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Environmental Regulation Impacts on Eastern Interconnection Performance

July 2013

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ENVIRONMENTAL REGULATION IMPACTS ON EASTERN INTERCONNECTION PERFORMANCE

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

In the United States, recent environmental regulations will likely result in the removal of nearly 30 GW of oil and coal-fired generation from the power grid, mostly in the Eastern Interconnection (EI). The effects of this transition on voltage stability and transmission line flows have previously not been studied from a system-wide perspective. This report discusses the results of power flow studies designed to simulate the evolution of the EI over the next few years as traditional generation sources are replaced with environmentally friendlier ones such as natural gas and wind.

1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) recently finalized the Mercury and Air Toxics Standards (MATS) and the Cross-State Air Pollution Rule (CSAPR), which are regulations designed to reduce power plant emissions such as mercury, NO_x, SO_2, and ozone [1, 2]. Assuming these rules pass judicial review, as much as 30 GW of generation capacity (mainly coal and oil-fired units) will be taken offline within the next few years [3], mainly from the Eastern Interconnection. Most of this lost capacity is being replaced with natural gas-fired generation, such as gas turbines and combined-cycle plants. Since power injections are being removed from some points in the grid and added to others, the flow of power will be altered, which could have important implications for voltage stability and equipment ratings. This report presents a study designed to simulate and quantify the effects of MATS/CSAPR-related generator deactivations on bus voltages and transmission line flows in the Eastern Interconnection over the next few years.

1.1 MERCURY AND AIR TOXICS STANDARDS

According to the Environmental Protection Agency, coal and oil-fired power plants are responsible for approximately half of the airborne mercury emissions in the United States [2]. Upon entering water, biological processes convert the metal to methylmercury, an even more toxic substance that bioaccumulates in fish and other aquatic wildlife. Consumption of methylmercury-contaminated fish by pregnant women and children is particularly dangerous since it can affect nervous system development. In addition, coal and oil-fired power plants release toxic metals such as arsenic, chromium, and nickel, which are believed to be carcinogenic. The Mercury and Air Toxics Standards establish limits on the amounts of these substances that can be released into the environment, while also creating work practices designed to reduce emissions of organic air toxics such as dioxins and furans.

Power plants can limit their emissions by employing any of several different pollution control technologies, such as flue gas desulfurization (FGD), activated carbon injection (AJI), or fabric filtration [4]. However, retrofitting existing plants with these controls is both expensive and time consuming. In many cases, it would be uneconomical for plant owners to bring their generating stations into compliance. Thus, MATS will effectively shutter a large number of coal and oil-fired power plants.

1.2 CROSS-STATE AIR POLLUTION RULE

In July of 2011, the EPA finalized the Cross-State Air Pollution Rule (CSAPR), which applies to 23 states located within the Eastern Interconnection. CSAPR replaces the Clean Air Interstate Rule, and aims to reduce SO_2, NO_x, ozone, and fine particulate emissions produced by power plants. The

EPA cites a variety of health and environmental benefits resulting from the rule, including the annual avoidance of:

- 13,000-34,000 premature deaths
- 15,000 nonfatal heart attacks
- 19,000 emergency room visits
- 1.8 million lost work days or school absences
- 400,000 asthma attacks [1]

One of the most striking aspects of CSAPR is the speed at which the EPA expects compliance. The first reductions were scheduled to begin in January of 2012, with total implementation being achieved in 2014. The rule is currently being challenged by utilities in the federal court system, so the actual implementation timeline and number of affected plants is unknown. However, some utilities have already begun the process of retiring older plants, regardless of whether or not CSAPR takes effect [5-9].

1.3 STEADY-STATE ANALYSIS

Electrical power is unique compared to other commodities in that it must be consumed at the same time it is produced. Complicating matters, electrical energy is difficult to store in large quantities and cannot be easily routed along a particular transmission path. Rather, the flow of power is determined by the structure of the system itself [10]. It is this particular property that makes it difficult for significant topology changes to be made to the system without dramatically affecting the line flows and bus voltages.

Power flow (also called “load flow”) studies are the primary means of steady-state analysis used by system planners, and form the basis for dynamics studies as well. Given a model of the system and the loads it supplies, the load flow computes the load bus voltages, line flows, and generator bus angles. These quantities can then be used to determine which system components are operating outside of their limits. Because the power flow problem is non-linear, numerical techniques such as various forms of the Newton-Raphson method are employed to find the solution. Several commercial software packages exist for this purpose, including PSS/E, PowerWorld, and PSLF.

Environmental regulations such as MATS and CSAPR will most likely result in a large number of power plants being shut down. This represents a significant loss of generation capacity, which could be as small as 14.5 GW, or as large as 30 GW [3]. (Estimates of the actual amount vary depending on who is doing the calculation.) Obviously, this capacity must be replaced by some other means. Recent advancements in drilling technology have unlocked previously uneconomical natural gas reserves, most notably the Marcellus Shale. The drop in natural gas prices created by this additional supply has led many utilities to invest in gas-fired generating units, which can be quickly built at a much lower cost than nuclear plants [11]. One important constraint for gas plants, however, is that they must be built near both major gas pipelines and high-voltage transmission lines.

The shutdown of so many large coal and oil-fired units and their replacement with gas-fired generators could present some significant challenges to the grid. New plants will in many cases be built in different locations than the generators being shut down and will thus alter the topology of the system. As a result, the flow of power will be different than it is now. For example, lines that are presently operating below their capacity could become congested, which would have implications for system reliability and the locational marginal price (LMP) of electricity. Other areas could see voltage problems. NERC studied the potential impacts of the draft regulations from the perspective of reserve adequacy [12], but has not examined the possible steady-state consequences. Thus, there is a clear need for this type of study.

2. STUDY DESIGN

The Institute for Energy Research (IER) has compiled a list of power plants that it claims will likely be shut down as a result of MATS and CSAPR, which can be found in Appendix A [3]. A map of these plants is given in Fig. 2.1. It should be noted here that IER is tied to the energy industry and should not be considered a completely unbiased source [13]. However, because IER would presumably be very conservative in their estimation of the affected plants, their list can be thought of as a worst-case scenario. Using this list and a 29,000-bus model of the Eastern Interconnection, the proposed regulations' effects on the grid under a variety of different conditions were studied to identify those regions that would be negatively impacted.

