent test, rotor winding resistance within 5% of design value.	**10**
No rotor turn faults (shorts) indicated, insulation resistance > 100 megohms, polarization index (PI) >2.0, all as indicated by most recent test, rotor winding resistance within 5% of design value. (i.e., 1 of 4 criteria not met)	**8–9**
No rotor turn faults (shorts) indicated, insulation resistance > 100 megohms, polarization index (PI) >2.0, all as indicated by most recent test, rotor winding resistance within 5% of design value. (i.e., 2 of 4 criteria not met)	**5–7**
No rotor turn faults (shorts) indicated, insulation resistance > 100 megohms, polarization index (PI) >2.0, all as indicated by most recent test, rotor winding resistance within 5% of design value. (i.e., 3 of 4 criteria not met)	**2–4**
No rotor turn faults (shorts) indicated, insulation resistance > 100 megohms, polarization index (PI) >2.0, all as indicated by most recent test, rotor winding resistance within 5% of design value. (i.e., 4 of 4 criteria not met)	**1**
Rotor not serviceable due to ground faults, shorted turns or high resistance connections.	**0**

Stator Core Tests

The stator core health is critical to operation of the unit. Core assessment tools are primarily visual. However, two tests, which both require a unit outage usually with the rotor removed, have been developed to aid in locating of core faults (shorted laminations). Both tests produce a flux in the core. The rated flux method, "loop" test or "ring flux" test uses thermal imaging to detect overheating defects. The low flux method, the Electromagnetic Core Imperfection Detection (El-Cid) test utilizes a low (3%–4% rated) flux and a "Chattock Coil" to detect a voltage signal proportional to the eddy current flowing between laminations. These are not routine tests and are most likely performed in conjunction with a rewind or when core damage suspected. In the case there is no data for review this parameter will be automatically excluded from scoring mechanism by inputting "NA".

Chart 7 Stator Core Test Scoring	
Test Results	**Score for Condition**
Previous electrical core test, i.e., ElCid (low flux) or Loop Test (rated flux) showed no anomolies.	**10**
Previous electrical core test, i.e., ElCid (low flux) or Loop Test (rated flux) showed minor suspect areas, repaired.	**5–9**
Previous electrical core test, i.e., ElCid (low flux) or Loop Test (rated flux) showed minor suspect areas, not repaired.	**1–4**
Operating with known major defects.	**0**

Maintenance Requirement: Rating Criteria for Generator Parts

The amount of corrective maintenance that either has been or must be performed is an indication that how the generator condition is. No corrective maintenance is an indication that the generator is in good shape. Frequent and extensive corrective maintenance or stator failures typically requires a major outage and is indicative of severe duty and/or aging.

Other factors to consider for maintenance scoring include:

- The need of maintenance is increasing with time or problems are reoccurring;
- Deteriorating trend in insulation integrity test results;
- Previous failures related to the generator parts;
- Industry experience with failures and problems with generators of similar design.

The results of generator maintenance history (including routine maintenance and corrective maintenance) and trended test results are analyzed and applied to Chart 8 to score the generator.

Chart 8 Generator Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum level (normal condition): A small amount of routine preventive maintenance, cleaning and routine testing is required and performed at the recommended frequency.	**9–10**

Chart 8 Generator Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Low level: Small amounts of corrective maintenance (e.g., less than 3 staff days per unit per year). Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis (e.g., cooler tube cleaning, cooler system maintenance).	**7–8**
Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages (e.g., coil replacement, stator rewedge).	**5–6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., bearing oil leaks, cooler leaks, overheating electrical connections).	**3–4**
Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required.	**0–2**

Data Quality: Rating Criteria for Generator Parts

The Data quality scores reflect the quality of the inspection, test, and measurement results to evaluate the condition of generator parts. The more current and complete inspection, the more consistent the testing and trending, the higher the Data Quality scores. The frequency of normal testing is as recommended by the manufacturer, industry standards or dictated by operating organization's experience.

Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of turbine parts are developed in Chart 9.

Chart 9 Generator Data Quality Rating Criteria	
Data Availability, Integrity, and Accuracy	**Data Quality Score**
High: The generator maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurements were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8–10**
Medium: One or more of routine inspections, tests and measurements were completed 6–24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5–7**
Low: One or more of routine inspections, tests and measurements were completed 24–36 months past the normal frequency, or some of results are not available.	**3–4**
Very Low: One or more of required inspections, tests and measurements were completed >36 months past the normal frequency, or significant portion of results are not available.	**0–2**

6. GENERATOR CONDITION AND DATA QUALITY INDICATORS

In Table J-1 final condition score of the generator (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,8} S_C(K,J)\times F(K)\times F(J)}{\sum_{K=1,M}^{J=1,8} F(K)\times F(J)} \quad (1)$$

The generator Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K)\times F(K)}{\sum_{K=1,M} F(K)} \quad (2)$$

Here, M = the total number of parts/items associated with a generator; K = the identification No. of generator Parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 8, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of a generator part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a generator part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific generator testing, such as the hi pot and megger testing would more directly reveal the condition of generator.

7. REFERENCES

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HydroAMP (2006). Hydropower Asset Management-Using Condition Assessments and Risk-Based Economic Analyses. Appendix E- Equipment Condition Assessment Guides.

GENERATOR INSPECTION FORM AND CHECKLIST

REVISION 1.1, 12/15/2011

Generator: Inspection Form

General Information:

Date of Site Visit: ____ Unit No.________

Plant name: ____

Source/s of data:____

Manufacturer: ____Age:____________

Turbine Rated Output (MW):________Max. Turbine Output (MW):_______Rated Speed (rpm):________

General Generator Description:____

____

____

____

Summary Failure History/Maintenance History / Major Repairs Description:

____

____

____

____

____

____

Typical Operating Mode:____

Stator

Rating:__________________@________pf

Voltage: __________________________ Current Insulation Class:____________________________

Winding Age:_____________________ Last Rewedge:___________________________________

Winding Description (e.g., pitch, span, circuits, turns/coil): ______________________________

____

Installed Instrumentation/Monitoring:____

____

Rotor

Insulation Class:______ No. Poles:________

Type Construction:____

Excitation Requirements:____

Installed Instrumentation/Monitoring:____

Addition specification data:

____

____

____

____

____

Cooling System:

General Description of Stator /Rotor Cooling System:

____

____

Modifications:____

No. of Air Housing Coolers:___________

Cooler Tube Material:_______________ Cooler Design Data (flow rate, water temp, temp rise):

____

Temperature Control Method:____

Addition specification data:

____

____

Neutral Grounding:
Neutral Ground Method (e.g., high impedance, low impedance, resistance):

Neutral Beaker:____________ Neutral Disconnect:_______________

Ratings:____

Oil Filled Components:____

Addition specification data:

Thrust Bearings:
Type/LocationMaterial: ____

Installed Instrumentation/Monitoring:____________________________________

Cooling Description:____

Addition specification data:

____
____
____
____

Guide Bearing(s):
Type/LocationMaterial: ____

Installed Instrumentation/Monitoring:____________________________________

Cooling Description:____

Addition specification data:

____
____
____
____

Generator Shaft:
Fabrication Description/ Material: ______________________________________

Vibration Monitoring System
Description:____________________________________

Vibration Alarm Point(s):______________________Trip Point:____________________

Addition specification data:

____
____
____
____

Generator Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History				
Stator Coil Replacement/Repair				
Coils Jumpered/Cut out				
Stator Rewedge—Complete				
Stator Rewedge—Partial				
Loose winding blocking/bracing/lashings/spacer repairs.				
Core Replacement				
Core Repairs				
Core Tightening				
Have all plant records regarding stator maintenance, repairs, operating conditions and performance data been requested/gathered?				

Generator Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Have there been hi-pot test failures?				
Have there been any out-of phase synchronizing events?				
Has there been any inadvertent energization at standstill?				
Rotor Rewinds?				
Shorted Turn Repairs, pole or lead connection issues?				
Amortisseur winding issues/repairs?				
Rotor or Stator Roundness Issues?				
Field Grounds?				

Generator Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Other Stator / Rotor Failures/Repairs Not Included Above				
Neutral Transformer/Reactor/Resistor Issues or Replacements				
Neutral Breaker/Disconnect Issues or Replacements				
Air Housing Cooler Tube Leak Repairs/Plugged Tubes				
Air Housing Cooler Replacements				

Generator Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment				
Do current electrical visual inspection results show evidence of winding looseness, hot spots, corona, wedge or filler migration, vent duct or finger plate, foreign object or mechanical damage, oil and or dirt contamination?				
Do electrical rotor and stator test result trends indicate marginal insulation integrity?				
Do stator or rotor bridge measurements show deterioration?				
Does on-line temperature information indicate any stator or rotor overheating?				
Cooler Tubes Air Side Fouled / Water Side Plugged/Mechanical Damage or Fin/Baffle Separation				
Cooler RCW System Temperature Controller Fully Functional				

Generator Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Thrust Bearing Failures/Replacements				
Guide Bearing Failures/Replacements				
Bearing Oil Cooler Failures/Replacements				
Generator Shaft Repairs or Modifications				

Generator Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment (Continued)				
Rated capacity from RCW supply pumps				
Availability of spare cooling system long lead components				
Operational bearing/oil overtemperature				
Thrust Bearing Babbitt issues (babbitt)bond, electrolysis, scoring				
Bearing oil cooler periodically inpected and tested				
Neutral Grounding visual assessment				

Generator Data Collection Sheet	
Topic	**Data Input**

APPENDIX K. GUIDE FOR EXCITER CONDITION ASSESSMENT

REVISION 1.0, 01/17/2012

CONTENTS

1.0 GENERAL

The excitation system is a critical component in the powertrain of a hydropower plant. A failure of the exciter or its components can result in an extended outage and extensive repairs. For purposes of this guide the excitation system will include the source of the field current and components required for its control (regulator). These components will be referred to interchangeably as the “excitation system” or “Exciter”. Failure or degradation of the exciter or its control components may result in operation at reduced output or may result in catastrophic failure. While operation with a degraded condition such as excessive brush wear, low insulation resistance, failed electronic components may continue undetected, a thorough condition assessment may avert a costly forced outage and the results can be used to justify upgrades and improvements. Exciter reliability can decline with time while the annual cost of repairs and maintenance increases with time. Thus, rehabilitation and possible replacement of aging exciter (or exciter components) may become more economical and less risky than maintaining the original excitation system, especially considering the potential reliability improvements possible with state-of-the-art excitation design. Yet, excitation system condition assessment is essential to estimate the economic lifespan and potential risk of failure, and to evaluate the benefits and cost of exciter upgrades.

For any excitation system, the following three step analyses are necessary to arrive at an exciter condition indicator:

1) What parts should be included for an excitation system condition assessment and which parts are more important than others (parts and their weighting factors)?

2) What metrics/parameters should be investigated for quantitative condition assessment and which ones are more important than others (condition parameters and their weighting factors)?

3) How to assign numerical scores to the excitation system parts (rating criteria)?

This appendix provides guides to answer the above questions, which can be applied to the excitation system and its various subcomponents. The condition assessment is performed on individual exciters/regulators in a plant, because even the originally identical units may have experienced different Operation & Maintenance (O&M) stories and would arrive at different values of condition indicators. Due to the uniqueness of each individual excitation system, the guides provided in this appendix cannot quantify all factors that affect individual system condition. Mitigating factors not included in this Guide may trigger testing and further evaluation to determine the final score of the excitation system condition and to make the decision of exciter/regulator replacement or rehabilitation.

This appendix is not intended to define excitation system maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information. Exciter performance is a function of exciter type, and North American Electric Reliability Corporation NERC related performance testing and evaluation are not included in this assessment.

2.0 CONSTITUENT PARTS ANALYSIS

Excitation systems and their constituent parts are analyzed and listed in Table K-1 (reference to HAP Taxonomy). The excitation system can be broadly divided into a power section and a control (regulator) section. IEEE standards have identified 19 different configurations of DC, AC and static exciters for purposes of power system stability studies. The power section includes all components not electrically isolated from the exciter output. For purposes of this assessment guide the exciter power circuits will stop at the collector rings (or rotating diodes for a brushless unit). The ability to function at rated capacity with some degradation of either section depends on the design. For example, a solid state power section with a failed power rectifier bridge may function at rated capacity if there is a redundant bridge. The same is true for a solid state control (regulator) section that includes installed redundancy. Among all the system parts, a power source or collector ring failure would have the most impact on capacity and availability. If any part does not exist in a particular excitation system, this part will be excluded from scoring mechanism by inputting "NA" into the table. The effect of one part exclusion is usually insignificant to the entire assessment, which may not justify any adjustment of the weighting factors for other parts of the excitation system.

3.0 METRICS FOR EXCITATION SYSTEM CONDITION ASSESSMENT

For excitation system condition assessment, it is recognized that the physical condition cannot be properly and sufficiently evaluated based on the visual inspections only while the results from some routine or available tests are more critical as indication of the exciter condition. Although these testing results can be categorized into the Physical Condition, they are listed separately in addition to the visual condition to emphasize the importance of these metrics. Thus, as listed in Table K-1, the following six condition parameters are considered for condition assessment of excitation system.

- The Visual Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- Exciter Electrical Tests (excluding performance testing)
- The Maintenance Requirement

These six condition parameters are scored based on the previous testing and measurements, historical O&M records, original design drawings, previous rehabilitation feasibility study reports if conducted, interviews with plant staff, and some limited inspections or previous inspections. It is noticed that there are certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmarking condition assessment without specific new testing and measurements conducted on site, these six parameters are regarded as providing the basis for assessing the condition of excitation components. If any type of tests or metrics are not applicable for some parts input "NA" into the cells of irrelevant parts for this metrics.

In addition, the Data Quality Indicator, as an independent metrics, is to reflect the quality of available information and the confidence on the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity, and any of these situations could affect the results of condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part/item to indicate the data availability, integrity and accuracy and the confidence on the given condition ratings.

4.0 WEIGHTING FACTORS

There are two categories of weighting factors in Table K-1. It is recognized that some condition parameters affect the exciter condition to a greater or lesser degree than other parameters; also some parts are more or less important than other parts of the excitation system. These weighting factors should be pre-determined by consensus among experienced hydropower electrical engineers and plant O&M experts. Once they are determined for each system, they should be largely fixed from plant to plant except for special designs found in a system where the weighting factors have to be adjusted. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors won't affect the Condition Indicator of an excitation system which is the weighted summation of all scores that assigned to the system parts and six condition parameters.

Table K-1. Typical exciter condition assessment and scoring: XXX Hydropower Plant (Unit #)

Exciter for Unit___	Taxonomy ID	Visual Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Exciter Electrical Tests	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Rotating Armature/Stationary Field	4.1.4.1								2.5
Collector / Commutator / Brushes	4.1.4.2								2.5
Power Potential Transformer	4.1.4.3								2.5
Alternate Power Source	4.1.4.4								2.5
Rheostats	4.1.4.5								1.0
AC Input Breaker	4.1.4.6								1.0
DC Field Breaker	4.1.4.7								1.0
Regulator / Electronics	4.1.4.8								1.5
SCR / Rectifier Bridge / Rotating Diodes	4.1.4.9								2.0
Fans / Sensors / Relays / Auxilliaries	4.1.4.10								1.0
Weighting Factors for Condition Parameters		1.0	2.0	2.0	1.0	1.5	1.5	Data Quality -->	*0.00*
								Exciter Condition Indicator -->	***0.00***

5.0 RATING CRITERIA

Visual Condition: Rating Criteria for Excitation System Parts

Visual Condition of excitation system parts refers to those features that are observable or detected through visual inspections. Collector, commutator and brush rigging condition, motor operated rheostats contacts, AC input and field breaker conditions, wiring, and overall cleanliness are all factors to consider in a visual assessment.

For HAP site assessment, it is important to review previous inspection records and interview and discuss with plant personnel to score the visual condition of the excitation system. The results of all related information are analyzed and applied to Chart 1 to assign the condition scores of the excitation system.

Chart 1 Exciter Visual Condition Rating Criteria		
Visual Condition Rating Scale		Visual Condition Score
Excellent	No noticeable defects. Some aging or wear may be noticeable. Very clean and well maintained.	9 – 10
Very good	Only minor deterioration or defects are evident, and function is full. Normal amount of carbon dust. None of the conditions cited under "very poor."	7 – 8
Good	Some deterioration or defects (see "very poor") are evident, but function is not significantly affected.	5 – 6
Fair	Moderate deterioration (see "very poor"), function is still adequate, but the unit operating flexibility may be affected.	3 – 4
Poor	Serious deterioration (see "very poor") in at least some portions, function is inadequate, unit operating flexibility or availability significantly affected.	2
Very poor	Extensive deterioration. Barely functional. Excessive carbon dust and contamination in collector/brush area, collector or commutator issues, brush issues, some regulator components out of service. Rheostat and breaker contacts corroded, pitted. Signs of overheating, insulation deterioration, physical damage, environmental damage.	1
Failed	Excitation System is non-functional.	0

Age: Rating Criteria for Excitation System Components

Age is an important factor to consider for excitation system reliability and upgrade potential. Electrical insulation critical to the system will irreversibly age and its remaining life will be a function of the original design and operating and maintenance history. When the system ages, the electrical insulation is more likely to develop grounds, particularly in the presence of excessive carbon dust or other contaminates. Age scoring is relatively more objective than other condition parameters. The detailed scoring criteria developed in Chart 2 allows the age score be automatically generated in the HAP Database by the actual years of the installed part.

Chart 2 Age Rating Criteria for Excitation System		
Age of the Excitation System Power Components	Age of the Excitation System Control Components	Age Score
< 5 years	< 5 years	**10**
5-10 years	5-10 years	**9**
10-15 years	10-15 years	**8**
15-20 years	15-20 years	**7**
20-25 years	20-25 years	**6**
25-35 years	25-35 years	**5**
35-40 years	35-40 years	**4**
40-45 years	40-45 years	**3**
45-50 years	45-50 years	**2**
> 50 years	> 50 years	**1**

Installed Technology Level: Rating Criteria for Excitation System Parts

The Installed Technology Level indicates levels of sophistication of the excitation system. Fully solid state inverting systems with redundant capacity and control channels represents the state of the art for excitation. At the other extreme will be varieties of rotating exciters with motor operated rheostats and rudimentary controls. The outdated technology may bring difficulties for spare parts supply and prolonged outage when it fails.

