Analysis of Hydropower Plant Revenues in Independent System Operator New England (ISO-NE)

September 2019

Rui Shan
Brennan Smith
Stephen Signore

ORNL/SPR-2019/1294

Approved for public release.
Distribution is unlimited.

Acknowledgments

The authors would like to extend their sincere gratitude to the reviewers of this document for their time and effort including Ms. Charlie Horak and Mr. Scott Deneale of Oak Ridge National Laboratory, Mr. John Simonelli of Flashover LLC, Dr. Todd Levin of Argonne National Laboratory, and Dr. Mark Christian of the Department of Energy's Water Power Technologies Office. The authors would like to extend a special thanks to the U.S. Department of Energy's Water Power Technologies Office for financial support.

Analysis of Hydropower Plant Revenues in Independent System Operator New England (ISO-NE)

Rui Shan
Brennan Smith
Stephen Signore

September 2019

Executive Summary

This case study uses electric quarterly report data to analyze the recent trend in the revenue of hydropower plants, excluding pumped storage, in the Independent System Operator New England (ISO-NE) market. There is a clear declining trend in the total revenue received by hydropower plants associated with the declining energy price. Run-of-river plants have a higher revenue measured in capacity ($/kW) due to higher capacity factors, and peaking plants have a higher revenue measured in energy ($/MWh) due to their operating strategy. The major revenue source is still the energy, followed by capacity payment and other ancillary services, including uplift, which contributes only a small part of the total revenue. Despite the low revenue, hydropower plants in ISO-NE participate in the market of almost all the services. With the increased penetration of intermittent resources, we expect more participation from hydropower in providing contingency reserves and voltage support.

Acronyms and Abbreviations

EQR	electric quarterly reports
FERC	Federal Energy Regulatory Commission
ISO-NE	Independent System Operator New England

Contents

Figures

1.0 Data Source, Completeness, and Accuracy

All the data used for analysis in this report, unless otherwise specified, was extracted from electric quarterly reports (EQRs)[1] during 2008–2017. EQR data has been collected and managed by the Federal Energy Regulatory Commission (FERC) since 2005, and in 2013 some of the formatting of the reports was changed. The sellers in the market are required to report their contract and transaction data through the EQR filing system. The transaction data contains the product type, sale price, volume of the product, place of delivery, delivery time, contract period, and a variety of other useful information. However, different sellers in different markets file their transaction data in different ways. For example, one utility might report the place of delivery of an electricity sale at the node, while another utility might report the place of delivery at the zone of the market. Such differences increase the difficulty of data cleaning and plant identification. In this case study, the plants are identified by either the generating node or the company, and then presented at the plant level. Transaction data from pumped storage facilities is excluded from this analysis.

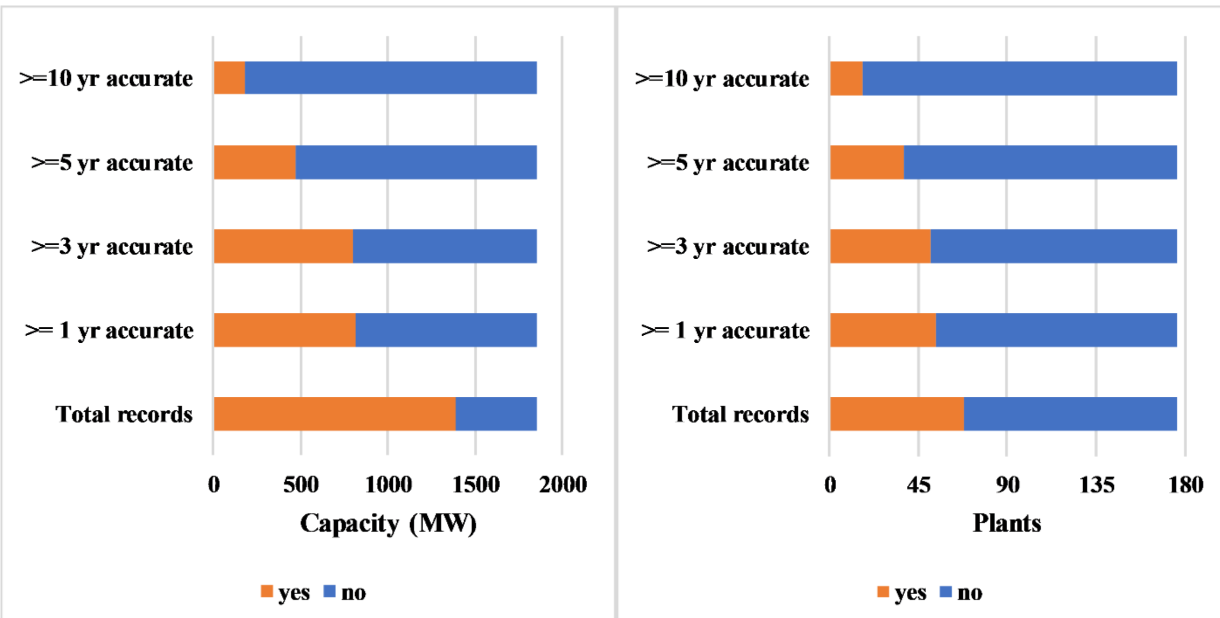


Figure 1. Generation data completeness and accuracy.