Before any simulations could be performed, it was necessary to first develop the information infrastructure needed to create, manage, and analyze a large number of simulation cases. The first portion of this task involved creating a database table of all generators that could conceivably be added or removed from the model. For the affected generators, the IER list mentioned earlier was used to populate the table. In a few cases, this list was augmented or corrected by media reports issued after its publication. Data for new generation facilities and nuclear power plants were obtained from the 2010 U.S. Energy Information Agency Form 860 data file [14] and the Nuclear Regulatory Agency [15], respectively. The table structure for the generator data is given in Table 2.1.

Table 2.1 Description of generator database table

Field	Description
generatorId	Primary key; a unique identifier for this generator independent of PSS/E
fuelType	Numerical indicator to represent fuel type
busnum	Corresponding bus number in PSS/E. A foreign key tied to the 'bus' table.
unitId	Corresponding unit ID in PSS/E
capacity	Summer capacity, in MW
plantName	Name of the plant
startYear	Year the plant went into operation, if known
endYear	Year the plant is scheduled to be taken offline
lat	Latitude
lng	Longitude
city	City
state	State
inModel	Boolean variable indicating if the generator exists in the model or not
syncon	Not used

Additional tables were created to store data related to the lines, buses, areas, and zones found in the PSS/E model. Foreign key constraints were applied to maintain data consistency and integrity. These constraints made it impossible to, for example, link a generator to a bus that did not exist in the model.

The Eastern Interconnection model used in this study represents the Summer 2015 peak load case. It was developed by the Multiregional Modeling Working Group (MMWG) in 2010, and contains approximately 29,000 buses and 4,000 generators. Most of the EI system is included in the model, however Florida and some parts of the extreme northeast have been removed. Although the model contains the necessary mathematical attributes describing each system component, it does not include their geographical information such as latitude and longitude. Fortunately, the Energy Visuals models available for Power World include this data for most of the buses in the system (Fig. 2.2). Since the bus numbers in both models are generally the same, the latitudes and longitudes could easily be merged using the statistical analysis software SPSS and added to the database.

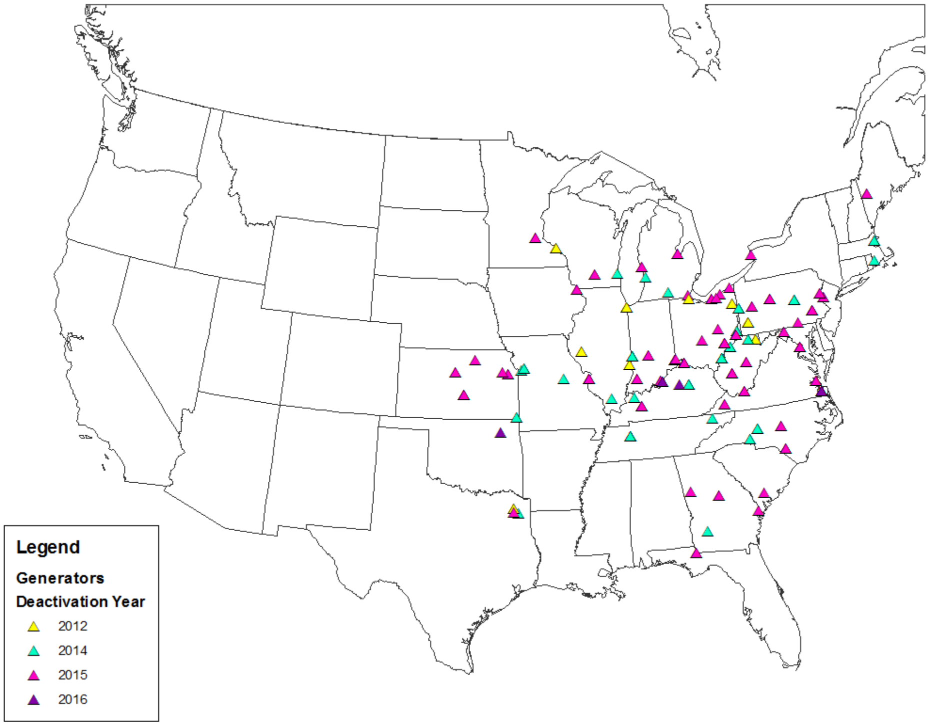

Fig. 2.1. Map of generators by deactivation year

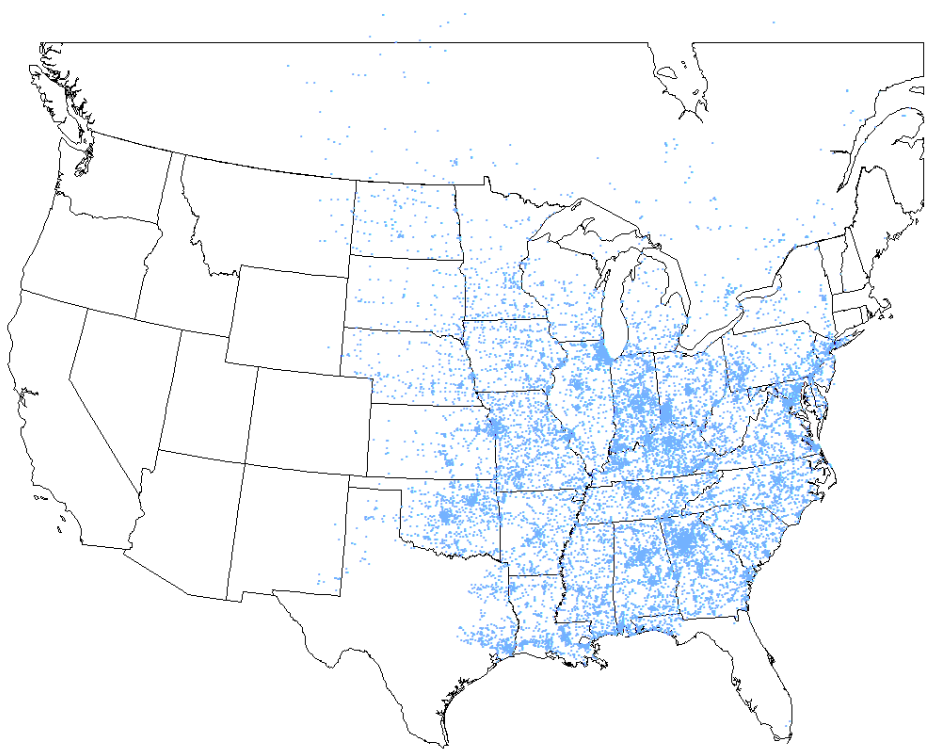

Fig. 2.2. Bus locations in 2015 MMWG EI model

Because the objective of this research was to quantify the effects of adding and removing different generators from the system, the next step was to determine which machines in the model (as identified by a bus number and two-character unit identifier) corresponded to those found in the generator table. Several of the MATS/CSAPR-affected generators had already been located during previous studies, which greatly simplified this task. However, some generators (particularly new ones) still needed to be located. This was done by manually searching for the plant name in the Energy Visuals model to yield the associated bus number, which was then matched against the machines found in the MMWG model. In all, 151 of the 223 generators identified by IER and media reports were successfully located using this method.