With the development of solid state silicon controlled rectifier (SCR) bridge circuits and electronic controls, overall control, response time and efficiency (reduction of losses) have been markedly improved. Older rotating systems usually have greater potential to gain efficiency and capacity by replacing and using the state-of-the-art fully solid state designs and materials.

The competence, professionalism and reputation of the original suppliers could also imply the installed technology levels. Compared with those from large and well-known manufacturers, the exciter parts supplied by small and unnamed companies whose industry track record shows history of reliability issues due to their design would get lower scores.

Chart 3 describes the ratings of exciter technology.

Chart 3 Exciter Technology Rating Criteria	
Technology Levels of the Parts/Items (as defined by IEEE 421.5 models)	**Score for Installed Technology Level**
ST (static excitation systems)	**8 - 10**
AC (alternator supplied rectifier excitation systems)	**4 - 7**
DC (direct current commutator exciters)	**1 - 3**

Operating Restrictions: Rating Criteria for Exciter Parts

The exciter operating restrictions refer to any limitations on the output of MVAR assuming sufficient excitation is available for Speed No Load (SNL). Operational limitations play a role in determining the serviceability of the excitation system.

To prevent rotor overheating, excitation (lagging or positive vars) may be limited; however, in this case the generator (rotor) would get a lower score and not the excitation system. If excitation was limited due to a failed bridge circuit or diodes then the excitation system rather than the generator would get lower score for the operating restrictions.

Chart 4 describes the ratings of exciter operating restrictions.

Chart 4 Exciter Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
No operating resistrictions or limitations due to excitation. Exciter operates at full capacity. Limiters appropriately set (if applicable).	**8 - 10**
No operating resistrictions or limitations due to excitation. Exciter operates at full capacity. No limiters provided, requires operator intervention.	**5 - 7**
Moderate restraints: Temperature limitations, less than full output capacity from excitation system. Where redundancy exist in design, redundant feature lost.	**3 - 4**
Severe limitations: The exciter is undesirable to operate anymore or has failed. Restoration or repair required.	**0 - 2**

Exciter Electrical Tests

In conjunction with a thorough visual inspection electrical testing will reveal the most information about the power and control circuits. Basic tests include the insulation resistance (IR) test, polarization index (PI) test, pole drop and high-potential test. The high potential test establishes the adequacy of the insulation to withstand both normal operating and transient voltages. The test may be either an acceptance test (new equipment) at standard test voltages or a service test at 65% of the standard test voltage. Either AC or DC tests may be performed. Engineering judgment will be required to assign a score based on available test data and weighing of comparative test results.

Chart 5 describes the ratings of exciter testing.

Chart 5 Excitation System Electrical Test Scoring	
Test Results	**Score for Electrical Condition**
Insulation resistance of power section (IR) > 50 megohms, polarization index (PI) >2.0, withstood AC/DC or VLF hipot.	**8 - 10**
Insulation resistance of power section (IR) < 50 megohms, > 1 megohms, polarization index (PI) >2.0, withstood AC/DC or VLF hipot	**5 - 7**
Insulation resistance (IR) < 1 megohms, polarization index and (PI) >2.0, withstood AC/DC or VLF hipot.	**2 - 4**
Insulation resistance (IR) < 1 megohms, polarization index and (PI) < 2.0.	**0 - 1**

Maintenance Requirement: Rating Criteria for Exciter Parts

The amount of corrective maintenance that either has been or must be performed is an indication that how the exciter condition is. No corrective maintenance is an indication that the exciter is in good shape. Frequent and extensive corrective maintenance or failures typically requires a major outage and is indicative of severe duty and/or aging.

Other factors to consider for maintenance scoring include:

- The need of maintenance is increasing with time or problems are reoccurring;
- Deteriorating trend in insulation integrity test results;
- Previous failures related to the exciter parts;
- Industry experience with failures and problems with exciters of similar design;
- Availability of service and/or replacements parts.

The results of exciter maintenance history (including routine maintenance and corrective maintenance) and trended test results are analyzed and applied to Chart 6 to score the maintenance demand of exciter components.

Chart 6 Exciter Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum Level (normal condition): A small amount of routine preventive maintenance, cleaning and routine testing is required and performed at the recommended frequency. Spare parts and service support readily available.	**9 - 10**
Low Level: Small amounts of corrective maintenance (e.g., less than 3 staff days per unit per year). Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis (e.g. rheostat cleaning, breaker maintenance). Some parts not readily available but still supported by a manufacturer.	**7 - 8**
Moderate Level: Some corrective maintenance that causes extensions of unit preventative maintenance outages (e.g., collector ring / commutator maintenance). Some parts not available and service not supported by OEM.	**5 - 6**
Significant/Extensive Level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., parts and service not available, major component replacement).	**3 - 4**
Severe Level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required. Spare parts and service not available.	**0 - 2**

Data Quality: Rating Criteria for Exciter Parts

The Data Quality scores reflect the quality of the inspection, test, and measurement results to evaluate the condition of excitation systems. The more current and complete inspection, the more consistent the testing and trending, the higher the Data Quality scores. The frequency of normal testing is as recommended by the manufacturer, industry standards or dictated by operating organization's experience.

Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data. Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of excitation systems are developed in Chart 7.

Chart 7 Exciter Data Quality Rating Criteria	
Data Availability, Integrity and Accuracy	**Data Quality Score**
High – The exciter maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurement were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8 - 10**
Medium – One or more of routine inspections, tests and measurement were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 - 7**
Low – One or more of routine inspections, tests and measurement were completed 24-36 months past the normal frequency, or some of results are not available.	**3 - 4**
Very Low – One or more of required inspections, tests and measurement were completed >36 months past the normal frequency, not completed or significant portion of results are not available.	**0 - 2**

6.0 EXCITATION SYSTEM CONDITION AND DATA QUALITY INDICATORS

In Table K-1 the final condition score of the excitation system (i.e., the Condition Indicator, *CI*), can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,6} S_C(K,J) \times F(K) \times F(J)}{\sum_{K=1,M}^{J=1,6} F(K) \times F(J)} \qquad (1)$$

The excitation system Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K) \times F(K)}{\sum_{K=1,M} F(K)} \qquad (2)$$

Here, M = the total number of parts/items associated with an excitation system; K = the identification No. of excitation system parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 6, respectively for visual condition, age, installed technology,,….);$S_C(K, J)$ = the condition score of an excitation system part for one of 6 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; and $F(K)$ = the weighting factor for an excitation system part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific excitation system testing, such as the hi pot and megger testing would more directly reveal the condition of excitation system insulation.

7.0 REFERENCES

IEEE 421.1, Standard Definitions for Excitation Systems for Synchronous Machines.

IEEE 421.3, Standard for High Potential Test Requirements for Excitation Systems for Synchronous Machines.

IEEE 421.4, Guide for the Preparation of Excitation System Specifications.

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TVA (2010). Enterprise Asset Management (EAM) Asset database Modification and Unique Identification of Structures, Systems, and Components.

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USACE (1985). Engineer Manual, No. 1110-2-1701. Engineering and Design – HYDROPOWER, US Army Corps of Engineers.

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EXCITER INSPECTION FORM AND CHECKLIST

REVISION 1.0, 1/17/2012

Exciter: Information Form

General Information:
Date of Site Visit: ____ Unit No.________________
Plant name: ____
Source/s of data: ____
Generator SNL Field Current: ____________________
Generator Rated Load Field Current: ______________

Main Exciter
Rating: __________________
Voltage: _________________________
Age: _____________________
Type Drive: ________________________
General Description (IEEE 421.5 Model No. if known): ____
____
____

Summary Failure History/Maintenance History / Major Repairs Description: ____
____
____
____
____
____

Installed Instrumentation/Monitoring: ____
____
____

Power Potential Transformer
Rating: ______________________ Primary Voltage: ___________________ Secondary Voltage: __________________
Winding Configuration: ____
Indoor/Outdoor: ____
Installed Instrumentation/Monitoring: ____

Power Systems Stabilizer: (yes/no) ___________

Pilot Exciter
Rating: _____________________ Voltage: _____________________

Voltage Regulator
Manufacturer: ____
Type/Model: ____
General Description: ____
Installed Instrumentation/Monitoring: ____

Alternative Power Source Data: (description and ratings)

____

____

____

____

____

Exciter Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History				
Commutator and Riser Maintenance				
Field Pole Repairs/Reinsulation				
Collector Ring Resurfacing				
Brush Holder Replacement				
Breaker Maintenance (AC Supply and/or DC Field)				
Electronic Regulator Components				
Motor Operated Adjusters/Rheostats				
Auxiliary Component Issues (e.g., fans, sensors)				

Exciter Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Bus Bar Connections				
Pilot Exciter				
Have all plant records regarding stator maintenance, repairs, operating conditions and performance data been requested/gathered?				

Topic	Yes	No	N/A	Comments/Details
Equipment Condition Assessment				
Do current electrical visual inspection results show evidence of collector ring pitting, scoring, or discoloration?				
Do electrical rotor test result trends indicate marginal insulation integrity?				
Is there evidence of excessive carbon dust, oil or other contamination in the exciter housing?				
Does on-line temperature information indicate any exciter overheating?				

Exciter Data Collection Sheet	
Topic	**Data Input**

APPENDIX L. GUIDE FOR TRANSFORMER CONDITION ASSESSMENT

REVISION 1.0, 1/17/2012

CONTENTS

1.0 GENERAL

The importance of the main power transformer to the hydropower plant cannot be overstated. The availability of the main power transformer (MPT) is critical for the entire power train of the generating station. A major failure of the MPT can result in not only a lengthy unplanned outage, but a catastrophic failure that can damage adjacent equipment and other major components in the power train as well. Although the MTP is one of the most efficient generation components, degradation of critical parts will occur over time affecting reliability and efficiency. Age and degradation can also lead to increased annual maintenance and repair costs.

MPT condition assessment is a valuable resource for both short term and long term operational planning of the transformer. Incipient faults or unknown degradation of the various transformer components may be detected during the assessment process, which could allow corrective maintenance to be scheduled instead of unplanned breakdown maintenance. The condition assessment also provides insight for improvements, potential upgrades, and may assist in justification for replacement of the MPT. Modern transformers typically provide lower losses than older transformer fleets, and the state-of-the-art design and material technology advancements provide for increased reliability and efficiency. The MPT assessment will assist in evaluating the current and future needs of the MPT and provides a baseline for further assessment and trending.

The following three step analyses are necessary to arrive at a main power transformer condition indicator:

1) What parts should be included for a MPT condition assessment and what is their relative level of importance (parts and their weighting factors)?

2) What metrics/parameters should be investigated for quantitative condition assessment and which ones are more important than others (condition parameters and their weighting factors)?

3) How to assign numerical scores to rate the various transformer parts (rating criteria)?

This appendix provides guides to answer the above questions which can be applied to the main power transformer. The condition assessment is performed on each MPT at the plant to obtain accurate condition indicators for the specific transformer. Each MPT should be assessed and evaluated on its own merits. Due to the uniqueness of each MPT, the guides provided in this appendix cannot quantify all factors that affect individual MPT condition. Mitigating factors not included in this Guide may trigger additional testing and further evaluation to determine the final score of the MPT condition and to assist in the decision process of MPT rehabilitation or replacement. This appendix is not intended to define main power transformer maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2.0 CONSTITUENT PARTS ANALYSIS

Main power transformers and their constituent parts are analyzed and listed in Table L-1 (reference to HAP Taxonomy). All the constituent parts listed are critical integral parts of the MPT and each must perform its intended function for reliable and efficient operation of the transformer. These parts will be found on all main power transformers and no exclusion is necessary in the scoring mechanism.

3.0 METRICS FOR MAIN POWER TRANSFORMER CONDITION ASSESSMENT

In performing main power transformer assessments, the following eight condition parameters are considered for the condition assessment of the MPT and associated constituent parts. Each parameter is listed in Table L-1.

- The Visual Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- Dissolved Gas-in-Oil Analysis
- Transformer Electrical Tests
- Insulating Oil Quality Tests
- The Maintenance Requirement

These eight condition parameters are scored based on the previous testing and measurements, historical O&M records, review of original design nameplate and factory test data, previous rehabilitation feasibility study reports if conducted, interviews with plant staff, and inspections. It is noted that there are certain levels of relevance between the age and physical condition, and maintenance needs. However, as a benchmarking condition assessment (without specific new testing and measurements conducted on site), these eight parameters are regarded as providing the basis for assessing the condition of the main power transformer. If any type of tests or metrics are not applicable for some parts (e.g., the Transformer Electrical Tests are not applicable to the Tank), input “NA” into the cells of irrelevant parts for this metrics.

In addition, the Data Quality Indicator, as an independent metrics, is to reflect the quality of available information and the confidence of the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity, and any of these situations could affect the results of condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part/component to indicate the data availability, integrity, accuracy, and the confidence on the given condition ratings (MWH 2010).

4.0 WEIGHTING FACTORS

There are two categories of weighting factors in Table L-1. It is recognized that some condition parameters affect the MPT condition to a greater or lesser degree than other parameters; also some parts are more critical than others when considering the MPT as a whole. These weighting factors should be pre-determined by consensus among experienced hydropower mechanical and electrical engineers and plant O&M experts. Once they are determined for the MPT, they should be largely fixed from plant to plant unless some special non-standard design in encountered. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors will not affect the Condition Indicator of a main power transformer, which is the weighted summation of all scores that are assigned to the MPT parts and eight condition parameters.

Table L-1. Typical main power transformer condition assessment and scoring: XXX Hydropower Plant (Unit #).

Transformer for Unit ___	Taxonomy ID	Visual Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Dissolved Gas-in-Oil Analysis Score	Transformer Electrical Tests Score	Insulating Oil Quality Tests Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Core	4.1.5.1	NA						NA			1.5
Windings	4.1.5.2	NA						NA			2.0
Solid Insulation	4.1.5.3	NA									2.5
Insulating Fluid	4.1.5.4	NA									1.5
Bushings	4.1.5.5							NA			2.0
Cooling System	4.1.5.6						NA	NA			1.0
Oil Preservation System	4.1.5.7				NA		NA				1.0
Tank	4.1.5.8				NA	NA	NA	NA			0.5
Weighting Factors for Condition Parameters		1.0	1.5	1.0	1.5	2.5	2.0	1.5	1.0	Data Quality -->	*0.00*
										Condition Indicator -->	***0.00***

5.0 RATING CRITERIA

Visual Condition: Rating Criteria for Main Power Transformer

The Visual Condition of the transformer refers to an external inspection of the transformer and visually available associated components. The physical condition of the bushings, tank, cooling system, oil preservation system as well as evidence of oil leakage and instrumentation issues can be observed and documented. The internals of the transformer (core, windings, solid insulation, and insulation fluid) cannot be assessed by visual condition. Reports of any previous internal inspections of the transformer can provide valuable information into the overall physical condition of the transformer.

For HAP site assessment, it is important to review previous inspection records and interview and discuss with plant personnel to assist in scoring the visual condition of the MPT. The results of all related information are analyzed and applied to Chart 1 to assign the condition scores of MPT parts.

Chart 1 Main Transformer Visual Inspection Condition Rating Criteria		
Visual Condition Rating Scale		Visual Condition Score
Excellent	No significant defects noted.	**8 - 10**
Good	Some deterioration or defects are evident, but function is not affected. Isolated evidence of oil leakage, rust, flaking paint, minor control or instrumentaion defects.	**5 - 7**
Fair	Moderate deterioration, function is still adequate, but the transformer efficiency and reliability may be affected. Some areas exhibiting significant oil leaks, some missing or faulty cooling system components, minor oil preservation system defects, faulty or missing controls or temperature indicators.	**3 - 4**
Poor	Serious deterioration in at least some portions, function is inadequate, efficiency or availability significantly affected. Major oil leaks, major rust, major cooling system issues, oil preservation system faulty, bushing defects noted, overheating and/or overloading evident, significant control and protection device degradation,or excessive vibration.	**0 - 2**

Age: Rating Criteria for Main Power Transformer Parts

Age is an important factor to consider for MPT reliability, upgrades, or potential candidates for replacement. Age is one indicator of the remaining life of the transformer. During the service life of any transformer, the mechanical and insulating properties of electrical insulating materials, such as cellulose and pressboard, deteriorate. Mechanical compromise, from deterioration, of the insulating materials can lead to failure of the windings, core, and bushings. External systems, such as the cooling and oil preservation system, experience wear out and higher maintenance costs with age. When considering potential upgrades, age and estimated remaining life are important indicators as to whether it is economically sound to pursue major upgrades. This can also be applied to identify potential candidates for replacement.

The detailed scoring criteria developed in Chart 2 allows the age score be automatically generated in the HAP Database by the actual years of the installed MPT. Typically, the age of nearly all the parts will be the same with the exception of the bushings, which may vary because of replacement. Although, the actual service life of a transformer can vary widely, the average expected life of an individual transformer in a large population of transformers is statistically about 40 years. Some well-maintained hydro plant MPT's have been known to achieve 50+ years of service.

Chart 2 Main Transformer Age Rating Criteria	
Age of the Transformer	**Age Score**
< 30 years	**9 - 10**
30-35 years	**7 - 8**
35-40 years	**5 - 6**
40-45 years	**3 - 4**
> 45 years	**1 - 2**

Installed Technology Level: Rating Criteria for Transformer Parts

The Installed Technology Level indicates advancement levels of monitoring devices which may have a have a direct impact on the MPT's performance and reliability. Many advanced monitoring systems are now available for on-line monitoring for the detection of incipient faults and other problems which allow for corrective maintenance and repairs to the various parts of the transformer.

Scoring the Installed Technology Level requires historic knowledge of main power transformer technology advancement and current state-of-the-art monitoring systems. Current technology provides for improved on-line monitoring of the functional integrity of many of the transformers parts.

Advanced on-line monitoring systems have been developed and can provide valuable information as to the health of the MPT, which directly affects reliability and efficiency of not only the transformer, but the generating plant as well. A review of the enhanced monitoring systems in use is compared to Chart 3 to determine the score for the installed technology level.