Taking the 2016 National Hydropower Asset Assessment Program dataset[2] as the reference and excluding pumped storage plants, 74% of hydropower capacity and 38% of hydropower plants are captured through our analysis of EQRs in the ISO-NE, as shown in Figure 1. Because some small plants and plants with low transaction volumes are not required to file EQRs, it is not possible to capture all the plants in this dataset, especially in ISO-NE since 43% of hydro plants

[1] More info about EQR: https://www.ferc.gov/docs-filing/eqr.asp
[2] https://hydrosource.ornl.gov

in ISO-NE are smaller than 2.8 MW. To make a more convincing analysis, only the plants with accurate annual generation data are included in the following analysis.

As for data validation, we compare the generation data from EQRs and the annual generation data from EIA-923 Power Plant Operations Report. We have assessed that a difference between the two sources up to 10% is acceptable. About 44% of the capacity we captured from the EQRs has at least one-year of data consistent with the EIA-923 validated using this criterion. As for the ancillary service[3] record, we have not found another public data source that provides detailed ancillary service information on plants; thus, the data completeness and accuracy of ancillary services have not been validated. Another data issue associated with ancillary services, capacity payment, and uplift is that different types of products and different companies file their transactions differently, causing some data quality issues, especially the data in 2013 when the data reporting format changed.

As market participation data was collected from EQR reports, this case study did not work with unit flow data. Water availability and unit availability are critical for hydropower assets to fully participate in the market and annual and seasonal variations in precipitation and snow melt impact water availability in a site-specific nature. Hydropower plants provide linkages between the river systems and the energy grid making wet and dry year impacts important in short-term analyses but are less important to multi-year trends.

Sample sizes in this data analysis can significantly impact the capacity-normalized revenue values. Careful distinctions must be made since some services are mutually exclusive. For example, a plant cannot use the same 1 kW capacity to deliver 1 kW of spinning reserve and supplemental reserve at the same time. Although we cannot add them together, we can still see the revenue potential in them. Additional care must be taken since the number of plants providing different services changes with time. Best described, Figure 3 takes all non-energy revenue divided by the capacity of the subset of plants that have provided any non-energy service in that year. The sample size in Figure 3 for energy revenues does not decrease year over year while the sample size for other services varies annually based on annual participation rates. Figure 9 discussed later will segment each non-energy service based on their individual sample size. Similar to the segmentation of services used for Figure 9, Figure 7 provides a 10-year average for each non-energy service using the total revenue from that service divided by the MW-years allocated to the provision of each service. Though these differences seem minor they have great effect of the values presented within this analysis.

---

[3] The ancillary service here refers to regulation, reserve, blackstart and voltage support

2.0 Revenue Overview

As shown in the Figure 2, the revenue of hydropower plants, measured by dollar/kilowatt of capacity, is still dominated by the revenue from providing energy rather than from providing other services. On a dollar/kilowatt basis, energy makes up between 77%–99% of the total annual revenue for hydropower plants. In the ISO-NE wholesale market, the revenues from energy production accounts for 49%–73% of the total revenues across all ISO-NE utilities from 2013 to 2017[4], as shown in Figure 2. This indicates that the revenue source of hydropower plants is not as diversified as other generating sources within ISO-NE. The main differences in revenue are from capacity payment, voltage support, blackstart, and others[5]. Some of these transactions are delivered at the company level not the node level and thus, we are unable to tell whether the revenue from selling such services comes from the hydro power plant the company owns, leading to an underestimation of the plant's revenue from these services. To mitigate this underestimation, the analysis is adjusted by the participation, which means that only the plants which provided those services will be considered during the revenue analysis of such service. This causes the sample sizes to vary significantly over the course of the analyses, as shown in Figure 3.