Generators that could not be found, as well as new units that needed to be added to the model, presented a unique challenge. In order to adequately model the power flow, each unit must be connected to a bus in the model that approximates its physical location in the system. This was done by utilizing the Google Maps API in Python to convert each generator's city and state to a latitude and longitude, which was then used to find the nearest high voltage (>100 kV) bus in the model.

To avoid double-counting generators, the PSS/E model needed to be checked to ensure that the new units were not already included. This was done by using the Jaro-Winkler string similarity measure to compare the 12-character PSS/E bus names to the complete plant names found in the database. The Jaro-Winkler distance was chosen because it is well-suited for short strings and provides a similarity between zero and one, with one being a perfect match [16]. To limit the number of comparisons that needed to be made, the plant names were only matched against buses within 0.5 degrees of latitude and longitude. A Jaro-Winkler similarity of at least 0.7 was required for a bus to be considered as a match candidate. The list of possible matches was then reviewed manually and the generator database was updated to reflect any duplications found.

2.1 SIMULATION SCENARIOS

For this research, 60 different scenarios were developed that reflect the possible evolution of the Eastern Interconnection in the next few years. These scenarios are based on projected generator deactivations, forecasted demand growth, and likely construction of new generating capacity. Table 2.2 describes several base cases that serve as the experimental controls. Each cell contains the unique numerical identifier assigned to a particular scenario. The first row represents the "do-nothing" or "business as usual" case, that is, it assumes that no generators are taken offline, but includes expected load growth. The next row represents the removal of generators as a result of MATS and CSAPR. Row three describes scenarios where some of the affected generators are instead used as synchronous condensers. Summer demand forecasts for the Eastern Interconnection from 2012 through 2017 are given in

Table 2.3 [17]. Since the model used in this study lumps some portions of the system together, its load must be scaled proportionally as given in Table 2.4.

Table 2.2 Base Cases and Identifiers

	2012	2013	2014	2015	2016	2017
Anticipated load increases only, all generators in place	1	23	27	7	17	14
With MATS/CSAPR coal-fired generators removed	2	24	28	10	16	15
With synchronous condensers added	50	51	52	49	53	54

Table 2.3 Forecasted Summer Demand for the Eastern Interconnection

	Summer Demand, MW					
Region	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
FRCC	51,499	52,645	53,641	54,862	56,100	57,346
MRO (US)	48,009	48,786	49,536	50,288	51,101	51,799
NPCC (US)	66,219	66,952	67,604	68,210	68,758	69,299
RFC	195,700	198,400	201,100	203,600	206,200	208,600
SERC	221,590	225,650	230,208	234,597	238,792	243,056
SPP	47,012	47,715	48,428	49,152	49,876	50,640
MRO (CA)	6,650	6,717	6,780	6,763	6,821	6,869
NPCC (CA)	50,392	50,476	50,546	50,347	50,452	50,655
Total (MW)	**687,071**	**697,341**	**707,843**	**717,819**	**728,100**	**738,264**

Table 2.4 Adjusted Demand for the 29,000-bus EI Model

	2012	**2013**	**2014**	**2015**	**2016**	**2017**
Total Load (MW)	554,798	563,120	571,567	580,140	588,842	597,675

Much of the generation capacity lost due to CSAPR and MATS will be replaced with gas turbines or combined-cycle plants. According to the U.S. Energy Information Agency, approximately 21.5 GW of gas-fired generation will be built between now and 2017 [14]. A list of planned gas power plants can be found in Appendix B. The scenarios given in the first row of Table 2.5 represent the projected installations of new gas turbines given anticipated increases in load. The second row includes the 8 GW of wind turbine generation planned in the next five years. A list of planned wind power installations can be found in Appendix C.

Table 2.5 Gas Base Cases

	2012	**2013**	**2014**	**2015**	**2016**	**2017**
With no wind	3	25	29	12	18	20
With planned wind buildout	22	26	30	13	19	21
Gas Base Case with synchronous condensers added	55	56	57	58	59	60

Although fossil fuels will continue to supply a large portion of the electrical demand in the United States for the foreseeable future, concerns over global warming and future environmental regulations have led to a renewed interest in nuclear power [18]. The U.S. Nuclear Regulatory Commission currently has 12 applications for new reactors under consideration [19]. Of these, six are scheduled for completion in the next few years [14, 20]. A list of these plants can be found in Appendix D. The nuclear base case described in the first row of Table 2.6 includes the new gas-fired generation from Table 2.5 and assumes that these reactors are finished on schedule, and that the license renewals for existing reactors are granted. Cases in the second row include planned wind generation. Finally, the last row describes scenarios where all nuclear plants are removed from the system, similar to what is being planned in Germany and Switzerland [21, 22].

Table 2.6 Nuclear Base Cases

	2012	2013	2014	2015	2016	2017
With no wind (includes gas)	31	32	33	34	35	36
With planned wind buildout	37	38	39	40	41	42
Nuclear Base Case with synchronous condensers added	61	62	63	64	65	66
With all nuclear plants removed	43	44	45	46	47	48

Each case was then described using a number of different parameters, which were then stored in a database table. The table structure for the case descriptions can be found in Table 2.7.

Table 2.7 Case table description

Field	Description
caseId	Primary key, a unique numerical identifier for the case
gensRemoved	Boolean to indicate if MATS/CSAPR-affected generators should be disabled
synCon	Boolean to indicate if synchronous condenser conversion should be performed
wind	Boolean to indicate if wind generation should be added
gas	Boolean to indicate if gas-fired generation should be added
nukesRemoved	Boolean to indicate if existing nuclear reactors should be removed
addNukes	Boolean to indicate if planned nuclear reactors should be added
year	The year this case represents
baseCaseFile	The previously saved PSS/E model file that this case should modify

2.2 SIMULATION PROCEDURES

The large number of generators (487) being manipulated in this study made it virtually impossible for the PSS/E model to be modified manually. Thus, the PSS/E Python API was used to automate the process of adding and removing generators from the system and running the power flow. A Python script was written to load the case description from the database along with its corresponding base case model. Next, the script removed each generator from the IER list one-at-a-time, increasing the remaining generation to compensate accordingly, and solved the power flow. If the power flow successfully converged, it then saved a backup file to serve as a restore point for further simulations. If the power flow failed to converge after removing the generator, it was turned into a synchronous condenser by setting its real power output to zero. The power flow solution was then re-attempted. In the event of an unsuccessful simulation, the last restore point was reloaded and the simulation continued from that point. New generators were added by first scaling the existing generators' output down by the capacity of the new unit, followed by the creation of a 22-kV generator bus with a transformer connected to the previously identified high voltage bus. Next, the generator was added to the 22-kV bus using the parameters calculated according to Table 2.8. In order to improve convergence, the per-unit voltage setpoint of the generator was set to be equal to that of the associated high-voltage bus. For this study, it was assumed that each generator was designed to operate at a power factor of 0.8. The power flow was then solved before adding the next unit. This procedure was repeated for each of the 60 simulation cases.