Chart 3 Main Transformer Technology Rating Criteria	
Technology Levels of Enhanced Condition Monitoring Systems	**Score for Installed Technology Level**
Some enhanced condition monitoring systems are used which include: Thermography (fixed or portable), On-line Gas-in-Oil monitors, Fiber Optic Temperature Devices, Moisture-in-Oil sensors, Partial Discharge Monitors, On-line bushing power factor sensors, Vibration sensors. (At least 3 of these enhancements are used.)	**8–10**

Chart 3 Main Transformer Technology Rating Criteria	
Technology Levels of Enhanced Condition Monitoring Systems	**Score for Installed Technology Level**
Some enhanced condition monitoring systems are used which include: Thermography (fixed or portable), On-line Gas-in-Oil monitors, Fiber Optic Temperature Devices, Moisture-in-Oil sensors, Partial Discharge Monitors, On-line bushing power factor sensors, Vibration sensors. (At least 2 of these enhancements are used.)	**5–7**
Some enhanced condition monitoring systems are used which include: Thermography (fixed or portable), On-line Gas-in-Oil monitors, Fiber Optic Temperature Devices, Moisture-in-Oil sensors, Partial Discharge Monitors, On-line bushing power factor sensors, Vibration sensors. (At least 1 of these enhancements are used.)	**1–4**
No enhanced condition monitoring systems are used.	**0**

Operating Restrictions: Rating Criteria for Main Power Transformer Parts

MPT operating restrictions refer to any limitations of the transformer to provide rated output as designed. Any limitations imposed on the MPT's parts can have a direct impact on transformer output. For example, inefficiencies with the cooling system could impose thermal operational constraints on the MPT, which would require a reduction of load so as not to exceed temperature rise ratings of the transformer.

Operation of the MPT within its design parameters should not require any operating restrictions unless problems exist with one or more of the transformer parts or issues have been encountered with the original design.

Chart 4 is used to determine the score for any operating restrictions imposed on the MPT.

Chart 4 Main Transformer Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes, and the original transformer design has no constraints on the required operation. There are no known design or operational issues.	**8 – 10**
Minimal restraints: Some isolated temperature restrictions, isolated deratings, or cooling system inadequacies have been encountered. There are no known design or operational ineffeciencies.	**5 – 7**
Moderate restraints: Frequent temperature restrictions, frequent deratings, excessive vibration, significant cooling system degradation.	**3 – 4**
Severe limitations: The transformer does not meet the required operational criterea or the original design has significantly degraded and limited the performance and reliability if the transformer operates under current requirements.	**0 – 2**

Dissolved Gas-in-Oil Analysis

Dissolved Gas-in-Analysis (DGA) is one of the most important tools for determining and monitoring the health of the MPT. DGA samples are obtained while the MPT is in-service and is non-intrusive. Monitoring and trending DGA data provides diagnostics for the detection of incipient faults and abnormal conditions such as overheating, partial discharge, arcing, pyrolysis, and insulation degradation that may exist within the transformer. By analyzing the amount and generation rate of key combustible gases, the internal health of the MPT can be predicted and is very useful for operational performance and planned maintenance.

Trending of DGA data should be performed and the monthly generation rates of individual combustible gases as well as total dissolved combustible gas are calculated. These generation rates are the compared to Chart 5 for a DGA condition score.

Knowledgeable engineering judgment will be required to assign a score based on analysis of available test data and weighing of comparative test results.

Chart 5 Dissolved Gas-in-Oil Analysis (DGA) Scoring Criteria	
Test Results	**Score for DGA Condition**
Total Dissolved Combustible Gas (TDCG) generation rate < 30 ppm (parts per million)/month AND all individual combustible gas generation rates < 10 ppm/month. Exceptions: CO generations < 70 ppm/month AND acetylene (C2H2) generation rate = 0 ppm.	**10**
Total Dissolved Combustible Gas (TDCG) generation rate >= 30 and < 50 ppm/month AND all individual combustible gas generation rates < 15 ppm/month. Exceptions: CO generations < 150 ppm/month AND acetylene (C2H2) generation rate = 0 ppm.	**7**
Total Dissolved Combustible Gas (TDCG) generation rate >= 50 and < 80 ppm/month AND all individual combustible gas generation rates < 25 ppm/month. Exceptions: CO generations < 350 ppm/month AND acetylene (C2H2) generation rate < 5 ppm/month.	**3**
Total Dissolved Combustible Gas (TDCG) generation rate >=80 ppm/month AND all individual combustible gas generation rates < 50 ppm/month. Exceptions: CO generations >= 350 ppm/month AND acetylene (C2H2) generation rate < 10 ppm/month.	**0**

Main Transformer Electrical Tests

Routine electrical tests are typically performed on a MPT to determine the condition of the insulation and electrical health of the windings, core, bushings, and conductors. These tests would include insulation power factor tests (sometimes referred to as Doble tests) on the winding and bushing insulation, excitation tests on the core, capacitance tests on oil-filled condenser bushings, and winding resistance tests on the windings, conductors, and connections.

The power factor tests are normally rated using Doble Engineering ratings, with "Good" being the best rating. These tests are trended over time to monitor any contamination or degradation of the insulation. Excitation tests can indicate shorted turns in the winding, poor tap changer contacts, or problems associated with the core. The power factor and capacitance tests on bushings determine the electrical integrity of the bushing insulation and condenser. Winding resistance is extremely important to detect bad contacts in the tap changer, loose connections (bolted or brazed), and broken conductor strands within the windings. Overall, these tests provide the necessary data to determine the electrical health of the MPT. Engineering judgment will be required to assign scores based on the availability of data. The criteria for the assigning the electrical tests scores is given in Chart 6.

Chart 6 Main Transformer Routine Electrical Tests Scoring	
Test Results	**Score for Electrical Test Condition**
Winding Insulation power factor (PF) < 0.5% and rated Good, excitation values normal and comparable, Bushing C1 %PF < 75% nameplate value and rated Good, Bushing C1 capacitance < 10% increase from nameplate value, transformer winding resistance within +/- 5% of factory test values and balanced, all as indicated by most recent test.	**10**
Winding Insulation power factor (PF) < 0.5% and rated Good, excitation values normal and comparable, Bushing C1 %PF < 75% nameplate value and rated Good, Bushing C1 capacitance < 10% increase from nameplate value, transformer winding resistance within +/- 5% of factory test values and balanced, all as indicated by most recent test. (4 of 5 criteria met)	**8**
Winding Insulation power factor (PF) < 0.5% and rated Good, excitation values normal and comparable, Bushing C1 %PF < 75% nameplate value and rated Good, Bushing C1 capacitance < 10% increase from nameplate value, transformer winding resistance within +/- 5% of factory test values and balanced, all as indicated by most recent test. (3 of 5 criteria met)	**5**
Winding Insulation power factor (PF) < 0.5% and rated Good, excitation values normal and comparable, Bushing C1 %PF < 75% nameplate value and rated Good, Bushing C1 capacitance < 10% increase from nameplate value, transformer winding resistance within +/- 5% of factory test values and balanced, all as indicated by most recent test. (2 of 5 criteria met)	**3**
Winding Insulation power factor (PF) < 0.5% and rated Good, excitation values normal and comparable, Bushing C1 %PF < 75% nameplate value and rated Good, Bushing C1 capacitance < 10% increase from nameplate value, transformer winding resistance within +/- 5% of factory test values and balanced, all as indicated by most recent test. (1 of 5 criteria met)	**1**
None of the above criteria met.	**0**

Insulating Oil Quality Tests

Insulating oil is a required critical part of the main power transformer. The oil provides for the dielectric properties of the insulation system, maintains required electrical clearances, protects the insulation system from chemical and thermal degradation, and provides the necessary cooling for the internal transformer components.

Insulating oil samples are analyzed and the chemical and dielectric properties of the oil can be determined. As all paper and pressboard insulation systems are impregnated with the insulating oil, the oils properties have a direct impact on the aging process of the insulation. The oil also protects the windings and core electrically and prevents corrosion from contaminates.

The oil quality data should be compared with Table L-2 to determine if the specific test is within acceptable limits. This table lists the suggested acceptable limits for service-aged insulating oil as recommended by IEEE C57.106.

Table L-2. Suggested limits for continued use of service-aged insulating oil

Test and Method	**Voltage Class of Transformer**		
	≤69 kV	**>69–<230 kV**	**≥230 kV**
Dielectric Strength ASTM D1816 1 mm gap kV, min 2 mm gap kV, min	 23 40	 28 47	 30 50
Neutralization No. ASTM D974 mg KOH/g maximum	0.20	0.15	0.10
Interfacial Tension ASTM D971 mN/m minimum	25	30	32
Power Factor@20C ASTM D924 25 C % maximum	0.5	0.5	0.5
Water Content ASTM D1533 ppm maximum	35	25	20

After determining the compliance of each test with the above table, Chart 7 is used to determine the score for the oil quality.

Chart 7 Insulating Oil Quality Test Scoring	
Test Results	**Score for Oil Quality Condition**
Current oil quality tests indicate neutralization number (acid), interfacial tension (IFT), dielectric strength, % power factor, and water content to be within acceptable limits.	**10**
Current oil quality tests indicate neutralization number (acid), interfacial tension (IFT), dielectric strength, % power factor, and water content to be within acceptable limits. (4 of 5 criteria met)	**8 - 9**
Current oil quality tests indicate neutralization number (acid), interfacial tension (IFT), dielectric strength, % power factor, and water content to be within acceptable limits. (3 of 5 criteria met)	**5 - 7**
Current oil quality tests indicate neutralization number (acid), interfacial tension (IFT), dielectric strength, % power factor, and water content to be within acceptable limits. (2 of 5 criterea met)	**2 - 4**
Current oil quality tests indicate neutralization number (acid), interfacial tension (IFT), dielectric strength, % power factor, and water content to be within acceptable limits. (1 of 5 criterea met)	**1**
None of the above criterea met.	**0**

Maintenance Requirement: Rating Criteria for Main Transformer Parts

The amount of corrective maintenance that either has been or must be performed is an indication of the MPT condition. No corrective maintenance is an indication that the MPT is in relatively good shape. Frequent and extensive corrective maintenance or component failures typically requires a major outage and is indicative of more severe issues and/or aging.

Other factors to consider for maintenance scoring include:

- The need of maintenance is increasing with time or problems are reoccurring;
- Deteriorating trend in insulation integrity test results;
- Previous failures related to the main transformer parts;
- Abnormal levels of combustible gas and elevated generation rates;
- Industry experience with failures and problems with transformers of similar design.

The results of MPT maintenance history (including routine maintenance and corrective maintenance) and trended test results are analyzed and applied to Chart 8 to determine the maintenance requirement score.

Chart 8 Main Transformer Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum Level (normal condition) – A small amount of routine preventive maintenance, oil analysis and routine testing is required and performed at the recommended frequency.	**9 – 10**
Low Level – Small amounts of corrective maintenance peformed. Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis (e.g., cooling system maintenance, instrument calibration, minor oil leaks).	**7 – 8**
Moderate Level – Some corrective maintenance that causes extensions of unit preventative maintenance outages (e.g., bushing replacement, oil leak repair, cooling system repairs, oil preservation system repairs).	**5 – 6**
Significant/Extensive Level – Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., significant oil leaks, cooling system replacement, overheating electrical connections).	**3 – 4**
Severe Level – Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required.	**0 – 2**

Data Quality: Rating Criteria for Main Transformer Parts

The Data quality scores reflect the quality of the inspection, test, and measurement results to evaluate the condition of MPT parts. The more current and complete inspection, the more consistent the testing and trending, the higher the Data Quality scores. The frequency of normal testing is as recommended by the manufacturer, industry standards or dictated by operating organization's experience.

Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3–7. Conversely, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of MPT parts are developed in Chart 9.

Chart 9 Main Transformer Data Quality Rating Criteria	
Data Availability, Integrity and Accuracy	**Data Quality Score**
High – The transformer maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurement were performed within normal frequency. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8 – 10**
Medium – One or more of routine inspections, tests and measurement were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 – 7**
Low – One or more of routine inspections, tests and measurement were completed 24-36 months past the normal frequency, or some of results are not available.	**3 – 4**
Very Low – One or more of required inspections, tests and measurement were completed >36 months past the normal frequency, or significant portion of results are not available.	**0 – 2**

6.0 MAIN TRANSFORMER CONDITION AND DATA QUALITY INDICATORS

In Table L-1 final condition score of the main power transformer (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,8} S_C(K,J)\times F(K)\times F(J)}{\sum_{K=1,M}^{J=1,8} F(K)\times F(J)} \quad (1)$$

The main transformer Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K)\times F(K)}{\sum_{K=1,M} F(K)} \quad (2)$$

Here, M = the total number of parts/items associated with a main power transformer; K = the identification No. of the main transformer Parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 8, respectively for visual condition, age,…); $S_C(K, J)$ = the condition score of a main transformer part for one of 8 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a main transformer part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of any internal inspections and/or specialized testing results that may be performed, as these may reveal more information to enhance the condition assessment of the main power transformer.

7.0 REFERENCES

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TRANSFORMER INSPECTION FORM AND CHECKLIST

REVISION 1.0, 1/10/2012

Main Transformer: Information Checklist

General Information:
Date of Site Visit: ____ Unit No.________
Plant name: ____
Source/s of data: _________________________ Plant contacts: ________________________________
Main Transformer Nameplate Data:
Manufacturer: ____________________ Year Manufactured: ________ Serial No.:__________________
Voltage Ratings (kV):_______________ Rated Output (MVA):________________ Phase (1 or 3):______
Temperature Rise Rating: ___________ Cooling Class: _______________ BIL Rating: ______________
De-energized Tap Changer: No. of positions above and below set tap and % steps: ________________
Cooling System:
General description of the cooling system and components:
____
____

Cooling stages controlled by what temperature device____

Oil Preservation System:
General description and type of the oil preservation system:
____
____

Neutral Grounding:
Neutral Ground Method (e.g., oil filled reactor, air core reactor, resistance, solid):
____
____

Load Tap Changer (if equipped):
General description type, and tap positions of the load tap changer:
____
____
____
____

Advanced Technology Monitoring Instrumentation (if equipped):
Describe any advanced monitoring systems installed (e.g., winding temperature fiber optics, partial discharge probes, on-line gas-in-oil analyzer, bushing power factor monitors)

____
____
____

Summary Maintenance History / Major Repairs:

____
____
____
____
____
____

Summary Failure History/ Major Faults:

____
____
____
____
____
____

Summary Abnormal Operating Events:

____
____
____
____
____
____

Test Reports and Data Availability:

Factory Test Reports available (Yes/No): __________
Routine Electrical Test Reports available (Yes/No): __________
Thermographic Inspection data available (Yes/No): __________
Gas-in Oil Analysis data available (Yes/No): __________
Insulating Oil Quality data available (Yes/No): __________

Additional Information:

On-site spare transformer available (Yes/No): __________
System spare transformer available (Yes/No): __________
Critical spare parts available (Yes/No): __________
Fixed fire suppression system provided (Yes/No): __________
Oil containment system provided (Yes/No): __________

Additional Comments:

____
____
____
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____
____
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____
____

Main Transformer Inspection Checklist				
Plant____________________ Transformer Position___________ Serial No_________________________________ Date______________________				
Task	**Yes**	**No**	**N/A**	**Comments**
Main Tank				
Paint system in good condition				
Rust observed				
Tank grounds in good condition				
Provisions for future additional cooling				
Conduit and fittings secure				
External core ground provided				
Excessive vibration or noise observed				
Oil leakage observed				
Cooling System				
Radiator or cooler fins clean				
All valves to main tank open and secure				
All fans in place and operational				
All oil pumps in place and operational				
Oil flow indicators function properly				
Excessive vibration or noise observed				
Oil leakage observed				
Oil Preservation System				
Inert gas positive pressure system				
Pressure regulator for nitrogen blanket properly set				
Gas blanket pressure reading				
or				
Conservator (free breathing, membrane, air cell) system				
Oil level gauge indicating proper level				
Silica gel breather in good condition				
Oil cup on breather filled to proper level				
or				
Sealed tank system				
Pressure gauge reading on main tank				

Task	Yes	No	N/A	Comments
Bushings				
All bushings clean and no defects observed				
Bushing oil levels at proper level				
Oil leakage observed				
De-energized tap changer (DETC)				
Position indicator tap position recorded				
Locking mechanism properly engaged and secured				
Routinely exercised				
Load tap changer (LTC)				
Position indicator tap position recorded				
Oil level gauge (if equipped) indicating proper level				
Silica gel breather in good condition				
Oil cup on breather filled to proper level				
Oil leakage observed				
Control Cabinet				
All connections/components appear in good condition				
Weather tight seals in good condition				
Strip heaters in cabinet				
Evidence of moisture egress				
Protective and Indicating Devices				
Oil temperature indicator reading				
Oil temperature indicator set points				
Oil temperature remotely recorded				
Winding temperature indicator reading				
Winding temperature indicator set points				
Winding temperature remotely recorded				
Buchholtz Gas Accumulator relay alarm/trip				
Sudden pressure (rapid rise) relay alarm/trip				
Gas Detector relay alarm/trip				
Other monitoring or indicating devices installed				

Task	Yes	No	N/A	Comments
Other				
Additional comments or findings to be addressed				
Inspection performed by:				

APPENDIX M. GUIDE FOR INSTRUMENTS & CONTROLS SYSTEM CONDITION ASSESSMENT

REVISION 1.0, 1/11/2012

CONTENTS

1.0 GENERAL

The instruments and controls (I&C) system for automation is a critical component in a hydropower plant. Unlike the generators or transformers, catastrophic failure is rare to happen due to automation systems. The fail safe design to protect turbines and generators prevents serious physical damage to a facility. The most common failures in an automation system are failed power supplies, failed I/O, failed processors and lack of information wired to the system. Less common are programming errors that may create issues. Rehabilitation and replacement of an aging automation system may become more economical and less risky than maintaining an outdated system considering the potential efficiency improvement from the state-of-the-art automation design. The condition assessment for I&C system is essential to evaluate the benefits and cost of upgrading.