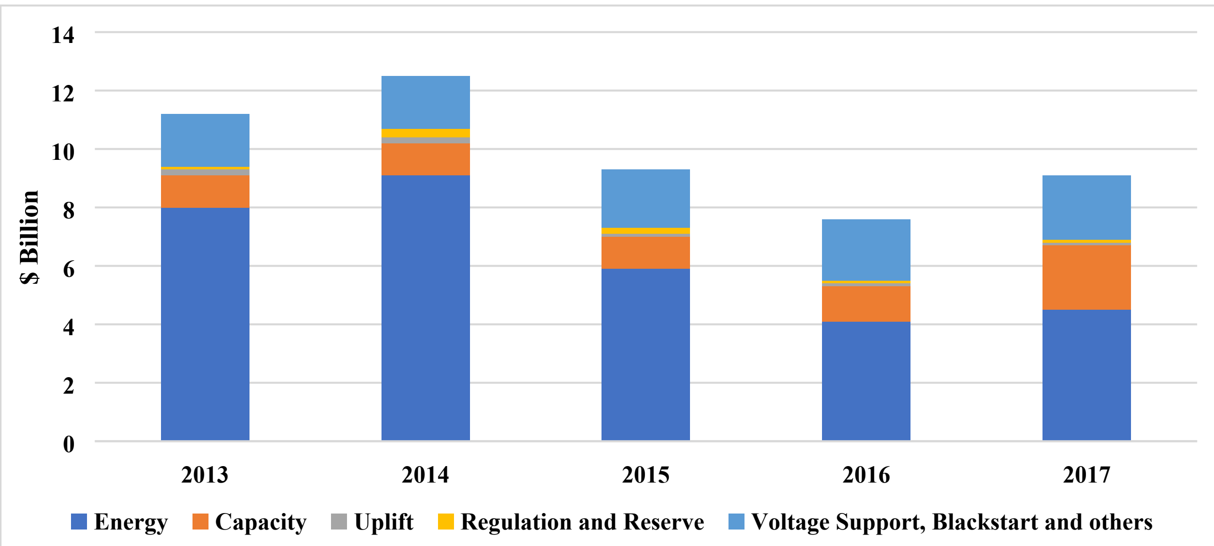


Figure 2. ISO-NE market cost distribution.

[4] ISO New England, *2017 Annual Markets Report*, May 2018; https://www.iso-ne.com/static-assets/documents/2018/05/2017-annual-markets-report.pdf

[5] *Voltage support, blackstart and others* refer to the Regional Network Load services in ISO-NE

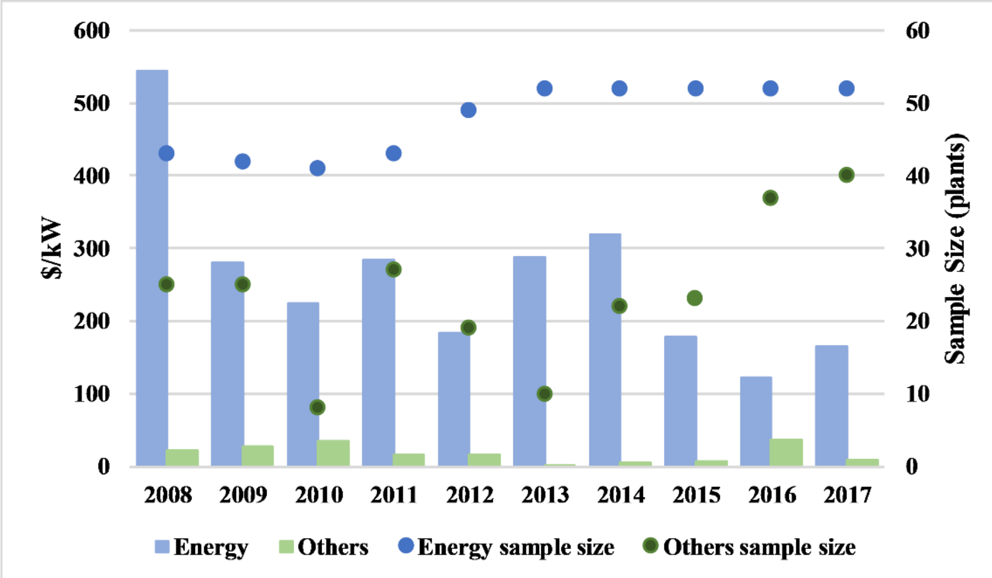
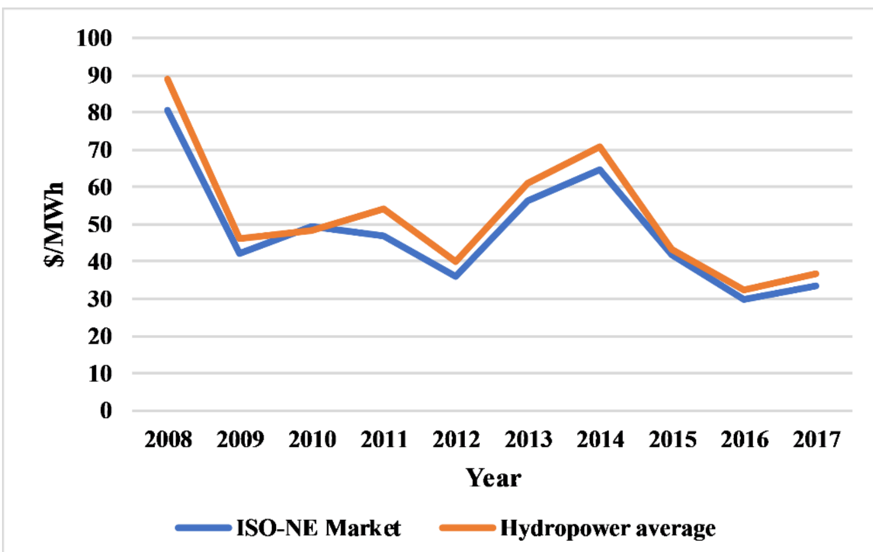