Table 2.8 Generator Parameter Calculations and Descriptions

Parameter	Calculation	Description
P_{GEN}	capacity × 0.95	Scheduled real power output, MW
P_{MIN}	capacity × 0.20	Minimum real power generation capacity, MW
P_{MAX}	capacity	Maximum real power generation capacity, MW
Q_{MAX}	(capacity/0.8) × 0.6	Maximum reactive power generation capacity, MVAr
Q_{MIN}	-(capacity/0.8) × 0.6	Minimum reactive power generation capacity, MVAr
M_{BASE}	capacity/0.8	Machine base apparent power, MVA

Upon completion of the simulations, a Python script was used to extract the high-voltage (>230 kV) buses and lines exceeding their voltage and current ratings, respectively. This information was recorded in the database tables named *busresult* and *branchresult*, which were then imported into ArcGIS to create intuitive visualizations of each scenario's results.

After performing the initial group of simulations where a large number of MATS/CSAPR-affected generators were removed and replaced with gas and wind generators, the bus voltages were used to locate areas in the system where synchronous condensers might be needed. Deactivated generators whose capacities were greater than 100 MW and within 50 miles of an out-of-limit bus were set as synchronous condensers, and the power flow studies were re-run.

Once all simulations had been performed, the converged cases were checked against the case descriptions stored in the database and summarized using a Python script. In general, deviations resulted when a particular machine could not be removed from the model without causing it to diverge during simulation. Since the goal of this study was to model the changes in the grid as accurately as possible, these machines were left in the model so that the effects of removing the remaining generators could be examined.

3. RESULTS

The following maps show the out-of-limit bus voltages and overloaded transmission lines resulting from each simulation, which are overlaid on the high voltage transmission grid of the Eastern Interconnection. The cases are grouped by the year they represent in the order given by Table 2.2, Table 2.5, and Table 2.6. Due to the fact that no new nuclear plants are scheduled to begin operation between now and 2014, the cases described in the first three rows of Table 2.6 for those years are not shown, since they duplicate the corresponding cases in Table 2.5.

3.1 2012

Fig. 3.1 shows simulation results from the 2012 business-as-usual case where no generators are deactivated and no additional generating capacity is added. It is apparent that many bus voltages are above 1.05 p.u., a trend that is visible in all the simulations performed for this study. This is largely due to the fact that the model used in these simulations is configured for the high-voltage transmission system buses to be slightly above their nominal ratings so that a given contingency will not result in low voltages that might violate NERC standards [23]. When the 23 MATS/CSAPR-affected generators are removed (Fig. 3.2), little, if any change is observed, possibly due to the relatively small amount of generation (4,240 MW) being removed from the system that year. However, it was found that the Bay Shore Power Plant in Oregon, Ohio needed to be operated as a synchronous condenser in order for the remaining MATS/CSAPR generators to be removed; this was required for many of the subsequent simulations. Since very few of the affected generators are located near the out-of-limit buses, only a few were converted into synchronous condensers (Fig. 3.3); their effect appears to be negligible.

The voltage profile appears to be relatively stable when 6,580 MW of new gas-fired generation (Fig. 3.4) and 1,526 MW of wind turbines were added (Fig. 3.5). As before, the addition of synchronous condensers did not make much difference (Fig. 3.6). For the final scenario involving the removal of all nuclear generators, 48 out of the 92 reactors were successfully disabled before the simulation failed to converge. This scenario resulted in a general lowering of bus voltages, with one bus being below 0.95 p.u. as shown in Fig. 3.7. Also, alterations made to the system did not have much effect on the number of overloaded lines, which stayed essentially constant for each of the 2012 scenarios. Because the geographical information for these lines could not be found, they are not shown on the maps below.