The plant PLC, SCADA or RTU based automation control system can vary widely from facility to facility. Control architectures have evolved into various types of systems. All these types of systems can perform their intended control functions and effectively control a hydro-electric facility. It is often a personal preference, based on the plant culture, as to what type of automation system is selected. There is some difficulty in writing up a checklist that fits all systems, especially in hardware. The currentchecklist makes basic assumptions and attempts to keep the evaluation as simple as possible. Local plant personnel, plant engineering or central engineering will likely be interviewedin evaluating the automation system. These interviewees are those individuals who are mostly familiar with the automation software and its unique attributes and understand its capabilities in a plant. The ease of implementing improvements in a control system is as much the combination of the skill and training of the plant's engineers and technicians as the automation hardware/software capabilities. Generally, engineering and plant support personnel would like the most current technology and plant efficiencies and thus will be willing to help in the assessment as it will improve their lives at work.

For assessing any type of an I&C system, the following three step analyses are necessary:

1) What is the highest level of automation desired at the facility?

   - Local manual control only
   - Local automatic control with no remote access nor remote control
   - Local manual with remote manual control
   - Local automatic control with some efficiency and remote access and remote control
   - Supervisory control—controlled remotely with efficiency controls (highest level of automation)

2) What is the level of obsolescence?

Obsolescence is a significant factor in an automation system. Turbines and other devices can last 50 years or more. Portions of a control system may become obsolete in as little as 5 years depending on the vendor and the date a particular version was installed. The installed system may be incapable of advanced control, which raises question: Is the system obsolete or undersized and what is required to update or upgrade it?

3) How to assign numerical scores to the system components (rating criteria)?

This appendix provides guides to answer the above questions, which can be applied to automation control and instrumentation systems regardless of type. The condition assessment is performed using generalized system component names (e.g., using "controller" to represent any of PLC, RTU, or controller). Similar generalization will also be used for SCADA or Data Server. The item of "condition monitoring" combines vibration, proximity (air gap), speed, temperature and partial discharge analysis as a whole (reference to HAP Taxonomy).

2.0 I&C SYSTEM ANALYSIS

There are two workbooks for I&C system due to the different rating metrics and criteria. One workbook is for Automation components (less meters), including condition monitoring (reference to HAP Taxonomy). The other workbook is for Instruments of Unit Performance Measurement (meters).The term 'meters' will be used interchangeably in this document with 'instruments for unit performance measurement'.

The automation system and its components (less meters) are analyzed and listed in Table M-1. These are components normally installed in a control room. Automation is the control system that interfaces with all the devices (such as governor, breakers, relays) and instruments (e.g., for monitoring or metering of power, flow rates, vibrations, turbine speed, headwater level, tailwater level) via their essential components. An example is the governor, which requires the MW meter to operate. The automation system sends commands to the governor to raise or lower MWs, but does not directly control MW. Automation assessment scoring is different from the mechanical or civil assessments, due to many possible configurations of the automation system.

Table M-1. Condition assessment of I&C automation

Automation System Unit ___	Taxonomy ID	Hardware Technology	Software Implementation[5]	Security	Data Quality Score	Weighting Factors for Components
(A) PLC or RTU or Controller[1]	4.3.3.1					5.0
(B) HMI (Human Machine Interface)[2]	4.3.3.2					2.0
(C) Data Server or SCADA[3]	4.3.3.3					5.0
(D) LAN: Process Control Network[4]	4.3.3.4					2.0
(E) Historical Archiving & Reporting	4.3.3.5					1.5
(F) Condition Monitoring[6]	4.3.1					4.0
Weighting Factors for Condition Parameters		3.0	4.0	1.0	Data Quality -->	0.00
Automation Condition Indicator -->						0.00

*1 Due to differences in vendor terminology these are viewed as equivalent
*2 [HMI and SCADA] or [HMI and Data Server] may be the same device in some systems.
Rate the HMI as a standalone device even though it may be the same physical hardware as the SCADA or Data Server
HMI includes alarming
*3 Even though these are slightly different in function, there is only one or the other at a plant.
*4 Includes security evaluations such as firewalls, IDS and Syslogs
*5 Includes local, automatic and off-site control evaluations and efficiency optimization
*6 Machine Condition Monitoring for vibration, proximity, keyphasor®, temperature, and partial discharge analysis

The Instruments for Unit Performance Measurement used in automation are listed in Table M-2. These components have transducers in the field and digital or analog displays on the meters installed in the control room. These meters normally have analog or digital outputs to control systems. Please note the rating criteria for metering assessment are different from the rating scales for the automation. The metering scoring system is similar to mechanical or civil component assessments, such as a turbine assessment.

Table M-2. Condition assessment for I&C instruments for unit performance measurement (meters)

Instruments for Unit Performance Measurement Unit __	Taxonomy ID	Physical Condition	Age Score	Installed Technology	Operating Restrictions	Maintenance Requirement	Data Quality Score	Weighting Factors for Components
Generator Voltmeters[1]	4.3.2.1							3.0
Generator Ammeters[1]	4.3.2.2							1.5
Generator MW Meter[1]	4.3.2.3							3.0
Generator MVAR Meter[1]	4.3.2.4							3.0
Generator Field Voltage[1]	4.3.2.5							2.0
Generator Field Ammeter[1]	4.3.2.6							1.0
Wicket Gate Position Indicator[2]	4.3.2.7							1.5
Blade Tilt Indicator (Kaplan)[3]	4.3.2.8							1.0
Head Water Elevation[4]	4.3.2.9							4.0
Tail Water Elevation[4]	4.3.2.10							4.0
Turbine Flow[5]	4.3.2.11							1.0
Weighting Factors for Condition Parameters		**2.0**	**1.0**	**3.0**	**1.0**	**1.5**	**Data Quality -->**	***0.00***
Metering Condition Indicator -->								***0.00***

*1 Treat each input as an individual meter if multi-function meters are used.
*2 Wicket gate measurements are commonly made by a LVDT (Linear Variable Differential Transformer) or a slide wire precision potentiometer attached to the gate servomotor linkage at the unit governor or to a synchro position transmitter. The synchro transmitter is likely to yield the most accurate measurement. On units with older mechanical governors, the feedback is a "restoring cable". In this case, the only method of evaluation may be the maintenance records.
*3 The blade tilt indicator for a Kaplan turbine may be difficult to evaluate outside of any maintenance records. There are two common types of feedback to the governor. The MLDT (Magnetostrictive Linear Displacement Transducer) is used on units with digital governors. On units with older mechanical governors, the feedback is a "restoring cable".
*4 Frequently in head water elevation and/or tail water elevation, there may be redundancy. Two level transmitters may be used that are of different types tied to two separate meters. As an example for head water elevation, one may be a

float type level transmitter and the other a submerged pressure transmitter. One meter may be an analog meter tied to the submerged pressure transmitter and the other meter a digital meter tied to the synchro (float type) transmitter. Both head water measurements may tie back to the control system. If there is this type of redundancy, give a higher score. Rank the higher quality of the two measurement types. A staff gage does not qualify as a meter in this assessment.
*5 Absolute turbine flow measurement is difficult. Generally pressure taps are used as sources to measure relative flow only. Winter-Kennedy piezometer taps installed in the scroll case with modeling software is the established way to accurately measure turbine flow. Often, those are only used for "index testing" every couple of years. If Winter-Kennedy type taps are permanently installed and in use, give a higher score.

It is rare for ammeters and voltmeters to fail as there are no moving parts, little chance of contamination, generally very minimal drift over time and they just work for years and years. The plant would not function without them. The wicket gate feedback and Kaplan blade angle readings are required to be accurate for the governors to function properly. In mechanical governors there is little to evaluate as all they have is restoring cables. Synchro transmitters are some of the most accurate measurements in the field and are commonly used for feedback on digital units. Once properly set up, they work well for years. Turbine flow is a relative measurement in most cases. It is physically impossible to have an extremely accurate measurement; even with the Winter-Kennedy taps the measurements are still at ±2%. Metering has to work for the plant to operate even in manual, but there is little performance improvement through just better metering. Automation is what brings more value and improved performance.

3.0 METRICS FOR CONDITION ASSESSMENT

As listed in Table M-1, the following three condition parameters are considered for condition assessment of the Automation System (less meters):

- Hardware Technology
- Software Implementation
- Security Level

These three parameters are regarded as providing the basis for assessing the condition of the Automation System. There is no “Installed Technology” or "Maintenance" category, as they are covered in Hardware Technology and/or Software Implementation, as well as the hardware and software upgrades. Each cell in the worksheet is quite specific and not as generalized as in other assessment manuals. Be sure to read the cell for the weight selected and the footnotes.

As listed in Table M-2, the following five condition parameters are considered for condition assessment of the Instruments for Unit Performance Measurement (metering):

- Physical Condition
- Age
- Installed Technology
- Operating Restrictions
- Maintenance Requirements

Off-site evaluation, after a site visit, will be required to evaluate the vendor current offerings and capabilities versus the installed versions, so the Hardware Technology, Software Implementation, or Installed Technology can be properly scored.

The scores of data quality are determined by the on-site evaluators for each assessed part/item to indicate the data availability, integrity and accuracy and the confidence on the given condition ratings. In some cases, data may be missing or there may be uncertainty of the component's capability.

4.0 WEIGHTING FACTORS

There are two categories of weighting factors in Tables M-1 and M-2. Some condition parameters affect the system condition to a greater or lesser degree than other others; also some components are more or less important than others to an entire control system. These weighting factors should be pre-determined by consensus among experienced hydropower controls and operations engineers. Once determined, the weighting factors should be largely fixed from plant to plant. The range of absolute values of weighting factors won't affect the Condition Indicator of an automation system, which is the weighted summation of all scores that assigned to a system and its condition parameters. Facilities that fall under NERC regulations will find that Security will be serious as fines could hit $1 million per day. Security may have a lower status in the weighting, but it is absolutely essential for any facility.

5.0 RATING CRITERIA

For HAP site assessment, it is important to interview and discuss with plant personnel to score the condition of I&C components. All related information are collected, analyzed and applied to:

- Charts 1–5 Automation Hardware Rating Criteria
- Charts 6–10 Automation Software Implementation Rating Criteria
- Charts 11–15 Automation Security Rating Criteria
- Charts 16–18 Machine Condition Monitoring Rating Criteria
- Chart 19 Automation Data Quality Rating Criteria
- Charts 20–24 Instruments for Unit Performance Measurement(metering) Rating Criteria
- Chart 25 Instruments for Unit Performance Measurement (metering) Data Quality Rating Criteria

The charts listed above will guide the assessors to assign component condition scores. The gathering of data in the checklists will provide detailed information that will likely exceed the requirements for an assessment.

Chart 1 Hardware Assessment: PLC or RTU or Controller		
Condition Description		Score
Excellent	Capable of all required and future controls expansion for its area w/o an extensive CPU upgrade. At current revision level and vendor support level.	**9–10**
Good	Not at latest release version, but has vendor support. Not obsolete. Capable of all required and future controls expansion for its area w/o a CPU upgrade.	**7–8**
Fair	Considered obsolete by vendor and not configurable by current release software. Capable of all required and future controls expansion for its area w/o a CPU upgrade.	**5–6**
Poor	Considered obsolete by vendor and/or capable of all currently required controls for its area, but not able to handle future controls for its area.	**2–4**
Unacceptable	Obsolete and/or minimal control capability. For example, it can only monitor devices and has limited control.	**0–1**

Chart 2 Hardware Assessment: HMI (Human Machine Interface)		
Condition Description		**Score**
Excellent	Computer (or thin client) has currently supported operating system and currently supported vendor HMI software and is capable of controls system expansion without a significant upgrade.	**9–10**
Good	Computer (or thin client) may have an older operating system and/or older (though supported) vendor HMI software. Capable of controls system expansion without an upgrade.	**7–8**
Fair	Computer (or thin client) may have an older though supported operating system. The HMI software is considered obsolete. Capable of controls system expansion without an upgrade.	**5–6**
Poor	Obsolete operating system and obsolete HMI software.	**2–4**
Unacceptable	No HMI or simple local digital panels with minimal information.	**0–1**

Chart 3 Hardware Assessment: Data Server or SCADA		
Condition Description		**Score**
Excellent	Computer has currently supported operating system and currently supported vendor software. It is capable of controls system[1] expansion without a significant upgrade.	**9–10**
Good	Computer may have an older operating system and/or older (though supported) vendor SCADA or Server software. Capable of controls system[1] expansion without an upgrade.	**7–8**
Fair	Computer may have an older though supported operating system. The SCADA or Server software is considered obsolete. Capable of controls system expansion without an upgrade.	**5–6**
Poor	Obsolete operating system and obsolete SCADA or Server software.	**2–4**
Unacceptable	No SCADA or Server system.	**0–1**

Chart 4 Hardware Assessment: LAN: Process Control Network		
Condition Description		Score
Excellent	Redundant LAN or ring which minimizes a single point of failure. Current technology supported by vendor(s). If there is a connection to the Internet or business network, a firewall is installed. All wireless communications are secure.	**9–10**
Good	Flat network with no redundancy or ring structure. A single switch failure could result in a plant failure or automatic switchover to manual mode. The switch(es) are current technology. At minimum, there is a redundant power supply and a firewall, if there is a business network or Internet connection.	**7–8**
Fair	Flat network with no redundancy or ring structure. A single switch failure could result in a plant failure or automatic switchover to manual mode. The switch(es) are not current technology and/or there are no redundant power supplies. If there is a business network or Internet connection, a firewall is installed.	**5–6**
Poor	A single switch failure could result in a plant failure or automatic switchover to manual mode. Obsolete network components and/or no firewall even if there is a business or Internet connection.	**2–4**
Unacceptable	No networking at all. Each unit is stand alone and there are no communications.	**0–1**

Chart 5 Hardware Assessment: Historical Archiving & Reporting		
Condition Description		Score
Excellent	Full stand alone system to collect historical data. The system is of current technology. Historical data is available to both the operator and to central control. Long term data storage and off-site backup built into the system.	**9–10**
Good	Full stand alone system to collect historical data. The system is not current technology. Historical data is available to both the operator and to central control. Long term data storage and backup built into the system.	**7–8**
Fair	Limited historical data collection. The system may or may not be current technology. Historical data is not available to both the operator and to central control. Long term storage is archived.	**5–6**
Poor	There is limited historical archiving. The ability to do annual comparisons and long term data analysis is not possible.	**2–4**
Unacceptable	There is no historical archiving.	**0–1**

Chart 6 Software Implementation: PLC or RTU or Controller		
Condition Description		Score
Excellent	Software in controller(s) fully controls the plant including supervisory optimized inputs from a central control. Score 9 if it meets above. Add 1 if controller configuration software is current release.	**9–10**
Good	Software in controller(s) fully controls the plant, but does not have optimized supervisory control. It can however be operated remotely from a central control. Score 7 if it meets above. Add 1 if controller configuration software is current release.	**7–8**
Fair	Software in controller(s) fully controls the plant, but does not have optimized supervisory control and it cannot be operated remotely from a central control. Score 5 if it meets above. Add 1 if controller configuration software is current release.	**5–6**
Poor	Software in controller(s) has limited control functionality. Its primary function is monitoring with little control. Software is not obsolete.	**2–4**
Unacceptable	Software in controller(s) has limited control functionality. Its primary function is monitoring with little control. Software is obsolete. Also score a 0 if source configuration software is missing.	**0–1**

Chart 7 Software Implementation: HMI (Human Machine Interface)		
Condition Description		**Score**
Excellent	The HMI has access to all control points. The HMI is easy to navigate and read. The operator is comfortable with the HMI. The vendor software is at a current release version or at a version supported by the vendor. The alarms are optimized. The alarms have clear information for operator action. The sequence of events (first out alarms) are clear and quick to access.	**9–10**
Good	The HMI has access to all control points. The HMI is easy to navigate and read. The operator is comfortable with the HMI. The vendor software is at a current release version or at a version supported by the vendor. The alarms are not optimized. There is a sequence of events alarm.	**7–8**
Fair	The HMI has access to all control points. The HMI may not be easy to read or navigate. The operator may not be comfortable with the HMI or the vendor software is not at a current release version or at a version supported by the vendor. The alarms are not optimized. There is no sequence of events alarm.	**5–6**
Poor	The HMI has access to most control points. The HMI may not be easy to read or navigate. The operator may not be comfortable with the HMI or the vendor software is not at a current release version or at a version supported by the vendor. The displays or alarms are out of date. There are many points that are not valid or not functioning. The alarms are not optimized.	**2–4**
Unacceptable	The HMI and alarming are minimal.	**0–1**

Chart 8 Software Implementation: Data Server or SCADA		
Condition Description		Score
Excellent	The software is a current release version and the PC has a currently vendor supported operating system. All points (via a driver or directly) are available. All alarm points are accurately defined. Tags or points are accurately described. Data is fast(minimal lag time, average less than 1 s to an HMI and/or output to a controller)	9–10
Good	The software is a current release version and the PC has a currently vendor supported operating system. All points (via a driver or directly) are available. All alarm points may not all be accurately defined. Tags or points may not all be accurately described. Data is fast (minimal lag time to an HMI and/or output to a controller).	7–8
Fair	The software may be an older release version though the PC has a currently vendor supported operating system. All points (via a driver or directly) are available. All alarm points may not all be accurately defined. Tags or points may not all be accurately described. Data is slow (lag time to an HMI and/or output to a controller is high >1 s).	5–6
Poor	The software and/or the operating system may be obsolete. All points (via a driver or directly) may not be available. All alarm points may not all be accurately defined. Tags or points may not all be accurately described. Data rate may be acceptable.	2–4
Unacceptable	The software and/or the operating system may be obsolete. All points (via a driver or directly) may not be available. All alarm points may not all be accurately defined. Tags or points may not all be accurately described. Data rate is unacceptable.	0–1

Chart 9 Software Implementation: LAN: Process Control Network		
Condition Description		**Score**
Excellent	Managed switches are configured to optimize communications. Firewall and/or DMZ is programmed to protect the network. Bandwidth is optimized if there is high volume. Network diagnostics are available to the operator and/or to central control.	**9–10**
Good	Managed switches are configured to optimize communications. Firewall and/or DMZ is programmed to protect the network. Bandwidth is optimized if there is high volume. There is little network diagnostics available to the operator and/or to central control.	**7–8**
Fair	Managed or unmanaged switches are used and with no configuration. Firewall and/or DMZ is programmed to protect the network. There is little network diagnostics available to the operator and/or to central control.	**5–6**
Poor	Managed or unmanaged switches are used with no configuration and no diagnostic capability of any kind. Firewall and/or DMZ are minimal.	**2–4**
Unacceptable	No networking at all. Each unit is unique and there are no communications.	**0–1**