Figure 3. Average revenue trend.

Overall, there is a declining trend of total revenue and the energy revenue. The trend is consistent with the total market cost trend and the energy cost trend at the market scale. This declining trend persists if the revenue is measured by dollar of megawatt hour of generation, in other words, average electricity price (Figure 4). Comparing with the average market real-time hub price[6], the average electricity price received by sampled hydropower plants has the same trend but is slightly higher caused by the operation strategy of hydropower plants preferentially generating electricity when the price is high.



[6] From ISO-NE Annual Market Reports, 2008-2017: https://www.iso-ne.com/markets-operations/market-monitoring-mitigation/internal-monitor

Figure 4. Average electricity price.

Even within the hydropower plants, such strategy will elevate the revenue measured by energy ($/MWh). As shown in Figure 3, revenue from energy dominates the total revenue composition on the plant average basis. It is reasonable to assume that the run-of-river plants are less sensitive to the average price, while some peaking plants and others are more likely to generate electricity only at a higher price. Within our sample, we identified plant types from the FERC licenses and found 24 run-of-river plants (including 2 canal/conduit) and 30 plants that are peaking, intermediate peaking, or other types of plants. As shown in Figure 5, except for 2010 and 2011, run-of-river plants had lower revenues per unit of generation than other types of plants, although not statistically significant.

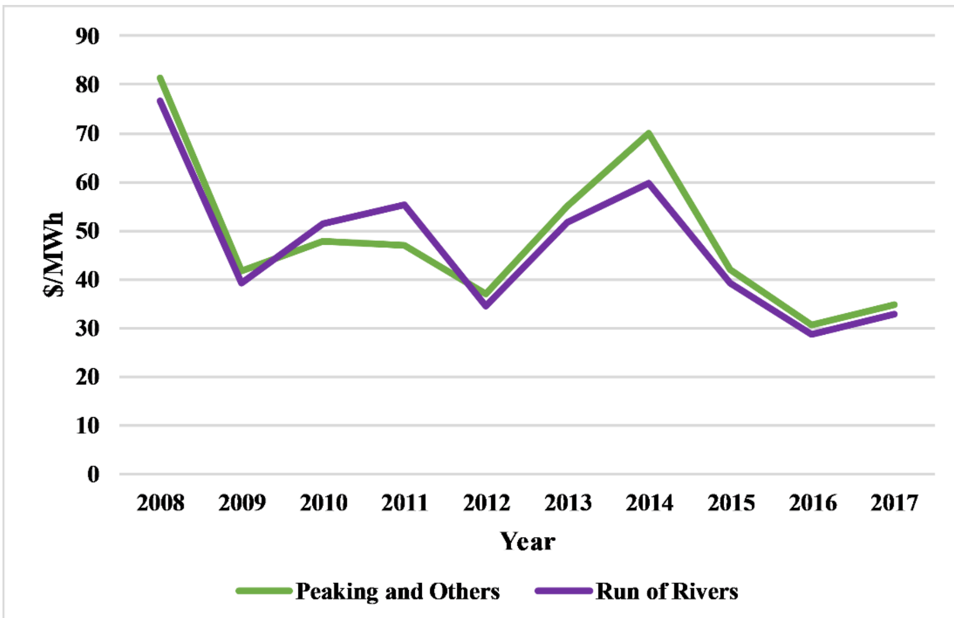


Figure 5. Revenue ($/MWh) of different types of hydro plants.

However, in terms of revenue per unit of capacity ($/kW), over the years the run-of-river plants have had a higher revenue than other types of plants, as shown in Figure 6 (left). Because the main part of the revenue is still energy, this difference is caused by the higher capacity factors, as shown in Figure 6 (right). Run-of-river plants have consistently higher capacity factors and can make the best use of their capacity, leading to a higher revenue measured by dollars/kilowatt.