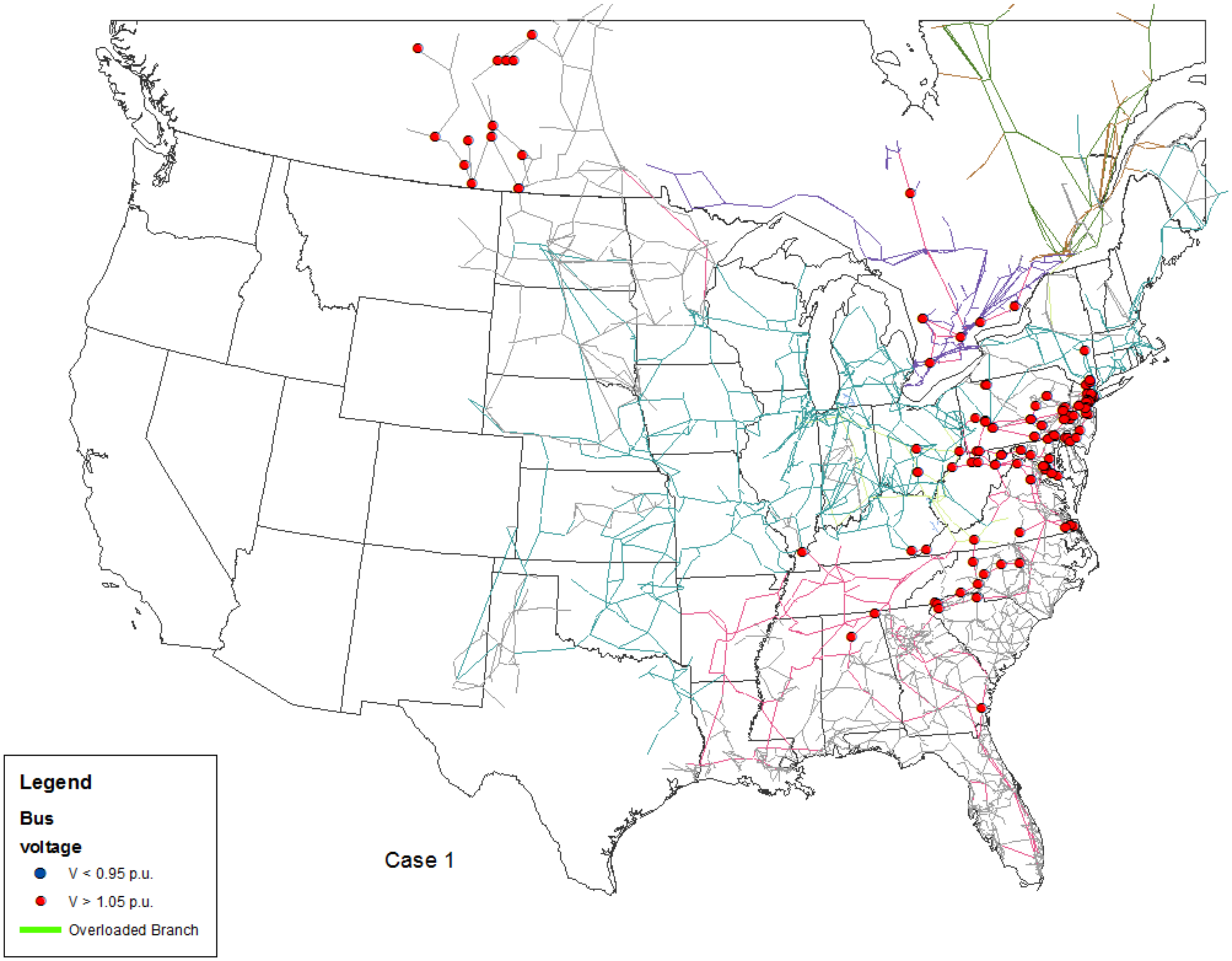

Fig. 3.1. 2012 base case

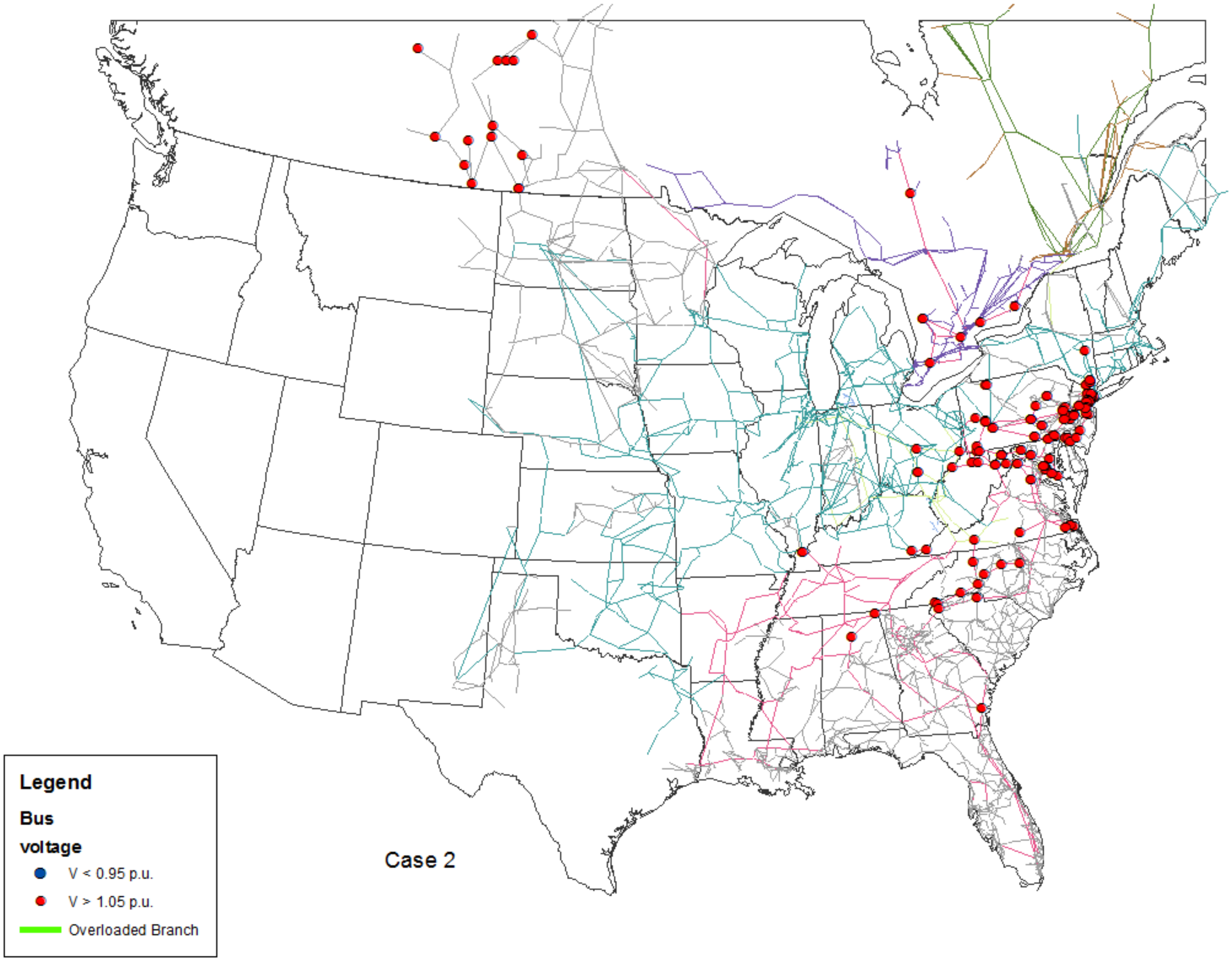

Fig. 3.2. 2012 base case with generators removed

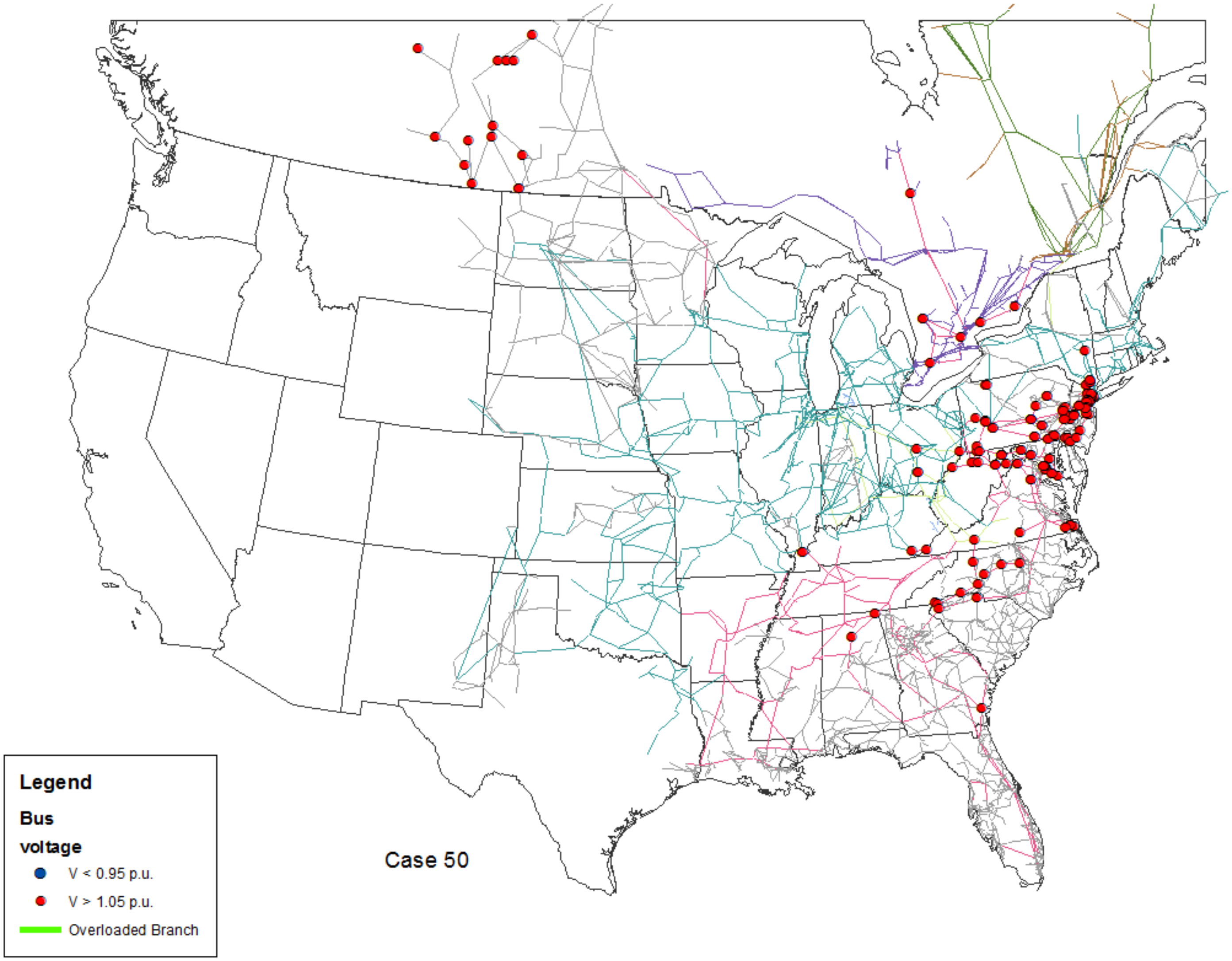

Fig. 3.3. 2012 base case with generators removed, synchronous condensers added

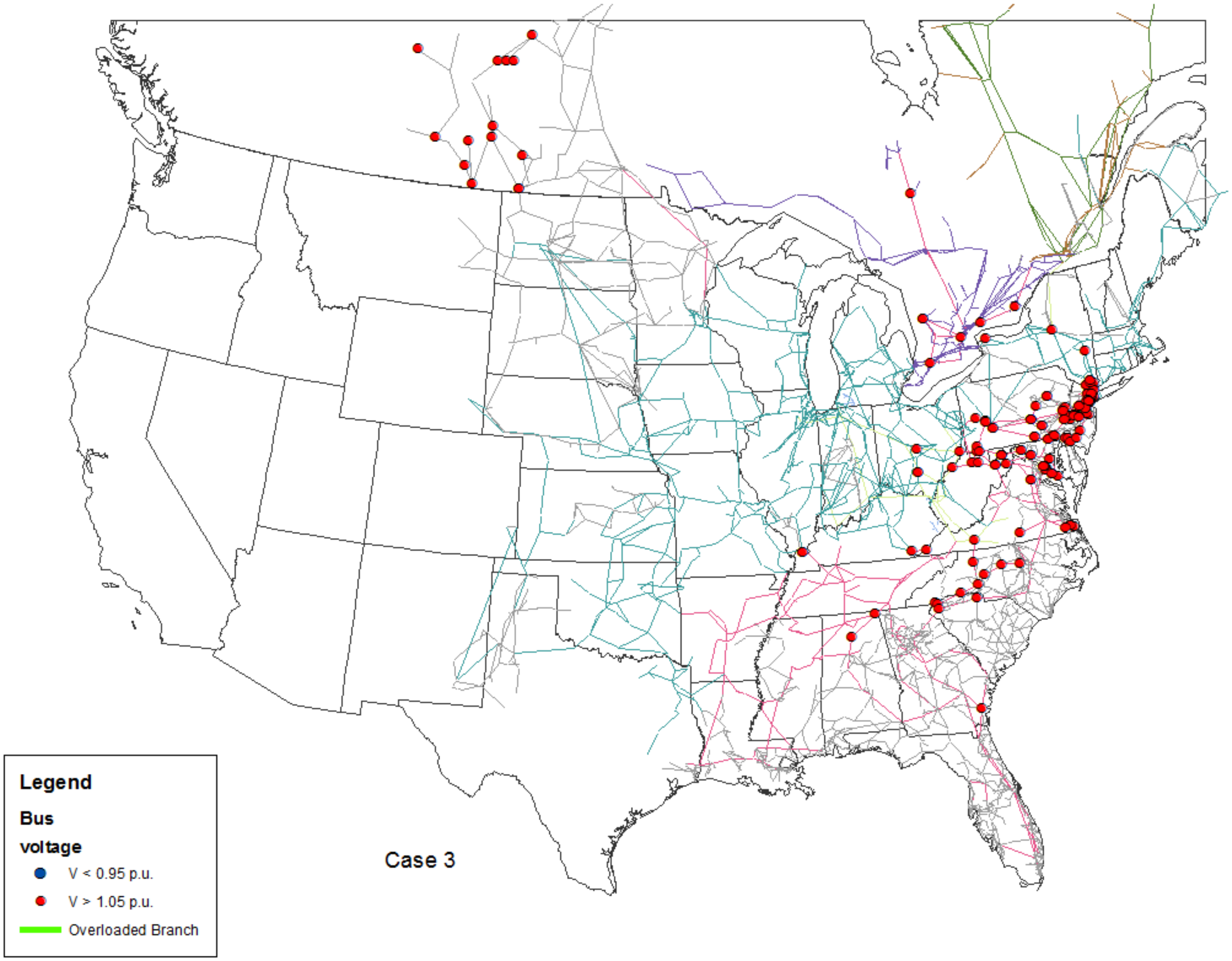

Fig. 3.4. 2012 gas base case

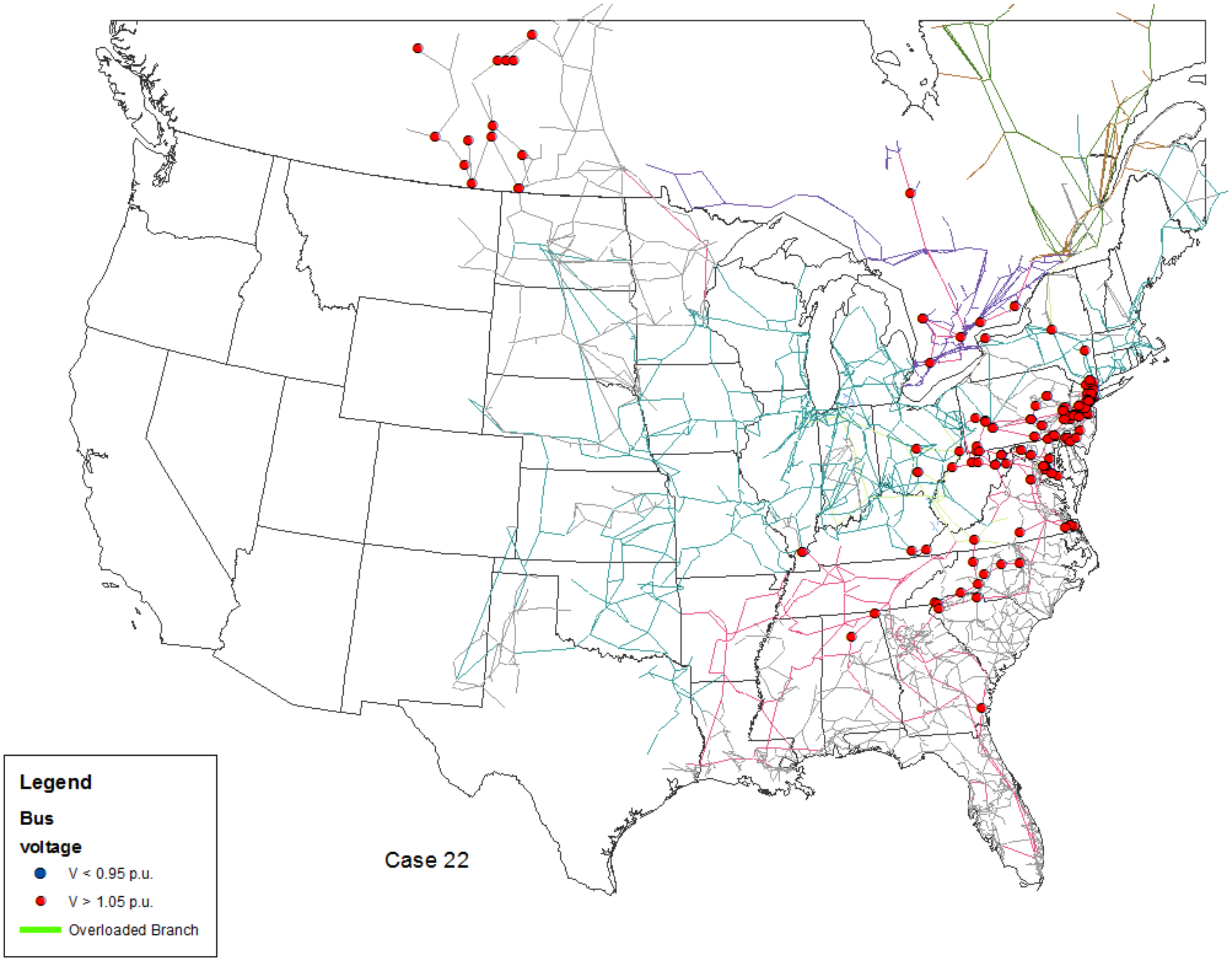

Fig. 3.5. 2012 gas base case with wind

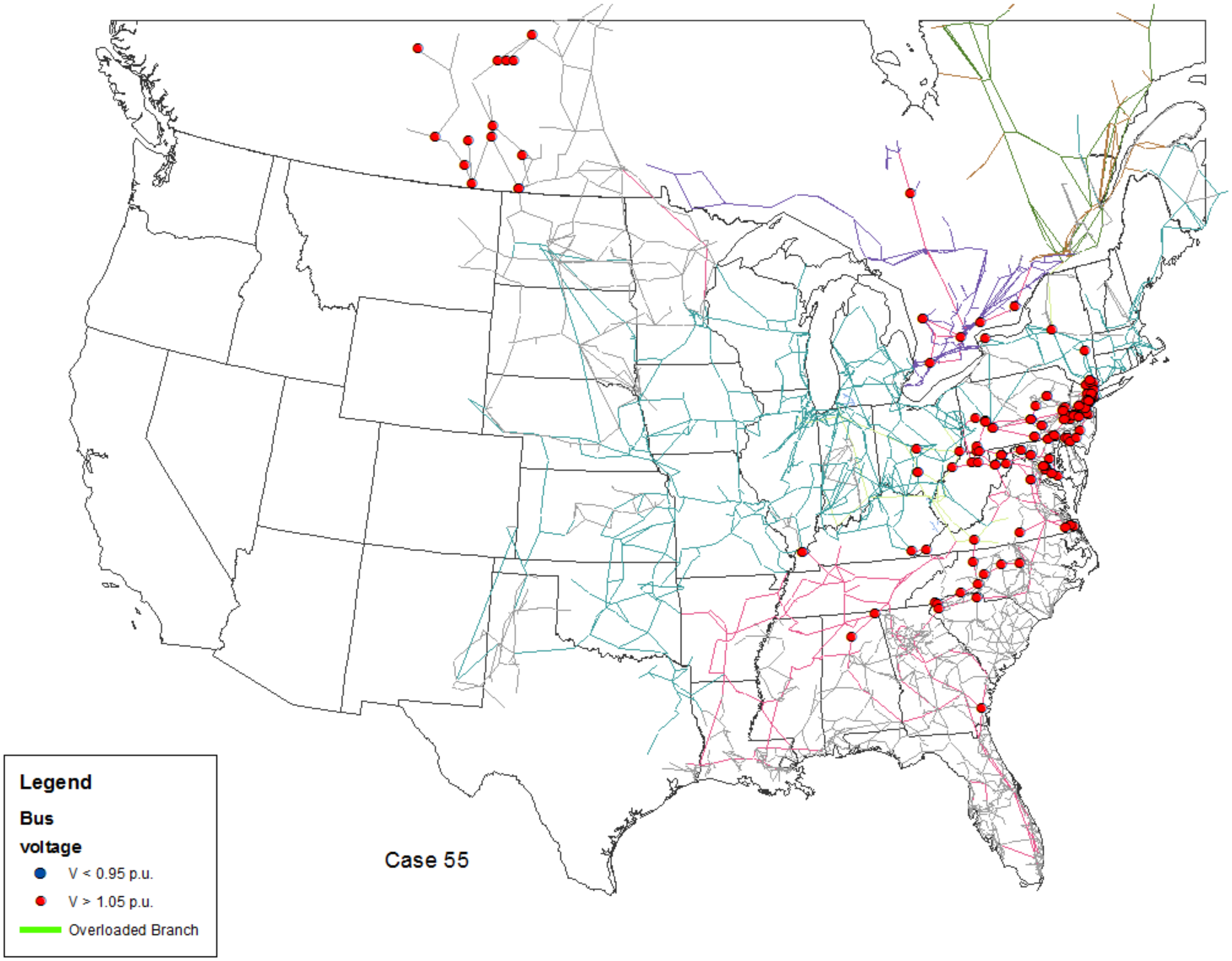