Chart 10 Software Implementation: Historical Archiving & Reporting		
Condition Description		**Score**
Excellent	The software is a current version and easily used. Data can be accessed that is several years old to compare to current operations. Excellent reporting capabilities. Data is available at both central control and the local operator.	**9–10**
Good	The software is a current version and easily used. Data can be accessed that is several years old to compare to current operations. Data is not widely available as archiving is only in one location.	**7–8**
Fair	The software may be an older version and no longer vendor supported. Data can be accessed that is several years old to compare to current operations. Data may not be widely available as archiving may only in one location.	**5–6**
Poor	The software may be an older version and no longer vendor supported. Data can NOT be accessed that is several years old to compare to current operations. Data may not be widely available as archiving may only in one location.	**2–4**
Unacceptable	There is no historical archiving.	**0–1**

Chart 11Security: PLC or RTU or Controller		
Condition Description		Score
Excellent	Controller is protected from unauthorized access by a strong password and/or key switch. The controller is physically secured in a locked room or cabinet. All ports and services are minimized where there are Ethernet communications.	**9–10**
Good	Controller is protected from unauthorized access by a strong password and/or key switch. The controller may be easily physically accessed. All ports and services may not be minimized where there are Ethernet communications.	**7–8**
Fair	Controller is protected from unauthorized access by a strong password and/or key switch. The controller may be easily physically accessed. All ports and services have not been tested where there are Ethernet communications.	**5–6**
Poor	Controller is protected from unauthorized access by password only. The passwords are easily guessed. The administrative password is still the default vendor password. The controller may be easily physically accessed. All ports and services have not been tested where there are Ethernet communications.	**2–4**
Unacceptable	There is no observable nor documented security of the controller.	**0–1**

Chart 12 Security: HMI (Human Machine Interface)		
Condition Description		**Score**
Excellent	The computer has all anti-virus, software patches, operating system and vendor security patches at current released versions. The computer is accessed via a strong password. There are no default administrator passwords. Ports and services have been evaluated and minimized. The computer runs in an operator mode—never in an administrator mode.	**9–10**
Good	The computer has all anti-virus, software patches, operating system and vendor security patches at current released versions. The computer is accessed via a strong password. There are no default administrator passwords. Ports and services have NOT been evaluated and minimized. The computer runs in an operator mode—never in an administrator mode.	**7–8**
Fair	The computer may not have all anti-virus, software patches, operating system and vendor security patches at the current released versions. The computer may be accessed with an easily guessed password. There are no default administrator passwords. Ports and services have NOT been evaluated and minimized.	**5–6**
Poor	The computer may not have all anti-virus, software patches, operating system and vendor security patches at the current released versions. The computer may be accessed with an easily guessed password. Administrator password defaults are still intact. Ports and services have NOT been evaluated and minimized. The computer may run in administrator mode.	**2–4**
Unacceptable	There appears to be little security enabled or poorly updated.	**0–1**

Chart 13 Security: Data Server or SCADA		
Condition Description		Score
Excellent	The computer has all anti-virus, software patches, operating system and vendor security patches at current released versions. The computer is accessed via a strong password. There are no default administrator passwords. Ports and services have been evaluated and minimized. The computer runs in an operator mode—never in an administrator mode. Image backups are made on a regularly scheduled basis.	**9–10**
Good	The computer has all anti-virus, software patches, operating system and vendor security patches at current released versions. The computer is accessed via a strong password. There are no default administrator passwords. Ports and services have NOT been evaluated and minimized. The computer runs in an operator mode—never in an administrator mode. Image backups are made on a regularly scheduled basis.	**7–8**
Fair	The computer may not have all anti-virus, software patches, operating system and vendor security patches at the current released versions. The computer may be accessed with an easily guessed password. There are no default administrator passwords. Ports and services have NOT been evaluated and minimized. Image backups are made on a regularly scheduled basis.	**5–6**
Poor	The computer may not have all anti-virus, software patches, operating system and vendor security patches at the current released versions. The computer may be accessed with an easily guessed password. Administrator password defaults are still intact. Ports and services have NOT been evaluated and minimized. The computer may run in administrator mode. There may not be image backups.	**2–4**
Unacceptable	There appears to be little security enabled or poorly updated.	**0–1**

Chart 14 Security: LAN: Process Control Network		
Condition Description		Score
Excellent	All LAN device(s) configuration is protected by a strong password. The firewall and other LAN devices that support syslogs have logs sent to a syslog server and the logs are regularly evaluated. There are no default passwords on any device.	**9–10**
Good	All LAN device configuration is protected by a strong password. There may not be any network logging. There are no default passwords on any device.	**7–8**
Fair	LAN device configuration is protected by an easily guessed password. There may not be any network logging. There are no default passwords on any device.	**5–6**
Poor	LAN device configuration is protected by a simple to guess password. There may not be any network logging. Default passwords may be on a device.	**2–4**
Unacceptable	There appears to be little security enabled or poorly updated.	**0–1**

Chart 15 Security: Historical Archiving & Reporting		
Condition Description		**Score**
Excellent	The computer has all anti-virus, software patches, operating system and vendor security patches at current released versions. The computer is accessed via a strong password. There are no default administrative passwords. Ports and services have been evaluated and minimized. The computer runs in an operator mode—never in an administrator mode. Image backups are made on a regularly scheduled basis. Tapes or disks are made regularly of historical data and saved in a secure storage.	**9–10**
Good	The computer has all anti-virus, software patches, operating system and vendor security patches at current released versions. The computer is accessed via a strong password. There are no default administrative passwords. Ports and services have NOT been evaluated and minimized. The computer runs in an operator mode—never in an administrator mode. Image backups are made on a regularly scheduled basis. Tapes or disks are made regularly of historical data and saved in a secure storage.	**7–8**
Fair	The computer may not have all anti-virus, software patches, operating system and vendor security patches at the current released versions. The computer may be accessed with an easily guessed password. There are no default administrative passwords. Ports and services have NOT been evaluated and minimized. Image backups are made on a regularly scheduled basis.	**5–6**
Poor	The computer may not have all anti-virus, software patches, operating system and vendor security patches at the current released versions. The computer may be accessed with an easily guessed password. Administrative passwords defaults are still intact. Ports and services have NOT been evaluated and minimized. The computer may run in administrator mode. There may not be image backups.	**2–4**
Unacceptable	There appears to be little security enabled or poorly updated.	**0–1**

Chart 16 Hardware Assessment: Condition Monitoring		
Condition Description		Score
Excellent	All or the majority of the following items are installed: Turbine: 2-axis guide bearing vibration, guide bearing temperature, draft tube vibration, speed, seal ring position, wicket gate position. Generator: air gap, 2-axis guide bearing vibration, guide bearing temperatures, thrust bearing oil film thickness, end winding vibration, core vibration, stator frame vibration, thrust bearing pad vibration, thrust bearing pad temperatures, generator winding temperatures, partial discharge probes, and cooling water flow. All signals wired back to a control system.	**9–10**
Good	Majority of the above items are installed, but does not have partial discharge analysis: All signals wired back to a control system.	**7–8**
Fair	Majority of the above items are installed, but does not have partial discharge analysis and/or does not have all signals wired back to a control system:	**5–6**
Poor	Only some of the above items are installed and/or does not have all signals wired back to a control system:	**2–4**
Unacceptable	There is minimal amount of the above installed and not wired back to a control system.	**0–1**

Chart 17 Software Implementation: Condition Monitoring		
Condition Description		Score
Excellent	The probes are installed as listed in the hardware implementation. The control system will automatically trip on all abnormal conditions including partial discharge analysis.	**9–10**
Good	The probes are installed as listed in the hardware implementation. The control system will automatically trip on all abnormal conditions but does not have partial discharge analysis.	**7–8**
Fair	The probes are installed as listed in the hardware implementation. The control system will automatically trip on some abnormal conditions and requires operator decision making on some abnormal conditions.	**5–6**
Poor	The probes are installed as listed in the hardware implementation. The control system does not automatically trip on abnormal conditions. The probes that are installed are viewable on the HMI.	**2–4**
Unacceptable	The probes are installed as listed in the hardware implementation. The control system does not automatically trip on abnormal conditions. The probes that are installed are NOT viewable on the HMI.	**0–1**

Chart 18 Security: Condition Monitoring		
Condition Description		**Score**
Excellent	The probes are installed as listed in the hardware implementation. The condition monitoring system (usually separate from the controller) is on a protected network or isolated from the network by hard wires back to a control system. The vibration system is protected from accidental configuration changes by a key or a strong password.	**9–10**
Good	The probes are installed as listed in the hardware implementation. The condition monitoring system (usually separate from the controller) is on a protected network or isolated from the network by hard wires back to a control system. The vibration system is NOT protected from accidental configuration changes by a key or a strong password.	**7–8**
Fair	NA	**5–6**
Poor	The probes are installed as listed in the hardware implementation. The condition monitoring system (usually separate from the controller) is NOT on a protected network and NOT isolated from the network by hard wires back to a control system. The vibration system is protected from accidental configuration changes by a key or a strong password.	**2–4**
Unacceptable	The probes are installed as listed in the hardware implementation. The condition monitoring system (usually separate from the controller) is NOT on a protected network and NOT isolated from the network by hard wires back to a control system. The vibration system is NOT protected from accidental configuration changes by a key or a strong password.	**0–1**

Data Quality: Rating Criteria for Automation System Parts

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of Automation System components are developed in Chart 19.

Chart 19 Automation System Data Quality Rating Criteria		
Condition Description		Score
High	1.) Vendor or plant configuration documentation at the site or at engineering is excellent including all security and able to physically see all components. 2.) Able to view controller, HMI, SCADA in real time for data-CPU loading, tags, memory etc. where practical. This data can be obtained from local support if they can provide the documentation without going online. Condition monitoring viewable in real time. LAN analysis documentation or real time analysis is demonstrated. Historical data is viewable. 3.) Local engineering or tech support available at the site while doing the assessment to document or verbally confirm all items. They can also confirm off-site questions. 4.) Vendor online tech support via web or phone to confirm items for current offerings and current support levels.	8–10
Medium	Unable to have all 4 items above (where applicable), but a high level of confidence in the accuracy of the data.	5–7
Low	Unable to have 2 or more items above (where applicable). Made some assumptions on the system without firm documentation or plant confirmation or vendor confirmation.	3–4
Poor	Limited or no vendor documentation. No local engineering support available to confirm and no online verification able to be performed.	0–2

Chart 20 Instruments for Unit Performance Measurement: Physical Condition Rating Criteria		
Physical Condition Rating Scale		Physical Condition Score
Excellent	No noticeable defects. Some aging or wear may be noticeable. Display is easy to read and in a visible location for the operator. Clean and clear faceplate—either analog or digital. Pointer condition and indication is correct for operating point.	**9–10**
Very good	Only minor deterioration or defects are evident, and is fully functional.	**7–8**
Good	Some deterioration or defects are evident, but function is not significantly affected.	**5–6**
Fair	Only moderate deterioration and function is still adequate. The unit efficiency may be affected.	**3–4**
Poor	Serious deterioration in at least some portions, function is inadequate, unit efficiency or availability significantly affected. Meter is in a poor location for the operator.	**2**
Very poor	Extensive deterioration. Barely functional.	**1**
Failed	No longer functions, may cause failure of a major component.	**0**

Chart 21 Instruments for Unit Performance Measurement: Age Rating Criteria	
Ages of the Metering Components	Age Score
<5 years	**10**
5–10 years	**8–9**
11–15 years	**6–7**
16–20 years	**4–5**
21–25 years	**2–3**
26–35 years	**0–1**

Chart 22 Instruments for Unit Performance Measurement: Technology Rating Criteria	
Technology Levels of the Components/Items	**Score for Installed Technology Level**
The technology has not changed significantly since the part was installed; and the installed technology was supplied by brand name companies with great reputations. Has digital or high resolution[1] inputs and displays.	**8–10**
The technology has been more or less advanced but no problem is foreseen to supply the matching parts in next 5–10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may be less than the cost of replacement). The installed technology was supplied by medium companies with good reputations.	**4–7**
The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability of power generation. The installed technology was supplied by small companies with bad reputations.	**0–3**

*1: Low resolution inputs use 12 bit Analog to Digital converters. High resolution inputs are 13 bit or higher or use digital (serial) inputs. Older mechanical systems that do not have electrical feedback or metering should still have vendor support for a high ranking.

Chart 23 Instruments for Unit Performance Measurement: Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes and the original metering design has no constraints on the required operation.	**8–10**
The design standard has no changes and the original metering design has no constraints on the required operation. Newer technology offers more options that could be useful to the operation.	**5–7**
Moderate restraints: The quality of the data may be suspect. Newer technology offers better quality, but the system still functions with the known limitations.	**3–4**
Severe limitations: The data quality is unknown or highly suspect. Operations may be required at times to use alternate methods that may bypass the meter reading to verify values.	**0–2**

Chart 24 Instruments for Unit Performance Measurement: Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum level (normal condition): A small amount of routine recalibration or verification of data is required.	**9–10**
Low level: A small amount of routine recalibration or verification of data is required. Repairs could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis.	**7–8**
Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages is required (e.g., faulty signals, rewiring).	**4–6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., failed instruments, faulty wiring, hard wired trips fail to function).	**0–3**

Data Quality: Rating Criteria for Instruments for Unit Performance Measurement (Metering)

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of Instruments for Unit Performance Measurement components are developed in Chart 25. Note the scoring method is different from Chart 19 for Automation System.

Chart 25 Instruments for Unit Performance Measurement: Data Quality Rating Criteria	
Data Availability, Integrity, and Accuracy	**Data Quality Score**
High: The metering maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurement were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8–10**
Medium: One or more of routine inspections, tests and measurement were completed 6–24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5–7**
Low: One or more of routine inspections, tests and measurement were completed 24–36 months past the normal frequency, or some of results are not available.	**3–4**
Very Low: One or more of required inspections, tests and measurement were completed >36 months past the normal frequency, or significant portion of results are not available.	**0–2**

6.0 I&C SYSTEM CONDITION AND DATA QUALITY INDICATORS

In Table M-1, the final condition score of the Automation System (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI(1) = \frac{\sum_{K=1,M}^{J=1,3} S_C(K,J)\times F(K)\times F(J)}{\sum_{K=1,M}^{J=1,3} F(K)\times F(J)} \qquad (1)$$

The I&C for Automation Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated components:

$$DI(1) = \frac{\sum_{K=1,M} S_D(K)\times F(K)}{\sum_{K=1,M} F(K)} \qquad (2)$$

Here, M = the total number of components associated with an Automation System; K = the identification No. of automation components (from 1 to M); J = the identification No. of condition parameters (from 1 to 3, respectively for hardware, software and security); $S_C(K, J)$ = the condition score of an Automation System component for one of 3 condition parameters; $S_D(K)$ = the data quality score for a component; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a component.

In Table M-2, the final condition score of the Instruments for Unit Performance Measurement (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI(2) = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J)\times F(K)\times F(J)}{\sum_{K=1,M}^{J=1,5} F(K)\times F(J)} \quad (3)$$

The I&C for Automation Metering Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated components:

$$DI(2) = \frac{\sum_{K=1,M} S_D(K)\times F(K)}{\sum_{K=1,M} F(K)} \quad (4)$$

Here, M = the total number of components associated with Instruments for Unit Performance Measurement; K = the identification No. of metering components (from 1 to M); J = the Identification No. of condition parameters (from 1 to 5, respectively for physical condition, age, installed technology, operating restrictions and maintenance requirements);$S_C(K, J)$ = the condition score of an Automation Metering component for one of 5 condition parameters; $S_D(K)$ = the data quality score for a component; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a component.

The overall I&C system *CI* will be weighted summation from automation and metering:

$$CI = CI(1) \times 0.8 + CI(2) \times 0.2 \quad (5)$$

The overall I&C system *DI* will be

$$DI = DI(1) \times 0.8 + DI(2) \times 0.2 \quad (6)$$

7.0 REFERENCES

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AUTOMATION SYSTEM CHECKLIST AND INSPECTION FORM

REVISION 1.0, 1/11/2012

Automation System: Inspection Form

General Information:
Date of Site Visit: ____________________ Units: ____________________
Plant name: ____________________
Source/s of data: ____________________

Control System Description: (Include any advanced controls such as supervisory and/or central control)

Maintenance History / Major Upgrades or Installation Description:

PLC(s), RTU(s) and/or Controller(s):(The term "controller" to be used interchangeably for PLC, RTU or Controller)
Physical location: ____________________ Description: ____________________
Controller Model: ____________________ FW Version: __________
Memory & CPU and % used: ____________________
Qty of this model: __________ Approx. Age of this model: __________ Redundant: Y / N
Configuration Software: ____________________ SW Version: __________
Quantity of tags, I/O, communications or other hardware or license limitations (and % used if applicable)

Communication Interfaces on CPU (Include protocol such as Ethernet, serial, Profibus, Modbus+, DN3, proprietary etc. Note what devices are on the other end of the communications. Note the number of ports on the CPU and note if they are used. If the software driver(s) is known, note that too.)
Port: __________ Protocol: ____________________ Connected to: ____________________
Port: __________ Protocol: ____________________ Connected to: ____________________
Port: __________ Protocol: ____________________ Connected to: ____________________
Additional CPU Port info: ____________________
Communication Interfaces other than CPU (Include protocol and connected devices as above)
Interface model: ____________________ # of Ports: __________
Protocol(s): ____________________

Connected device(s) to communications port(s): ____________________

Interface model: ____________________ # of Ports: __________
Protocol(s): ____________________

Connected device(s) to communications port(s): ____________________

Interface model: ____________________ # of Ports: __________

Protocol(s):____

Connected device(s) to communications port(s):____

(Controller continued)
I/O Modules: ____

CPU Power Supply(s): ______________________________ Redundant: **Y / N** Redundant source: **Y / N**
I/O Racks Power Supply(s): __________________________ Redundant: **Y / N** Redundant source: **Y / N**
Brief description of controlled processes: ____

General physical condition of controller and its components. Capable of expanding control w/o upgrade?