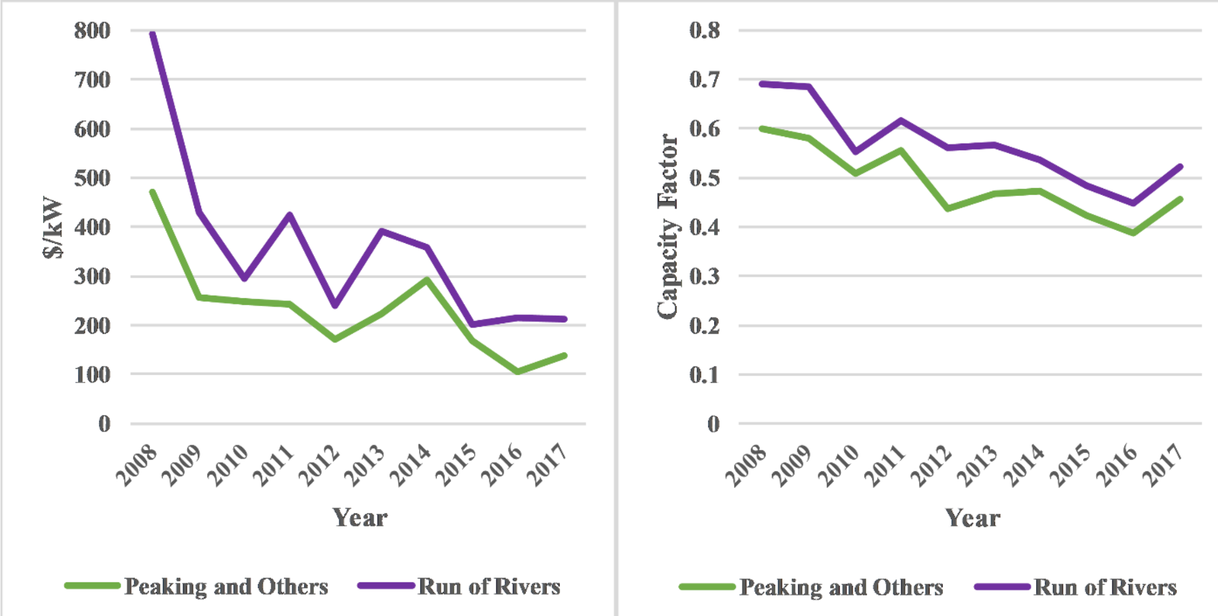


Figure 6. Revenue (left) and capacity factor (right) for different types of plants.

These two comparisons do not determine the profitability of these two types of hydropower plants, and the aforementioned differences might not be statistically significant based on the priorities and concerns of plant owners/operators. Capital cost is usually measured by capacity ($/kW), and to recover the sunk cost, measuring revenue by capacity would make run-of-river plants preferable. However, if the plant operator/owner is more concerned about variable operation cost or other costs associated with power generation, they will measure revenue by power generation and prefer peaking plants. Note that this difference is also a product of the revenue from capacity market which correlates with the plant's capacity factor.

3.0 Ancillary Service

Although ancillary services only account for a small portion of a plant's revenue, it is crucial to the reliability and stability of the grid and can reflect the flexibility and other capabilities of the plant. Because of the data reporting issue described in Section 1.0, when analyzing a service, we consider only plants that participate in the market for that service where plant participation is defined as an identifiable plant with identifiable transaction data of the service. Transactions reported by a different identifier of the plant (i.e., generating node or company) or even on behalf of another entity (i.e., parent company) are ignored. Uplift and capacity payment, although not defined as ancillary services, are also discussed here.

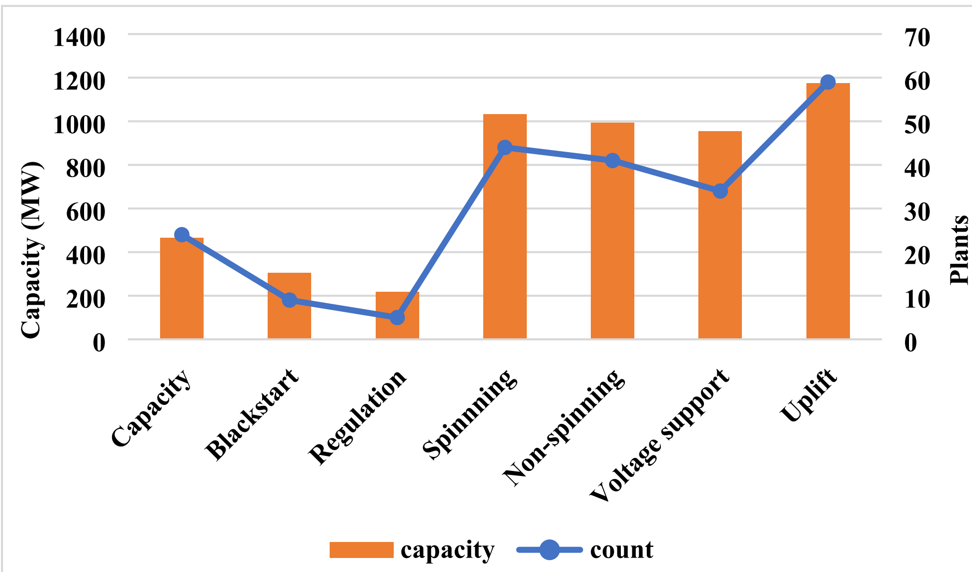


Figure 7. Ancillary service participation by type for 2008–2017.

Figure 7 shows the number of plants that have provided each service at any point from 2008–2017. Most of the hydropower plants within our analysis have not provided frequency regulation, but many of them have provided spinning reserve and supplemental reserve. Spinning reserve and supplemental reserve require a plant to come online within 10–30 min, and the regulation requires response within one minute or less. Despite this higher requirement, many hydropower plants have the capability to provide frequency regulation[7]. The low participation of hydropower plants in the regulating market might be due to the unknown cost associated with providing the service at aging plants, relatively low price, and competition with other generators and energy storage systems which may further reduce the compensation level. Alternatively, almost all the plants captured in the EQRs have received at least one uplift payment during these years. The

[7] Martínez-Lucas, Guillermo, et al. 2015. "Power-frequency control of hydropower plants with long penstocks in isolated systems with wind generation." *Renewable energy* 83: 245–255.
Kern, Jordan D., et al. 2011. "Influence of deregulated electricity markets on hydropower generation and downstream flow regime." *Journal of Water Resources Planning and Management* 138.4: 342–355.
Salhi, Issam, et al. 2014. "Frequency regulation for large load variations on micro-hydro power plants with real-time implementation." *International Journal of Electrical Power & Energy Systems* 60: 6–13.

uplift, named Net Commitment Period Compensation in ISO-NE, is designed to help generators recover the cost from the market when other means fail. For example, when a unit follows the ISO's instruction to operate uneconomically to ensure the resource adequacy, it will receive the extra payment to make such operation no financially worse than the best alternative schedule. The high number of hydropower plants receiving uplift payments partially indicates the high flexibility of hydropower plants (i.e., they can easily change their schedule).

Figure 7 also shows the average capacity of plants to provide different services. The blackstart, regulation, and voltage support services have a larger average capacity while capacity payment and uplift have a lower average capacity. A larger average capacity can be interpreted as larger plants providing the service or the service concentrating on fewer medium to large sized plants.

Figure 8 presents the trend of hydropower participation in different types of ancillary services. Over the years, participation of voltage support and frequency regulation has had low diversity of plants and is relatively constant pointing to a level of installed technology required. Frequency regulation requires a fast response, and only specific units or utilities might be willing or able to provide it. Another reason is the ideological willingness to accept risk costs, comparing with the regulation price, for aged assets theoretically associated with frequency regulation.

As for voltage support, which is more location dependent because of the considerable reactive power loss through transmission and distribution, the plants providing it must be spread geographically over the system and, thus, only the plants in a good location are selected. Similar to generation capacity payment, the units need to pass certain technical test to receive a special capacity payment for voltage support. From 2015 to 2018, hydropower, including pumped storage, provides about 9-10% of the eligible voltage support capacity[8], higher than its share in the generation mix as 6-7%. Within the hydropower, the pumped storage provides more than half of the voltage support capacity of hydropower resources, although pumped storage is not discussed in this report.

With urbanization, economic growth, and, more importantly, the growth of intermittent resources—which decreases the number of synchronous generators on the system—the system requires more frequency regulation and voltage support. Despite the requirements for solar and wind resource to provide regulation and voltage support, and the compeitiont with batteries, we still expect growth in future participation from hydropower plants.