Additional controller information such as current vendor release versions and vendor support:

<u>HMI (Human Machine Interface):</u>
Physical location:_____________________________ Description:_______________________________
Computer Model: ____ Version: _______________
Memory/CPU and other info: ____
Qty of this model: __________________ Approx. Age of this model: _____________ Redundant: **Y / N**
HMI Software: ____ SW Version: ___________
HMI Software last update**:** ____
Operating System: ____ OS Version: ___________
Anti-virus Version: ______________________ Last update: ______________ Updated regularly: **Y / N**
OS patches last update: _______________ Updated regularly**: Y / N**
Ports and Services evaluated: **Y / N** Last date ports and services were evaluated: _______________
Default passwords for OS deleted: **Y / N** Default passwords for HMI software deleted: **Y / N**
Does the HMI run under an OS administrator account: **Y / N**
Ethernet Communications or Serial Communications
Interface model: ____
Protocol(s):____
Connected device(s) to communications port(s):____
Interface model: ____
Protocol(s):____
Connected device(s) to communications port(s):____
Compare to current version of the OS and to the currently available HMI software. Indicate any limitations in the HMI software such as obsolescence, points that can be accessed, ease of use etc.

General physical condition of the HMI and its components:

Additional HMI information:

Data Server or SCADA:(The term server will be used to represent either in this list)
Physical location:______________________________Description:________________________________
Computer Model: ____ Version: _______________
Memory/CPU and other info: ____
Qty of this model: __________________ Approx. Age of this model: _____________ Redundant: **Y / N**
Server Software: ____ SW Version: ___________
Server Software last update: ____
Server points, tags or other license restrictions: ____
Operating System: ____ OS Version: ___________
Anti-virus Version: ______________________ Last update: ______________ Updated regularly: **Y / N**
OS patches last update: _______________ Updated regularly**: Y / N**
Ports and Services evaluated: **Y / N** Last date ports and services were evaluated: _______________
Default passwords for OS deleted: **Y / N** Default passwords for Server software deleted: **Y / N**
Does the Server run under an OS administrator account: **Y / N**
Ethernet Communications or Serial Communications to the Server
Interface model: ____
Protocol(s) and/or Driver(s): ____
____
Connected device(s) to communications port(s):____
Interface model: ____
Protocol(s) and/or Driver(s): ____
____
Connected device(s) to communications port(s):____
Interface model: ____
Protocol(s):____
____
Connected device(s) to communications port(s):____
____

Compare to current version of the OS and to the currently available Server software. Indicate any limitations in the Server software such as obsolescence, points that can be accessed, ease of use etc.
____
____
____
____
____
____
____
____

General physical condition of the Server and its components:
____
____
____
____

Additional Server information:
____
____
____
____
____

Process Control Ethernet LANs:

Are there two or more separate Ethernet LANs? **Y / N** If yes, start with the primary control LAN.

If only one LAN, then fill in primary control LAN. Secondary LANs are assumed to be I/O LANs.

Primary Control LAN (controller to controller and/or controller to server/SCADA communications)

Redundant network: **Y / N** Ring network: **Y / N** Flat network (no ring, no redundancy): **Y / N**

Router: **Y / N** Model: ___________________________ Connects to: ___________________________

Does the primary control LAN connect to a business network: **Y / N** (firewall in separate section)

Network Switches: (include model, number of ports, managed or unmanaged and qty)

____

____

____

____

Additional Primary LAN data:

____

____

____

Secondary Control LAN(s) (I/O to controller and/or to 3rd party devices)

Redundant network: **Y / N** Ring network: **Y / N** Flat network (no ring, no redundancy): **Y / N**

Router: **Y / N** Model: ___________________________ Connects to: ___________________________

Does the secondary control LAN connect to a business network: **Y / N** (firewall in separate section)

Network Switches: (include model, number of ports and qty)

____

____

____

____

Additional Secondary LAN data:

____

____

____

____

____

____

Ethernet Firewall(s):

Primary Control LAN Firewall

Model Number: ____ Version/Firmware: ______________

Age of Unit: _____________ Configuration software available to be reviewed: **Y / N**

Is the unit frequently updated with current patches or revision levels: **Y / N**

Encryption used: **Y / N** If using encryption, what method is used: ______________________________

Who maintains the firewall and configures it? Give a brief history of its configuration and maintenance:
____
____
____

Secondary LAN Firewall (if used)
Model Number: ______________________________________ Version/Firmware: ____________
Age of Unit: ___________ Configuration software available to be reviewed: **Y / N**
Is the unit frequently updated with current patches or revision levels: **Y / N**
Encryption used: **Y / N** If using encryption, what method is used: ___________________________
Who maintains the firewall and configures it? Give a brief history of its configuration and maintenance:
____
____

Wireless LAN(if used—security is built into the unit)
Model Number: ______________________________________ Version/Firmware: ____________
Age of Unit: ___________ Configuration software available to be reviewed: **Y / N**
Is the unit frequently updated with current patches or revision levels: **Y / N**
What security is used with the wireless LAN: _________________________
Who maintains the wireless devices and configures them? Give a brief history of its configuration and maintenance and what is monitored or controlled via wireless:
____
____
____
____

<u>GPS Clock</u>(time clock dedicated to the control system)
Model Number: ____ Age: __________
Describe the source of the clock and where it is used in the control system (e.g., PCs, controllers, SOE)
____
____
____
____

<u>Historical Archive</u>(long term data storage)
Software used: __________________________________ Version: ________________________
Computer hardware used: ____
Describe the hardware redundancy (if any, such as RAID) and backups to storage: _________________
____
____
How does the operator use historical data: ____
____

Alarming(process alarms)
Software used: ______________________________________ Version: ___________________________
Third party software alarm optimization: **Y / N**: ____
How many alarms per hour per operator (weekly or daily average): ___________
What percentage of the alarms are actionable by the operator: ____________
Do the alarms appear optimized in that there are minimal to no nuisance alarms: **Y / N**
Is there a sequence of events or first out indication for the operator on key items: **Y / N**
How are the first out or sequence events viewable by the operator:______________________________
____
____
Are alarms used for determining maintenance and if so, how: ___________________________________
____
Have all the alarms been verified and tested as accurate: _______________________________________
How does the operator use alarm data: ____
____
____

Machine Condition Monitoring
Turbine Probes
Guide Bearing 2-axis vibration: **Y / N**Mfg.__________Connected to AS (Automation System): **Y / N**
Comments:____
Guide Bearing temperature: **Y / N** Mfg.______________________________ Connected to AS: **Y / N**
Comments:____

Draft Tube Vibration (or head cover): **Y / N** Mfg.________________________ Connected to AS: **Y / N**
Comments:____

Speed (Keyphasor): **Y / N** Mfg.______________________________ Connected to AS: **Y / N**
Comments:____

List other Turbine probes

Type: _________________________________ Mfg. ______________________ Connected to AS: **Y / N**

Comments:____

Type: _________________________________ Mfg. ______________________ Connected to AS: **Y / N**

Comments:____

Type: _________________________________ Mfg. ______________________ Connected to AS: **Y / N**

Comments:____

Type: _________________________________ Mfg. ______________________ Connected to AS: **Y / N**

Comments:____

<u>Machine Condition Monitoring</u>
Generator Probes
Guide Bearing 2-axis vibration: **Y / N** Mfg.______________________________ Connected to AS : **Y / N**
Comments:____
Guide Bearing temperatures: **Y / N** Mfg.________________________________ Connected to AS: **Y / N**
Comments:____

Air Gap: **Y / N** Mfg.____ Connected to AS: **Y / N**
Comments:____

Thrust Bearing Oil Film Thickness: **Y / N** Mfg.__________________________ Connected to AS: **Y / N**
Comments:____

End Winding Vibration: **Y / N** Mfg.________________________________ Connected to AS: **Y / N**
Comments:____

Core Vibration: **Y / N** Mfg.________________________________ Connected to AS: **Y / N**
Comments:____

Stator Frame Vibration: **Y / N** Mfg.________________________________ Connected to AS: **Y / N**
Comments:____

Thrust Bearing Pad Vibration: **Y / N** Mfg.________________________________ Connected to AS: **Y / N**
Comments:____

Thrust Bearing Temperature: **Y / N** Mfg.________________________________ Connected to AS: **Y / N**
Comments:____

Generator Winding Temperature: **Y / N** Mfg.______________________________ Connected to AS: **Y / N**
Comments:____

Partial Discharge Probe: **Y / N** Mfg.______________________________ Connected to AS: **Y / N**
Comments:____

Cooling Water Flow: **Y / N** Mfg.______________________________ Connected to AS: **Y / N**
Comments:____

List other Generator probes

Type: ___________________________________ Mfg. ________________________ Connected to AS: **Y / N**

Comments:____

Type: ___________________________________ Mfg. ________________________ Connected to AS: **Y / N**

Comments:____

Type: ________________________________ Mfg. ______________________ Connected to AS: **Y / N**

Comments:____

Type: ________________________________ Mfg. ______________________ Connected to AS: **Y / N**

Comments:____

Automation Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
PLC or RTU or Controller: Hardware, Software and Security: List 1/2 Term controller used to represent any of the 3 items				
Controller: Hardware version documented				
Controller: Currently supported vendor hardware				
Controller: CPU and memory loading. Sufficient CPU and memory available for controls upgrade. Scan cycle < 100 ms.				
Controller: CPU has capability for expansion for more I/O for controls upgrade.				
Controller: CPU tags, I/O or other similar license limits investigated. Note limitations if any.				
Controller: Can be configured, without a major upgrade, to a supervisory control system with automatic remote efficiency set points.				
Controller redundant. Note which controllers are redundant.				
Redundant power to controllers.				
Redundant power supplies on CPU rack (if applicable).				
Controller(s) configured to fully operate plant in supervisory mode.				
Controller configuration software is latest release.				
If there is compiled code in the controller, all the source code is available.				
The plant can operate in local automatic mode and can be accessed remotely for some automatic control.				

Automation Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
PLC or RTU or Controller (Hardware, Software and Security) List 2/2 Term controller used to represent any of the 3 items				
Configuration backups are performed regularly, kept secure and additional backups are stored at a secure off-site repository.				
Controllers are protected by strong passwords or in a locked mode by a key or switch to keep someone from being able to download an unauthorized configuration.				
Controllers default passwords have been disabled or changed to strong passwords.				
Controllers are physically secure. Protected physical access.				
Controller Ethernet communications have been checked for ports and services. No unneeded services are running. The ability to browse the controller is disabled or at minimum requires a strong password.				
All wireless communications are secure if wireless I/O communications are installed.				

Automation Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
HMI (Human Machine Interface): Hardware, Software and Security: List 1/1				
Easy to navigate the interface. Operator is comfortable using the HMI.				
Clear graphical diagnostic tools to scan system integrity for controllers, I/O and network LAN.				
The amount of tags and graphics the HMI can support has been verified for the current version. Indicate values or limitations.				
The support and current release version of the HMI has been investigated. Indicate any issues.				
The amount of tags and graphics the HMI can support will support a move to a fully automated system.				
Grayscale graphics are used as described in automation best practices. Not critical.				
All HMI computers run under user accounts with strong passwords. No administrator accounts are used for normal operations. There are no easy to guess passwords.				
All HMI computers are current with anti-virus and software patches.				
All HMI computers on the network have minimized the ports and services to only those that are required and these are kept to the minimum by a scheduled verification of at least once per year.				
Alarming has been optimized in that operator actions in response to alarms are clearly defined and actionable.				
All HMI computers are running a currently supported operating system.				

Automation Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Data Server or SCADA: Hardware, Software and Security: List 1/1				
Software Drivers to controllers, I/O or other devices are responsive. HMI to device response <1 s.				
The amount of tags, graphics and communications to devices the Server can support, has been verified for the current version. Indicate any limitations.				
The support and current release version of the Server software has been investigated. Indicate any issues.				
The amount of tags and graphics the Server can support will support a move to a fully automated system.				
Servers are running a currently supported operating system.				
All Servers run under user accounts with strong passwords. No administrator accounts are used for normal operations. There are no easy to guess passwords.				
All Servers are current with anti-virus and software patches.				
All Servers on the network have minimized the ports and services to only those that are required and these are kept to the minimum by a scheduled verification of at least once per year.				

Automation Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
LAN- Process Control Network: Hardware, Software and Security: List 1/1				
Redundant LAN or network ring that minimizes a single point of failure.				
A firewall is installed if there is a connection to a business network or to the Internet. Firmware/software patches are current.				
All LAN device configurations (such as firewalls and managed switches) are protected by strong passwords.				
Switches and other devices on the network are current firmware and supported by the vendor.				
Syslogs are created and stored for all devices that support logging and are reviewed regularly.				
Bandwidth is optimized for high data volume systems through switch configuration or other network tools.				
Network diagnostics are readily available to the operator.				
There are no dual honed connections to the business network or to the Internet from a computer connected to the process control LAN. (i.e., a computer which has multiple LAN connections of which one is to the Process Control Network.)				

Automation Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Historical Archiving and Reporting: Hardware, Software and Security: List 1/1				
Historical archiving software is a current version and vendor supported. Indicate limitations.				
Tags are archived for easy retrieval for the past several years.				
The number of tags that can be stored for long term (> 2years) is sufficient per the license. Indicate limitations.				
The operating system is current and all patches and anti-virus are installed. Indicate limitations.				
Alarming is optimized and recorded for long term analysis. Indicate limitations.				
Historical files are backed up and stored off-site on a regular basis.				
Historical data is available at central control, engineering and to the local operators.				
A GPS clock is used to synchronizes alarms and controllers.				

Automation Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Machine Condition Monitoring				
Verified all condition monitoring probes in the field as practical.				
Verified which probes are connected to the control system.				
Verified which probes (primarily vibration and temperature) are used to automatically trip the unit.				
Is there communications from the condition monitoring system to the control system. If so, comment on type of communications.				
Verified security method of condition monitoring system.				
Advanced control, such as partial discharge, used in the control system.				
Condition monitoring data is stored in long term historical archive for analysis.				

Automation Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Instruments for Unit Performance Measurement - Metering				
Verified calibration data and maintenance records on all meters where practical.				
Verified HMI data values match meter displayed values or checked with operators who are experienced with both.				
Verified communications protocols where applicable.				
Checked quality of wiring and mounting where practical and time allowed. (optional)				
Documented model numbers and age of the meters where practical.				

Automation System Data Collection Sheet	
Topic	**Data Input**

Additional help in evaluation of systems:

This is important for security patches and upgrades. Windows XP SP 3 is the oldest operating system that continues to be supported (as of December 2011). Older XP service packs (service pack 1 or 2) are no longer supported. Windows is 2000 obsolete. The following tables are helpful in evaluation of operating systems:

Windows XP	Support end date	Comments
No service pack	Sept. 2004	Obsolete product
SP 1	Oct. 2006	Obsolete product
SP 2	Jul. 2010	Obsolete product
SP 3 & 4	Apr. 2014	Currently on extended support. All support ends in 2014. Recommended to move to Windows 7 or Windows 2008 Server or newer before 2014.

Windows Vista	Support end date	Comments
Versions < SP2	Apr. 2012	Obsolete product after Apr. 2012
SP 2	Apr. 2017	Will go to extended support after Apr. 2012. All support ends in 2017. There are few control systems that use Windows Vista.

Windows 2003	Support end date	Comments
All versions < SP2 or does include R2	2009	Obsolete product
SP 2 and R2	Jul. 2015	Currently on extended support. All support ends in 2015. Recommended to move to Windows 7 or Windows 2008 Server or newer before 2015.

The only reason, in many cases, to upgrade the operating system is for security to install the current anti-virus and operating system patches. Upgrading the operating system does not necessarily improve efficiency. Windows 7 is currently expected to be on extended support already in 2015. This is a serious challenge for automation systems. Every few years a major service pack must be installed and/or the operating system must be updated to the newest version. The computer hardware currently in service may not be able to support the operating system upgrade and/or the vendor software may not work with the latest Windows version. The automation system assessment is complex and can be

highly subjective when taking into account obsolescence. Vendors usually have support contracts with Microsoft and other suppliers for extended support as it is difficult for vendors to constantly change their software to keep up with the constant operating system changes. The automation vendor support and its supplier agreements are a significant factor in the assessment.