[8] Voltage Support, ISO-NE https://www.iso-ne.com/markets-operations/markets/voltage-support/

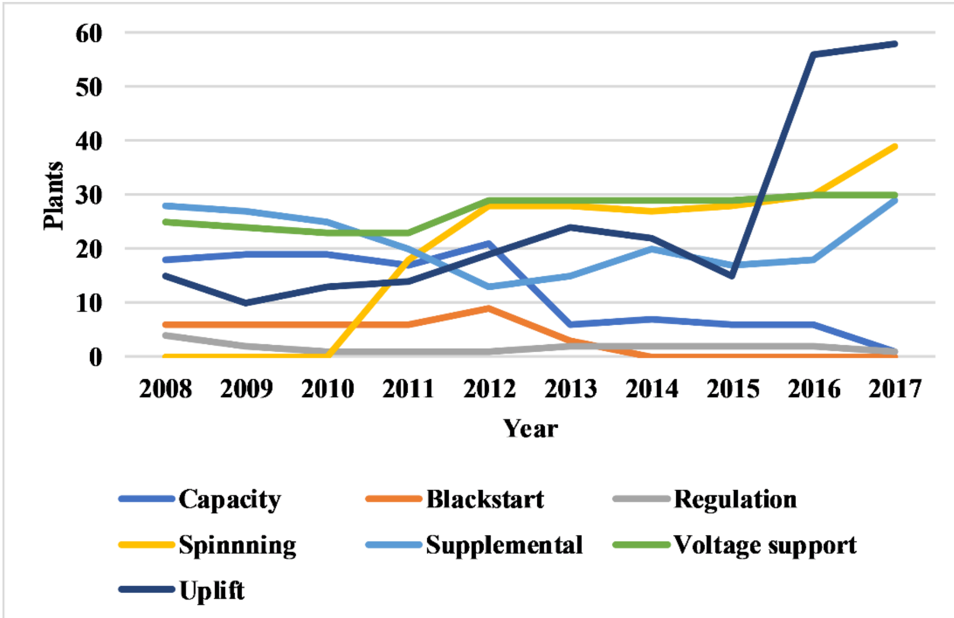


Figure 8. Trend of ancillary service participation.

In terms of growth of intermittent resources within ISO-NE, solar photovoltaics have grown from 40 MW in 2010 to 2,400 MW in 2017 and onshore wind has grown from 375 MW in 2011 to 1,300 MW in 2017[9]. We conjecture that the trend of hydropower's participation in spinning reserve, supplemental reserve, and uplift is in reaction to such growth. Upon entering a market for ancillary services, some plants may choose to provide spinning reserve rather than supplement reserve because of demand and price. In recent years, participation of both supplemental reserve and spinning reserve has increased in response to the recent capacity addition of solar and wind resources. As for the uplift, it reflects the imperfection in the market to match generation with load. The increased net load forecast error caused by solar and wind forecast errors will make it more difficult to perfectly operate the market, resulting in more and more plants receiving the uplift payment.

There are also other issues behind the increasing number of units who received uplift payment in recent years. In 2016, ISO-NE identified and eliminated a double payment in the real-time uplift, and after that the day-ahead uplift became the main part of uplift. ISO-NE 2017 State of the Market Report[10] points out the units receiving day-ahead uplift payments systematically receive more revenue than the market revenues. This situation causes lower-cost resources to set energy prices, and hydro could be one of them. With FERC Order 844, which requires the system operator to publish resource-specific uplift report, we will then know more about hydropower's role in uplift.

---

[9] van Welie, Gordon. 2018. "State of the Grid: 2018, ISO on Background." https://www.iso-ne.com/static-assets/documents/2018/02/02272018_pr_presentation_state-of-the-grid_2018.pdf

[10] Patton, D. B., LeeVanSchaick, P., & Chen, J., (2018). 2017 assessment of the ISO New England electricity markets. *Potomac Economics*.

Figure 9 shows the average revenue ($/kW) from services other than energy generation. In recent years, there has been an upward trend in the capacity payment, which is consistent with the market trend. The capacity cost increased from $1.1B in 2013 to $2.2B in 2017 (Figure 2). After capacity payment the next highest revenue is from spinning reserve, followed by blackstart and supplemental reserve.

Figure 9 shows the average revenue per kilowatt from services other than energy. In recent years, there is an upward trend in the capacity payment which is consistent with the market trend. The capacity cost increases from 1.1 billion dollars in 2013 to 2.2 billion dollars in 2017 (Figure 2). After the capacity payment the next highest revenue is from spinning reserve, followed by blackstart, and supplemental reserve.

Together Figure 8 and Figure 9 show that capacity payment gradually concentrates on a few plants, and it helps to explain the increase in capacity payment in terms of dollars/kilowatt. The participation of spinning reserve increases more than 30%, which might be a reaction to the high revenues seen in 2016, and then the high participation diminishes the revenue from spinning reserve in 2017. The blackstart can bring considerable revenue compared with other ancillary services, but it has disappeared since 2013. The disappearance can be partly affected by the change in the reporting standard of EQRs, but more possible reason is the NERC standards revision. In 2012 NERC retired and revised some reliability standards like EOP-005-2 R3.1, a requirement specifically for blackstart resources[11]. Additionally, a few Critical Infrastructure Protection standards proposed more requirements on the blackstart resources and restoration plan in the following years[12]. These changes make some units, especially some small units connected to distribution network no longer favored by the restoration plan and some units become too costly to provide blackstart.[13] As for uplift, although there has been a surge in recent years, the revenue from uplift is low with an average of about $1/kW and a variance of less than $0.01/kW to $8/kW.