INSTRUMENTS & CONTROLS SYSTEM INSPECTION FORM AND CHECKLIST

REVISION 1.0, 1/11/2012

Instruments for Unit Performance Measurement (metering): Inspection Form

General Information:
Date of Site Visit: ________________________________ Units: ____________________________
Plant name: ____
Source/s of data: ____
____
____
General Summary (include governor type—digital or mechanical)
Metering and Instrumentation Types: (e.g., multi-function, digital, analog, communication protocols)
____
____
____
____
____
____
____
____
____
____
____
____
____
____
____

Generator Voltmeters:
Phase A
Physical location: ____
Description: ____
Number of meters: ______ Selector switch: **Y / N** Approx. Age: ______________
Model: ______________________ Serial #: Type: _____________________
Calibration Date: __________________ Calibration Data Available: **Y / N**
Condition/Comments: ____
____
Output to Controller: Analog: _____ Digital (type): ______________________________ None: _____
Phase B
Physical location: ____
Description: ____
Number of meters: ______ Selector switch: **Y / N** Approx. Age: ______________
Model: ______________________ Serial #: Type: _____________________
Calibration Date: __________________ Calibration Data Available: **Y / N**
Condition/Comments: ____
____
Output to Controller: Analog: _____ Digital (type): ______________________________ None: _____
Phase C
Physical location: ____
Description: ____
Number of meters: ______ Selector switch: **Y / N** Approx. Age: ______________

Model: ______________________ Serial #: Type: _____________________
Calibration Date: ___________________ Calibration Data Available: **Y / N**
Condition/Comments: ____
Output to Controller: Analog: _____ Digital (type): _______________________________ None: _____

Generator Ammeters:
Phase A
Physical location: ____
Description: ____
Number of meters: ______ Selector switch: **Y / N** Approx. Age: _______________
Model: ______________________ Serial #: Type: _____________________
Calibration Date: ___________________ Calibration Data Available: **Y / N**
Condition/Comments: ____
Output to Controller: Analog: _____ Digital (type): _______________________________ None: _____

Phase B
Physical location: ____
Description: ____
Number of meters: ______ Selector switch: **Y / N** Approx. Age: _______________
Model: ______________________ Serial #: Type: _____________________
Calibration Date: ___________________ Calibration Data Available: **Y / N**
Condition/Comments: ____
Output to Controller: Analog: _____ Digital (type): _______________________________ None: _____

Phase C
Physical location: ____
Description: ____
Number of meters: ______ Selector switch: **Y / N** Approx. Age: _______________
Model: ______________________ Serial #: Type: _____________________
Calibration Date: ___________________ Calibration Data Available: **Y / N**
Condition/Comments: ____
Output to Controller: Analog: _____ Digital (type): _______________________________ None: _____

Generator MW Meter:
Physical location: ____
Description: ____
Number of meters: ______ Selector switch: **Y / N** Approx. Age: _______________
Model: ______________________ Serial #: Type: _____________________
Calibration Date: ___________________ Calibration Data Available: **Y / N**
Condition/Comments: ____
Output to Controller: Analog: _____ Digital (type): _______________________________ None: _____

Generator MVAR meter:
Physical location: ____
Description: ____
Approx. Age: _______________
Model: ______________________ Serial #: Type: _____________________
Calibration Date: ___________________ Calibration Data Available: **Y / N**
Condition/Comments: ____
____
Output to Controller: Analog: _____ Digital (type): _______________________________ None: _____

Generator Field Voltmeter:
Physical location: ____
Description: ____
Number of meters: ______ Selector switch: **Y / N** Approx. Age: _______________

Model: ______________________ Serial #: Type: _____________________
Calibration Date: ___________________ Calibration Data Available: **Y / N**
Condition/Comments: ____
Output to Controller: Analog: _____ Digital (type): _______________________________ None: _____

Generator Field Ammeter:
Physical location: ____
Description: ____
Number of meters: ______ Selector switch: **Y / N** Approx. Age: _______________
Model: ______________________ Serial #: Type: _____________________
Calibration Date: ___________________ Calibration Data Available: **Y / N**
Condition/Comments: ____
Output to Controller: Analog: _____ Digital (type): _______________________________ None: _____

Wicket Gate Position Indicator:
Description: ____
Model: ______________________ Serial # Type: _____________________
Calibration Date: ___________________ Calibration Data Available: **Y / N**
Condition/comments____
____
Approx. Age of this model: _____________

Kaplan Blade Tilt Indicator:
Physical location: ______________________________ Description: ________________________________
Model: ______________________ Serial # Type: ____________________
Calibration Date: ___________________ Calibration Data Available: **Y / N**
Condition/comments____
____
Approx. Age of this model: _____________

Turbine Flow Indicator:

Physical location: ____________________________ Description: ______________________________

____

Model: _____________________ Serial # Type: _____________________

Taps locations: ____

____

Winter-Kennedy Taps: Yes: _____ No: _____ Used permanently [ ] or just for Index Testing [ ]

Calibration Date: __________________ Calibration Data Available: **Y / N**

Condition/comments____

____

Approx. Age of this model: ____________

APPENDIX N. GUIDE FOR RAW WATER SYSTEM CONDITION ASSESSMENT

REVISION 1.0, 1/18/2012

CONTENTS

1.0 GENERAL

Unforeseen failure of the raw water system can have a substantial impact on power generation and revenues due to overheating damage to critical plant system leading to forced outage. Therefore, it is important to maintain an updated condition assessment of the raw water system and plan accordingly. A raw water system condition assessment is essential to estimate the economic lifespan and potential risk of failure, and to evaluate the benefits and cost of raw water system upgrading.

For any type of raw water system, the following three step analyses are necessary to arrive at a raw water system condition indicator:

1) What parts should be included for raw water system condition assessment and which parts are more important than others (parts and their weighting factors)?

2) What metrics/parameters should be investigated for quantitative condition assessment and which ones are more important than others (condition parameters and their weighting factors)?

3) How to assign numerical scores to the raw water system (rating criteria)?

This appendix provides guides to answer the above questions, which can be applied to all raw waters systems. The condition assessment is performed on individual raw water system in a plant, because even the originally identical raw water system may have experienced different Operation & Maintenance (O&M) histories and would arrive at different values of condition indicators. Due to the uniqueness of each individual raw water system, the guides provided in this appendix cannot quantify all factors that affect individual raw water system condition. Mitigating factors not included in this guide may trigger testing and further evaluation to determine the final score of the raw water system condition and to make the decision of raw water system replacement or rehabilitation.

This appendix is not intended to define raw water system maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2.0 CONSTITUENT PARTS ANALYSIS

The raw water system includes the supply intake, strainers, pumps, valves, generator air coolers, piping and instrumentation/monitoring. If any part does not exist in particular raw water system (i.e., pumps on a high head plant), this part will be excluded from scoring mechanism by inputting "NA" into the table. The effect of one part exclusion is usually insignificant to justify any adjustment for the weighting factors of other raw water parts.

3.0 METRICS FOR RAW WATER CONDITION ASSESSMENT

As listed in Table N-1, the following five condition parameters are considered for condition assessment of raw water system parts:

- The Physical Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on the previous testing and measurements, historical O&M records, original design drawings, previous rehabilitation feasibility study reports if conducted, interviews with plant staff and some limited inspections. It is noticed that there is a certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmarking condition assessment without specific testing and measurements conducted on site, these five parameters are regarded as providing the basis for assessing the condition of raw water system parts.

In addition, the Data Quality Indicator, as an independent metric, is to reflect the quality of available information and the confidence on the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity, and any of these situations could affect the results of condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part/item to indicate the information and data availability, integrity and accuracy and the confidence on the given condition ratings (MWH 2010).

4.0 WEIGHTING FACTORS

There are two categories of weighting factors in Table N-1. It is recognized that some condition parameters affect the raw water system condition to a greater or lesser degree than other parameters; also some parts are more or less important than other parts to an entire raw water system. These weighting factors should be pre-determined by consensus among experienced hydropower mechanical engineers and plant O&M experts. Once they are determined for each type of raw water system, they should be largely fixed from plant to plant for the same type of raw water system, except for special designs found in a raw water system where the weighting factors have to be adjusted. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors won't affect the Condition Indicator of a raw water system, which is the weighted summation of all scores that assigned to the raw water system parts and five condition parameters.

Table N-1. Typical raw water system condition assessment and scoring: XXX Hydropower Plant (Unit #)

Raw Water System for Unit ___	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Supply Intake	4.2.4.1							1.0
Stainers	4.2.4.2							1.0
Pumps	4.2.4.3							2.0
Valves	4.2.4.4							1.0
Generator Coolers	4.2.4.5							1.5
Piping	4.2.4.6							2.0
Instrumentation/Monitoring	4.2.4.7							1.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	0.00
							Condition Indicator -->	0.00

5.0 RATING CRITERIA

Physical Condition: Rating Criteria for Raw Water System Parts

Physical Condition of raw water system refers to those features that are observable or detected through measurement and testing, including some observed performance. It includes the observation of pump vibration and noise, pipeline leaks and sticking of valves, as well as the analysis result from pipe and valve internal inspections. The Best Practices of Raw Water System Condition Assessment can assist in evaluating the raw water system condition. For HAP site assessment, it is important to conduct interviews and discussions with plant personnel to score the physical condition of raw water parts. The results of all related information are analyzed and applied to Chart 1 to assign the condition scores of raw water parts.

Chart 1 Raw Water System Physical Condition Rating Criteria

Physical Condition Rating Scale		Physical Condition Score
Excellent	No noticeable defects. Some aging or wear may be noticeable. No evidence of pump vibration and noise or pipeline leaks.	7– 10
Good	Some deterioration or defects are evident, but function is not significantly affected. Observable evidence of pump vibration and noise and/or pipeline leaks.	4 – 6
Poor	Serious deterioration in at least some portions, function is inadequate, unit efficiency or availability significantly affected.	1 - 3
Failed	No longer functions, may cause failure of a major component.	0

Age: Rating Criteria for Raw Water System Parts

Age scoring is relatively more objective than other condition parameters. The detailed scoring criteria developed in Chart 2 allows the age score be automatically generated in the HAP Database by the actual years of the installed part.

Chart 2 Age Rating Criteria for Raw Water System Parts	
Age of the Raw Water System Major Parts/Items	Age Score
0 - 10 years	10
11 - 15 years	9
16 - 20 years	8
21 - 25 years	7
26 - 30 years	6
31 - 35 years	5
36 - 40 years	4
41 - 50 years	3
51 - 70 years	2
71 - 99 years	1
> 100 years	0

Installed Technology Level: Rating Criteria for Raw Water System Parts

The Installed Technology Level indicates advancement levels of designing, machining, installation and materials, which may effect on the unit and plant performance. The outdated technology may bring difficulties for spare parts supply and become a prolonged outage when it fails.

Scoring the Installed Technology Level requires historic knowledge of raw water system technology advancement and familiarity with the current piping construction standards (ASME B31.3). The basic design concepts for raw water systems at hydro plants have not changed substantially. However, there are a number of component design improvements for raw water systems that have become state of the art. Most of these changes have been driven by technical improvements in materials of construction and the cost of materials such as stainless steel and copper/copper alloys.

Materials of construction selection for raw water piping systems and components is based on the specific characteristics of the system including water quality of the raw water supply (e.g., suspended solids, tendencies to scale, potential bio-fouling, potential for corrosion) .

Exposed larger bore piping (>Ø4 in.) can be flanged or butt welded carbon steel or stainless steel (Flanged piping allows disassembly of the piping system for internal build-up cleaning out). Small bore piping is non-corrosive material such as stainless steel. Embedded piping is stainless steel or cement lined ductile iron (for larger bore piping) with flanged joints for external piping connections.

Valves larger than 6 in. are normally gate valves. Isolation valves Ø2½ to Ø6 in. are normally butterfly valves. Stainless steel ball valves are normally used for Ø2 in. and smaller valves. Valves are manually operated or remotely actuated based on process requirements, staffing levels, etc. Closed cell foam piping insulation systems for eliminating external piping condensation have replaced asbestos containing systems. Raw cooling water pump design has changed very little over time. However, mechanical seals have replaced packing glands. Advances in pump materials of construction, impeller design and manufacturing, as well as more efficient motor design provide improvements in pump reliability and operating and maintenance costs.

Current raw water system designs include stainless steel duplex automatic backwash strainers. Subsystems such as turbine seal water and fire protection can be equipped with finer mesh automatic backwash strainers for additional performance reliability for these systems. These features are labor saving methods, especially suitable for the facilities that are not continually staffed.

In addition, the competence, professionalism and reputation of the original suppliers could also imply the installed technology levels. Compared to those from large and well-known manufacturers, the raw water parts supplied by small and unnamed companies would get lower scores. A review of installed technologies in use is compared to Chart 3 to determine the score for the raw water system.

Chart 3 Raw Water System Technology Rating Criteria

Technology Levels of the Parts/Items	Score for Installed Technology Level
The technology has not been changed significantly since the part was installed; and the installed technology was supplied by brand name companies with great reputation.	**8 – 10**
The technology has been more or less advanced but no problem to supply the matching parts in next 5-10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may reduce the cost of replacement). The installed technology was supplied by medium companies with good reputation.	**4 – 7**
The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability of power generation. The installed technology was supplied by small companies with bad reputation.	**0 – 3**

Operating Restrictions: Rating Criteria for Raw Water System Parts

The raw water system operating restrictions refer to the limitations on normal operation range of water pressure and flow rate, based on the original design and current condition of raw water parts. Operational limitations play a role in determining the serviceability of raw water system pumps: the greater the limitations, the greater the loss of cooling efficiency throughout the system.

The operating restrictions may be sourced from the system itself. The operating ranges of maximum/minimum water flows and pressures are constrained due to the original design and/or currently deteriorated raw water physical condition (e.g., hot bearings and severe vibrations).

Chart 4 describes the ratings of raw water system operating restrictions.

Chart 4 Raw Water System Operating Restrictions Rating Criteria

Operating Restrictions or Off-Design Conditions	Score for Operating Restrictions
The design standard has no changes, and the original design has no constraints on the required operation. No known design and operational deficiencies.	8 – 10
Minimal restraints: Special operational requirements are needed to avoid minor maintenance issues. The operation range can be expanded with revised equipment selection and design. No known design and operational deficiencies.	5 – 7
Moderate restraints: Special operational requirements are needed to avoid major maintenance issues. The operation range and performance can be significantly improved with revised equipment selection and design.	3 – 4
Severe limitations: The equipment do not meet the operational criteria or not tested as required or has a known design and operational deficiency.	0 – 2

Maintenance Requirement: Rating Criteria for Raw Water System Parts

Maintenance of a raw water system is directly connected to the quality of the amount of corrective maintenance that either has been or must be performed is an indication of the raw water system condition. No corrective maintenance is an indication that the raw water system is in good shape. Severe corrective maintenance requires scheduled or forced outages to perform.

Other factors to consider for maintenance scoring include:

- The need of maintenance is increasing with time or problems are reoccurring;

- Previous failures related to the raw water system parts;
- Failures and problems of raw water system parts with similar design.

The results of raw water system maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5 to score the raw water system parts.

Chart 5 Raw Water System Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum level (normal condition): A small amount of routine preventive maintenance is required (e.g., Flow Charting). No corrective maintenance.	**9 – 10**
Low level: Small amounts of corrective maintenance (e.g., less than 3 staff days per unit per year). Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis.	**7 – 8**
Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages (e.g., Pump Replacement).	**5 – 6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., Cooler Rebuild/Replacement).	**3 – 4**
Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required.	**0 – 2**

Data Quality: Rating Criteria for Raw Water Parts

The Data quality scores reflect the quality of the inspection, test, and measurement results to evaluate the condition of raw water system parts. The more current and complete the inspection, testing and measurement results, the higher the Data Quality scores. The frequency of normal testing is as recommended by the organization. Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of raw water system parts are developed in Chart 6.

Chart 6 Raw Water System Data Quality Rating Criteria	
Data Availability, Integrity and Accuracy	**Data Quality Score**
High – The Raw Water System maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurement were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8 – 10**
Medium – One or more of routine inspections, tests and measurement were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 – 7**
Low – One or more of routine inspections, tests and measurement were completed 24-36 months past the normal frequency, or some of results are not available.	**3 – 4**
Very Low – One or more of required inspections, tests and measurement were completed >36 months past the normal frequency, or significant portion of results are not available.	**0 – 2**

In Table N-1, the final condition score of the raw water system (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J)\times F(K)\times F(J)}{\sum_{K=1,M}^{J=1,5} F(K)\times F(J)} \qquad (1)$$

The raw water system Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K)\times F(K)}{\sum_{K=1,M} F(K)} \qquad (2)$$

Here, M = the total number of parts/items associated with the raw water system; K = the identification No. of raw water system parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of the raw waters part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for raw water system.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific raw water system testing would more directly reveal the condition of the raw water system.

6.0 REFERENCES

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RAW WATER SYSTEM INSPECTION FORM AND CHECKLIST

REVISION 1.0, 1/18/2012

Raw water: Inspection Form

General Information:

Date of Site Visit: ____ Unit No._________________

Plant Name: ____

Source/s of data: ____

Total Raw Water System Flow rate:
(GPM):____

Max System Pressure (at source)
(PSI):____

Normal System Operating pressure: __________

Raw Water System Description:____

____

____

____

____

____

Maintenance History / Major Repairs/ Replacement Description:

____

____

____

____

____

____

____

Raw Water circulation: Pumped_______ Gravity _______

Pumped Circulation Systems (Only):

Pump
Manufacturer/Type/Model:_______________________________________Age:______________

Number of Pumps:________________________

Motor Nominal HP:_______________________

Pump ratings flow (gpm): _______ head (ft): _______

Pump Seals: Packing______ Mechanical Seals_________

Pump Maintenance History / Major Repairs/ Replacement Description:

____

____

____

____

Raw Water Strainer

Strainer Manufacturer: ____Age_________

Manual__________ Automatic________

Strainer Size: _______________________

Strainer type: Simplex___________ Duplex _________

Strainer Materials of Construction: Housing_______________ Basket(s)__________________

Perforation size__

Strainer Maintenance History / Major Repairs/ Replacement Description:

____

____

____

____

Proportional Valve (if installed)

Pro. Valve Manufacturer: ____Age_________

Actuation Operator (pneumatic, hydraulic, electric): ____________________________________

Actuation Control (analog, digital): ____

Type: ____Size: ____________________________
Connection type: Inlet_________________________ Discharge: ______________________________
Pro. Valve Material of Construction: ____
Rated Pressure______________________ Rated Flow Range: ______________________________
Pro. Valve Maintenance History / Major Repairs/ Replacement Description:

____
____
____
____

Raw Water Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History				
Are there plant preventive maintenance procedures (TPM) for the raw water system piping, valves, pumps? Are they routinely carried out?				
Have there been any major piping repairs/replacements?				
Have corrodible raw water systems materials or portion thereof been replaced with non- corrodible materials such as stainless steel, fiberglass, PVC, CPVC, ABS, HDPE, or other materials				
Has (have) the proportioning valve(s) Valve been rebuilt or replaced?				
Has the raw water piping system support system been maintained such that there are no known excessive stresses or stains being placed on piping, valves, fittings, strainers or pumps (if so equipped)?				
Are there signs or is there a history of settlement or movement of piping in relation to concrete/steel structures? If so have there been any leaks or other visible damage to raw water system components or the concrete/steel structures? If so, have there been repairs and a maintenance program in place to monitor and assess the need for ongoing maintenance and repairs to ensure the integrity of the raw water system and associated structure?				

Raw Water Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Have there been any major valve inspection/repairs/replacements?				
Are there valves that will not seal well enough to stop the flow of water to equipment needing to be isolated? If so are plans to address these valves?				

Raw Water Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment				
Are exposed sections of piping, valves, fittings, and other components insulated to eliminate corrosion due to condensation on its outer surface that is exposed to the local environment? (Note: “exposed” piping out in the open as opposed to piping “embedded in concrete”) If yes, does the insulation contain asbestos fibers?				
Are there signs of external corrosion on non-insulated sections of exposed piping and valves?				
Are there known “through the wall” leaks in raw water system components (e.g., piping, valves, fittings, strainers)?				
Has there been an effort to assess the build-up of biological or sedimentary materials on raw water system internals? If so, are there known build-ups of biological or sedimentary materials on raw water system internals? If so are systems in place to monitor internal build-ups and remove the materials before generating unit performance is adversely affected?				

Raw Water Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment (Continued)				
Are instruments connected and operational?				
Are alarm transmitters (differential pressure) operational?				
Is the proportioning valve performance adequate for controlling generator air temperature?				
Are there long term valve packing and or pump packing leaks for which attempts to repair have not been successful?				
Has the performance of the raw water system been a contributor to availability/performance events such as forced outages, forced unit deratings, or maintenance outage? If so, on average over the past 5 years how many MWHL (Megawatt Hours Lost) have been attributed to Raw Water System performance (or lack thereof)?				
Do the pumps (if equipped) run smooth (little to no vibration)?				
Are the pumps running in their Equipment Reliability Operating Envelope (EROE)?				

APPENDIX O. GUIDE FOR LUBRICATION SYSTEM CONDITION ASSESSMENT

REVISION 1.0, 12/15/2011

CONTENTS

1. GENERAL

Unforeseen failure of the lubrication system can have a substantial impact on power generation and revenues due to an extended forced outage. Therefore, it is important to maintain an updated condition assessment of the lubrication system and plan accordingly. A lubrication system condition assessment is essential to estimate the economic lifespan and potential risk of failure, and to evaluate the benefits and cost of lubrication system upgrading.

For any type of lubrication system, the following three step analyses are necessary to arrive at a lubrication system condition indicator:

1) What parts should be included for a lubrication system condition assessment and which parts are more important than others (parts and their weighting factors)?

2) What metrics/parameters should be investigated for quantitative condition assessment and which ones are more important than others (condition parameters and their weighting factors)?

3) How to assign numerical scores to the lubrication system parts (rating criteria)?

This appendix provides guides to answer the above questions, which can be applied to all lubrication systems. The condition assessment is performed on individual lubrication systems in a plant, because even the originally identical lubrication systems may have experienced different Operation & Maintenance (O&M) histories and would arrive at different values of condition indicators. Due to the uniqueness of each individual lubrication system, the guides provided in this appendix cannot quantify all factors that affect individual lubrication system condition. Mitigating factors not included in this guide may trigger testing and further evaluation to determine the final score of the lubrication system condition and to make the decision of lubrication system replacement or rehabilitation.

This appendix is not intended to define lubrication system maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2. CONSTITUENT PARTS ANALYSIS

The reliability related components of lubrication systems include the lubricant/oil, filter sub-system, cooling sub-system, oil pumps, vessel and piping, and instrumentation/alarm. If any part (e.g., instrumentation/alarm) does not exist in a particular lubrication system, this part will be excluded from scoring mechanism by inputting "NA" into the table. The effect of one part exclusion is usually insignificant to justify any adjustment for the weighting factors of other lubrication system parts.

3. METRICS FOR LUBRICATION SYSTEM CONDITION ASSESSMENT

As listed in Table O-1, the following five condition parameters are considered for condition assessment of lubrication system parts:

- The Physical Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on the previous testing and measurements, historical O&M records, original design drawings, previous rehabilitation feasibility study reports if conducted, interviews with plant staff and some limited inspections. It is noticed that there is a certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmarking condition assessment without specific testing and measurements conducted on site, these five parameters are regarded as providing the basis for assessing the condition of lubrication system parts.

In addition, the Data Quality Indicator, as an independent metrics, is to reflect the quality of available information and the confidence on the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity, and any of these situations could affect the results of condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part/item to indicate the information and data availability, integrity and accuracy and the confidence on the given condition ratings (MWH 2010).

4. WEIGHTING FACTORS

There are two categories of weighting factors in Table O-1. It is recognized that some condition parameters affect the lubrication system condition to a greater or lesser degree than other parameters; also some parts are more or less important than other parts to an entire lubrication system. These weighting factors should be pre-determined by consensus among experienced hydropower mechanical engineers and plant O&M experts. Once they are determined for each type of lubrication system, they should be largely fixed from plant to plant for the same type of lubrication system, except for special designs found in a lubrication system where the weighting factors have to be adjusted. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors won't affect the Condition Indicator of a lubrication system, which is the weighted summation of all scores that assigned to the lubrication system parts and five condition parameters.

Table O-1. Typical lubrication system condition assessment and scoring: XXX Hydropower Plant (Unit #)

Lubrication System for Unit ____	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Lubricant/Oil	4.2.5.1							2.5
Filter Sub-System	4.2.5.2							1.5
Cooling Sub-System	4.2.5.3							1.5
Oil Pumps	4.2.5.4							1.5
Vessel and Piping	4.2.5.5							1.0
Instrumentation/Alarms	4.2.5.6							1.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	0.00
							Condition Indicator -->	0.00

5. RATING CRITERIA

Physical Condition: Rating Criteria for Lubrication System Parts

Physical Condition of lubrication system parts refers to those features that are observable or detected through measurement and testing, including some observed performance. It includes the observation of pump vibration and noise, oil loss, looseness of pins and linkages, and sticking of valves, as well as the analysis result from lubricant/oil condition assessment testing. The Best Practices of Lubrication System Condition Assessment can assist in evaluating the lubrication system condition.

For HAP site assessment, it is important to conduct interviews and discussions with plant personnel to score the physical condition of lubrication system parts. The results of all related information are analyzed and applied to Chart 1 to assign the condition scores of lubrication system parts.

Chart 1 Lubrication System Physical Condition Rating Criteria		
Physical Condition Rating Scale		**Physical Condition Score**
Excellent	No noticeable defects. Some aging or wear may be noticeable. No evidence of pump vibration and noise, oil loss, looseness of pins and linkages, or sticking of valves. Oil cleanliness levels meet the requirements of ISO 4406.	**9–10**
Very good	Only minor deterioration or defects are evident, and function is full. Minor evidence of pump vibration and noise, oil loss, looseness of pins and linkages, or sticking of valves. Oil cleanliness levels largely meet the requirements of ISO 4406.	**7–8**
Good	Some deterioration or defects are evident, but function is not significantly affected. Observable evidence of pump vibration and noise, oil loss, looseness of pins and linkages, and sticking of valves. Oil cleanliness levels meet the requirements of ISO 4406 at most parts, and plan for cleaning process is needed.	**5–6**
Fair	Moderate deterioration, function is still adequate, but the unit efficiency may be affected. Wide evidence of pump vibration and noise, oil loss, looseness of pins and linkages, and sticking of valves. Oil cleanliness levels meet the requirements of ISO 4406 at some parts, and cleaning process is needed immediately.	**3–4**
Poor	Serious deterioration in at least some portions, function is inadequate, unit efficiency or availability significantly affected.	**2**
Very poor	Extensive deterioration. Barely functional.	**1**
Failed	No longer functions, may cause failure of a major component.	**0**

Age: Rating Criteria for Lubrication System Parts

Age scoring is relatively more objective than other condition parameters. The detailed scoring criteria developed in Chart 2 allows the age score be automatically generated in the HAP Database by the actual years of the installed part.

Chart 2 Age Rating Criteria for Lubrication System Parts	
Ages of the Lubrication System Major Parts/Items	**Age Score**
<2 years	**10**
2–5 years	**9**
5–7 years	**8**
7–10 years	**7**
10–12 years	**6**
12–17 years	**5**
17–20 years	**4**
20–22 years	**3**
22–25 years	**2**
25–30 years	**1**
>30 years	**0**

Installed Technology Level: Rating Criteria for Lubrication System Parts

The Installed Technology Level indicates advancement levels of designing, machining, installation and materials, which may effect on the unit and plant performance. The outdated technology may bring difficulties for spare parts supply and come a prolonged outage when it fails.

Scoring the Installed Technology Level requires historic knowledge of lubrication system technology advancement and familiarity with the current lubrication system manufacturing industry. Early designs for oil lubricating systems, for vertical hydro turbine-generator bearings, consisted of pumps driven by gears or belts from the main shaft or by simple viscosity pumps which move oil by hydrodynamic action. Horizontal hydro turbine-generator bearings were often lubricated by oil rings riding on top of the shaft. Modern designs have evolved into systems which move the oil by electric motor driven pumps. This has many advantages such as providing electrical controls, backup pumps (AC and DC), and flexible capacities such as flow rates and pressures.

As state of the art technology, stainless steel reservoir, vessels and piping are used to ensure minimum oil flushing time, optimum unit component life and unit reliability. The use of centrifugal pumps eliminates the need for relief and backpressure (bypass) control valves and thus reduces the oil system induced unit trips. Single stage centrifugal pumps can be used whenever the ambient temperature along with the use of thermostatically controlled reservoir heaters maintain an oil viscosity that allows the use of a centrifugal pump. Supplementary oil cleaning can be achieved by a separate system (Kidney Loop Oil Filtration System) in series with the existing lubrication system, which reduces failures caused by dirty oil.

In addition, the competence, professionalism and reputation of the original suppliers could also imply the installed technology levels. Compared to those from large and well-known manufacturers, the lubrication system parts supplied by small and unnamed companies would get lower scores.

Chart 3 Lubrication System Technology Rating Criteria

Technology Levels of the Parts/Items	Score for Installed Technology Level
The technology has not been changed significantly since the part was installed; and the installed technology was supplied by brand name companies with great reputation	**8 – 10**
The technology has been more or less advanced but no problem to supply the matching parts in next 5-10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may reduce the cost of replacement). The installed technology was supplied by medium companies with good reputation.	**4 – 7**
The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability of power generation. The installed technology was supplied by small companies with bad reputation.	**0 – 3**

Operating Restrictions: Rating Criteria for Lubrication System Parts

The lubrication system operating restrictions refer to the limitations on normal operation range of oil pressure and flow rate, based on the original design and current condition of lubrication system parts. Operational limitations play a role in determining the serviceability of lubrication system unit: the greater the limitations, the greater the heat generated and/or excess oil bypassed back to the oil reservoir.

The operating restrictions may be sourced from the system itself. The operating ranges of maximum/minimum oil flows and pressures are constrained due to the original design and/or currently deteriorated lubrication system physical condition (e.g., hot bearings and severe vibrations).

Chart 4 describes the ratings of lubrication system operating restrictions.

Chart 4 Lubrication System Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
The design standard has no changes, and the original design has no constraints on the required operation. No known design and operational deficiencies.	**8 – 10**
Minimal restraints: Special operational requirements are needed to avoid minor maintenance issues. The operation range can be expanded with revised equipment selection and design. No known design and operational deficiencies.	**5 – 7**
Moderate restraints: Special operational requirements are needed to avoid major maintenance issues. The operation range and performance can be significantly improved with revised equipment selection and design.	**3 – 4**
Severe limitations: The equipment do not meet the operational criteria or not tested as required or has a known design and operational deficiency.	**0 – 2**

Maintenance Requirement: Rating Criteria for Lubrication System Parts

Maintenance of an oil lubricated bearing is directly connected to the quality of the supplied oil used for lubrication and cooling. Any contamination of the oil either with debris or water will increase the likelihood of a bearing failure. Oil filters are usually positioned downstream of the oil coolers to prevent carbon steel (iron sulfide) particles from entering the machinery components and causing pre-mature wear/failure. A displacement flush is conducted typically based on a time interval vs. cleanliness (particle levels) to facilitate the removal of soluble and insoluble contaminants that would not typically be removed by system filters.

The amount of corrective maintenance that either has been or must be performed is an indication of the lubrication system condition. No corrective maintenance is an indication that the lubrication system is in good shape. Severe corrective maintenance requires scheduled or forced outages to perform.

Other factors to consider for maintenance scoring include:

- The need of maintenance is increasing with time or problems are reoccurring;
- Previous failures related to the lubrication system parts;
- Failures and problems of lubrication system parts with similar design.

The results of lubrication system maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5 to score the lubrication system parts.

Chart 5 Lubrication System Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum level (normal condition): A small amount of routine preventive maintenance is required (e.g., Oil Sampling). No corrective maintenance.	**9 – 10**
Low level: Small amounts of corrective maintenance (e.g., less than 3 staff days per unit per year). Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis.	**7 – 8**
Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages (e.g., Pump Replacement).	**5 – 6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., Cooler Rebuild/Replacement).	**3 – 4**
Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required.	**0 – 2**

Data Quality: Rating Criteria for Lubrication System Parts

The Data quality scores reflect the quality of the inspection, test, and measurement results to evaluate the condition of lubrication system parts. The more current and complete inspection, testing and measurement results, the higher the Data Quality scores. The frequency of normal testing is as recommended by the organization. Reasonable efforts should be made to perform visual inspections and data collection (e.g., measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is “Good” or numerically equal to some mid-range number 3–7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of lubrication system parts are developed in Chart 6.

Chart 6 Lubrication System Data Quality Rating Criteria	
Data Availability, Integrity and Accuracy	**Data Quality Score**
High – The Lubrication System maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurement were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8 – 10**
Medium – One or more of routine inspections, tests and measurement were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 – 7**
Low – One or more of routine inspections, tests and measurement were completed 24-36 months past the normal frequency, or some of results are not available.	**3 – 4**
Very Low – One or more of required inspections, tests and measurement were completed >36 months past the normal frequency, or significant portion of results are not available.	**0 – 2**

6. LUBRICATION SYSTEM CONDITION AND DATA QUALITY INDICATORS

In Table O-1, the final condition score of the lubrication system (i.e., the Condition Indicator, *CI*) can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J)\times F(K)\times F(J)}{\sum_{K=1,M}^{J=1,5} F(K)\times F(J)} \qquad (1)$$

The lubrication system Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K)\times F(K)}{\sum_{K=1,M} F(K)} \qquad (2)$$

Here, M = the total number of parts/items associated with a lubrication system; K = the identification No. of lubrication system parts (from 1 to M); J = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of a lubrication system part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; $F(J)$ = the weighting factor for a condition parameter; $F(K)$ = the weighting factor for a lubrication system part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific lubrication system testing, such as the efficiency/index test and paint film quality test, would more directly reveal the condition of the lubrication system.

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LUBRICATION SYSTEM INSPECTION FORM AND CHECK LIST

REVISION 1.0, 12/20/2011

Lubrication System: Inspection Form

General Information:

Date of Site Visit: ______________________________ Unit No.________________

Plant Name: ______________________________

Source/s of data: ______________________________

Console/ Skid Manufacturer:______________________________Age:______________

System Flow rated (GPM):______________________________

System Pressure (PSI):______________________________

Motor Nominal HP:______________________________ Redundant Pump ____________

Lubrication System Description:______________________________

____

____

____

____

____

Maintenance History / Major Repairs Description:

____

____

____

____

____

____

____

Lubricant/Oil:

Oil Manufacturer/Model: ______________________________

Viscosity Specification: ______________________________

Conventional mineral-based oil: ☐

Hydroprocessed synthetic oil: ☐

Addition specification data:

____

____

____

____

____

Filter Sub-System:

Make:__________ Model:__________
Type-surface depth:__________ Cartridge material:__________
Normal flow (GPM):__________ Max. flow (GPM):__________
Number of cartridges: __________Collapse P (PSI): __________
Clear filter ΔP max (PSI):__________ ΔP at max viscosity (PSI):__________
Addition specification data:

Cooling Sub-System:

Shell and tube: ☐ Air (fin & fan): ☐
Make:__________ Model:__________
Twin or Single:__________ Size (Diameter):__________
Heat load (BTU/h):__________ Oil side ΔP clean (PSI): __________
Fouling factor (total):__________ Oil flow (GPM):__________
Water quantity (GPM):__________
Addition specification data:

Oil Pumps:

Positive Displacement: ☐ Centrifugal: ☐
Make: __________ Model: __________

	Main	Aux
Disch. Press @10 centistroke (60 SSU*):	______	______
Disch. Press @ max centistroke (SSU*):	______	______
Rated flow @10 centistroke (60 SSU*):	______	______
Flow @ max. SSU:	______	______
Flow @ Relief valve press.:	______	______
(pos. displace. pumps only) Operating power (BHP):	______	______
End of Curve Power (BHP):	______	______
NPSH available (ft):	______	______
NPSH required (ft):	______	______

RPM: ______ Impeller Dia.:______ Volt/Freq./Ø/AMP: ______
Addition specification data:

Vessel and Piping:

Capacity (Gal):__________Construction:__________

Addition specification data:

____

____

Instrumentation/Alarms

Type:____________________Range:___________________Material:_____________________

Type:____________________Range:___________________Material:_____________________

Type:____________________Range:___________________Material:_____________________

Type:____________________Range:___________________Material:_____________________

Addition specification data:

____

____

*SSU = Saybolt Universal Second (measurement of viscosity)

Lubrication System Check List				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History				
Are there plant preventive maintenance procedures (TPM) for the lubrication system? Are they routinely carried out?				
Have there been any piping and/or vessel/reservoir repair?				
Have the pumps been rebuilt?				
Have filter bodies been repaired?				
Have cooler/heat exchanger bodies and/or tube leaks been repaired?				
Have pumps been replaced with the new design or similar to original design?				
Are there procedures and maintenance logs for system flushing?				

Lubrication System Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Maintenance & Major Repair History (Continued)				
Is there a formalized oil filter change interval?				
Has the Pressure Control Valve been rebuilt or replaced?				
Has the Filtering Transfer Valve been rebuilt or replaced?				
Are instruments connected and operational?				
Are alarm transmitters (differential pressure) operational?				
Have all plant records regarding lubrication system, repairs, operating conditions, temperature records etc. been requested/gathered?				

Lubrication System Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment				
Can the condition of the oil be assessed?				
Is there formalized oil sampling and/or laboratory examination?				
Is there a utilization of the high pressure lubrication system for lift on the thrust bearing for starts and shut downs?				
Can the position of the control valves be determine?				
Are system pipe lines labeled and colored?				
Are sight glasses thought the system functional?				
Is the non-operating filter vented?				

Lubrication System Check List (Continued)				
Topic	**Yes**	**No**	**N/A**	**Comments/Details**
Equipment Condition Assessment (Continued)				
Is the non-operating filter vented?				
Are Triple Modular Redundant transmitters used for control of the system?				
Is a supplementary filtration (kidney loop) in use?				

Lubrication System Data Collection Sheet	
Topic	**Data Input**

For overall questions
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