---

[11] Paragraph 81 Project Technical White Paper, NERC (2012): https://www.nerc.com/pa/Stand/Project%20201302%20Paragraph%2081%20RF/P81_Phase_I_technical_white_paper_FINAL.pdf

[12] Gracia, J., O'Connor, P., Markel, L., Shan, R., Rizy, D., & Tarditi, A. (2019). *Hydropower Plants as Black Start Resources* (No. ORNL/SPR-2018/1077). Oak Ridge National Lab. (ORNL), Oak Ridge, TN (United States).

[13] Personal communication with John M Simonelli on Sep 3rd, 2019.

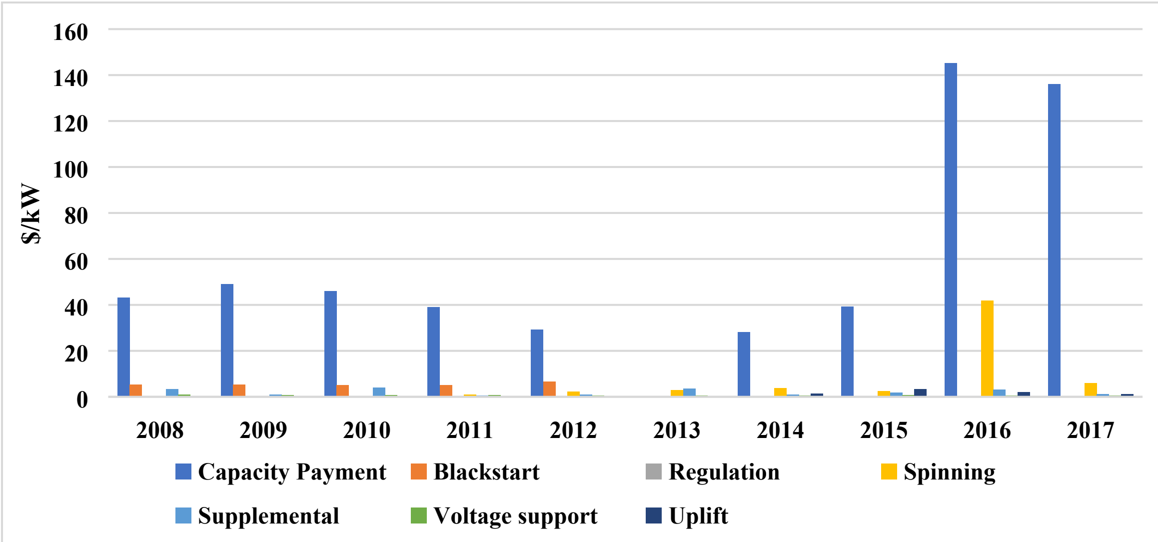


Figure 9 Average ancillary service revenue trend.

Note that the revenue data in Figure 9 only includes the plants providing the service in that year; thus revealing different information than Figure 2Figure 3, which contains all the plants in our validated sample that provided any single non-energy service. If a plant provides all these services at average prices in each service market in 2016, it can earn as high as $186/kW, which is higher than the average total revenue in 2016 and 2017. This however is misleading since many services are mutually exclusive. For example, a plant cannot use the same 1 kW capacity to deliver 1 kW of spinning reserve and supplemental reserve at the same time. The plant could use the same 1 kW capacity to receive both the capacity payment and the revenue from energy at the same time because of different contract mechanisms. Although we cannot add them together, we can still see the revenue potential in them. The high revenue from capacity payment is comparable to the revenue from energy, mitigating the concerns of declining energy price and providing confidence and revenue stability for new power plant investors. However, with more incentives[14] for renewable resources to participate in the capacity market of ISO-NE, it is uncertain whether the capacity payment will still be the comparable and necessary supplementary element to the revenue from selling energy for hydropower plants.

[14] Renewable technology resource designation allows some renewable resources to participate in the forward capacity auction without being subject to the minimum offer-price rule. The recent (Feb 2019) auction price was 3.8 $/kW-month, comparing with 2018 as 4.63$/kW-month.
https://www.iso-ne.com/static-assets/documents/2019/02/20190206_pr_fca13_initial_results.pdf

HydroWIRES
U.S. DEPARTMENT OF ENERGY

OAK RIDGE
National Laboratory

HTTPS://WWW.ENERGY.GOV/EERE/WATER/HYDROWIRES-INITIATIVE