Fig. 3.6. 2012 gas base case with wind generation and synchronous condensers

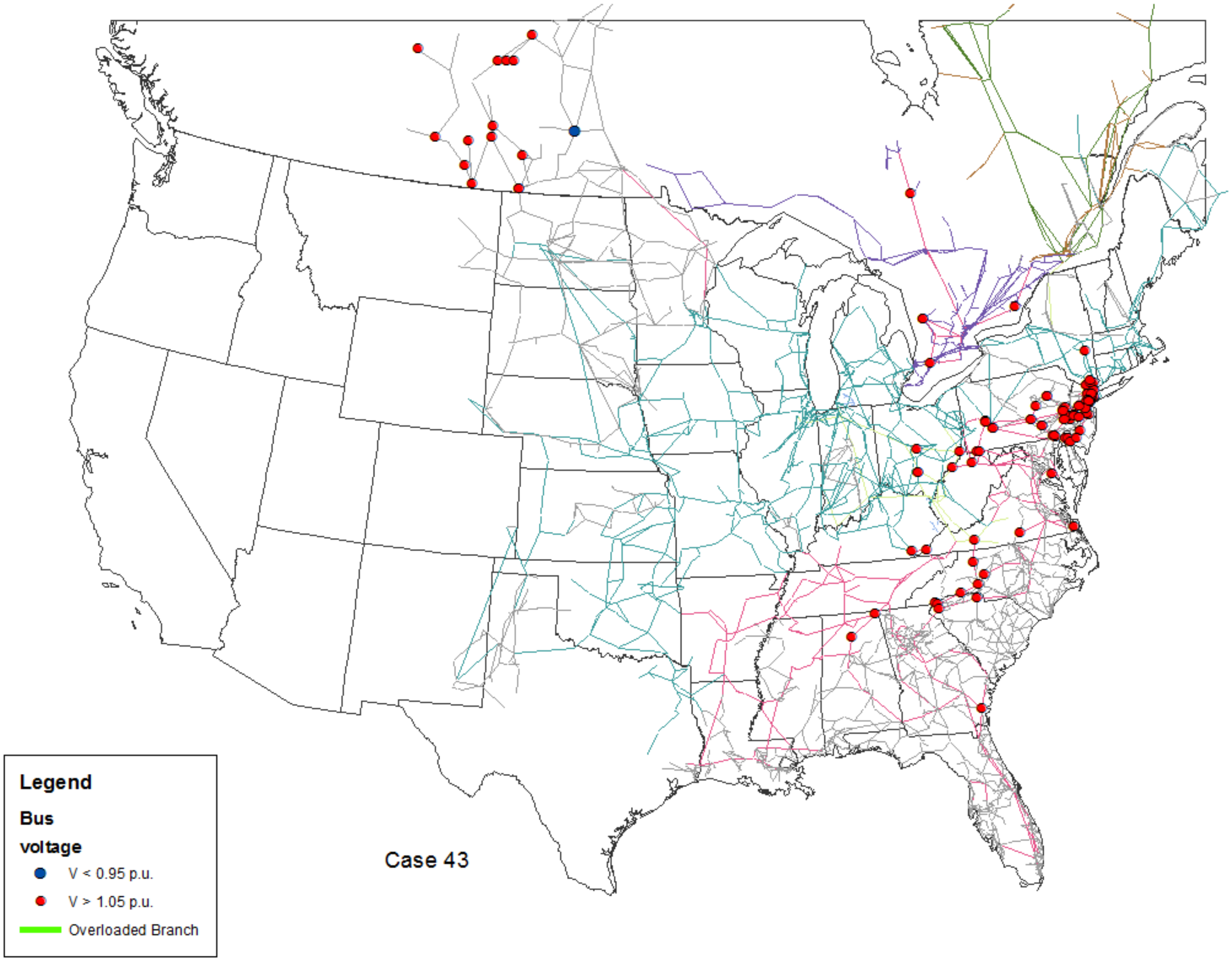

Fig. 3.7. 2012 gas and wind added, nuclear plants removed

3.2 2013

Simulation results from the 2013 base case are shown in Fig. 3.8. Like the 2012 base case, it shows a large number of overvoltage buses, though not quite as many. The 1.5% load growth from the previous year included in this case is probably responsible for the slight decline in bus voltages. No generators are due to be taken offline in 2013 as a result of MATS/CSAPR, thus Fig. 3.9 strongly resembles the corresponding figure from the 2012 scenarios. The conversion of some of the previously removed generators to synchronous condensers did not significantly affect the bus voltages (Fig. 3.10).

Only about 2,000 MW of gas-fired generation are to be added to the EI in 2013. This appears to add about 30 overvoltage buses to the system (Fig. 3.11) compared to the base case. The addition of 1,276 MW of wind generation (Fig. 3.12) has a negligible effect on the system, as does the conversion of some of the deactivated generators to synchronous condensers (Fig. 3.13). Only 38 nuclear reactors could be removed before the system failed to converge (Fig. 3.14), which is fewer than in the previous year. In most cases, only three high-voltage transmission lines were operated above their Rate B limits, the only exception being when the nuclear reactors were removed, leading to five overloaded lines.

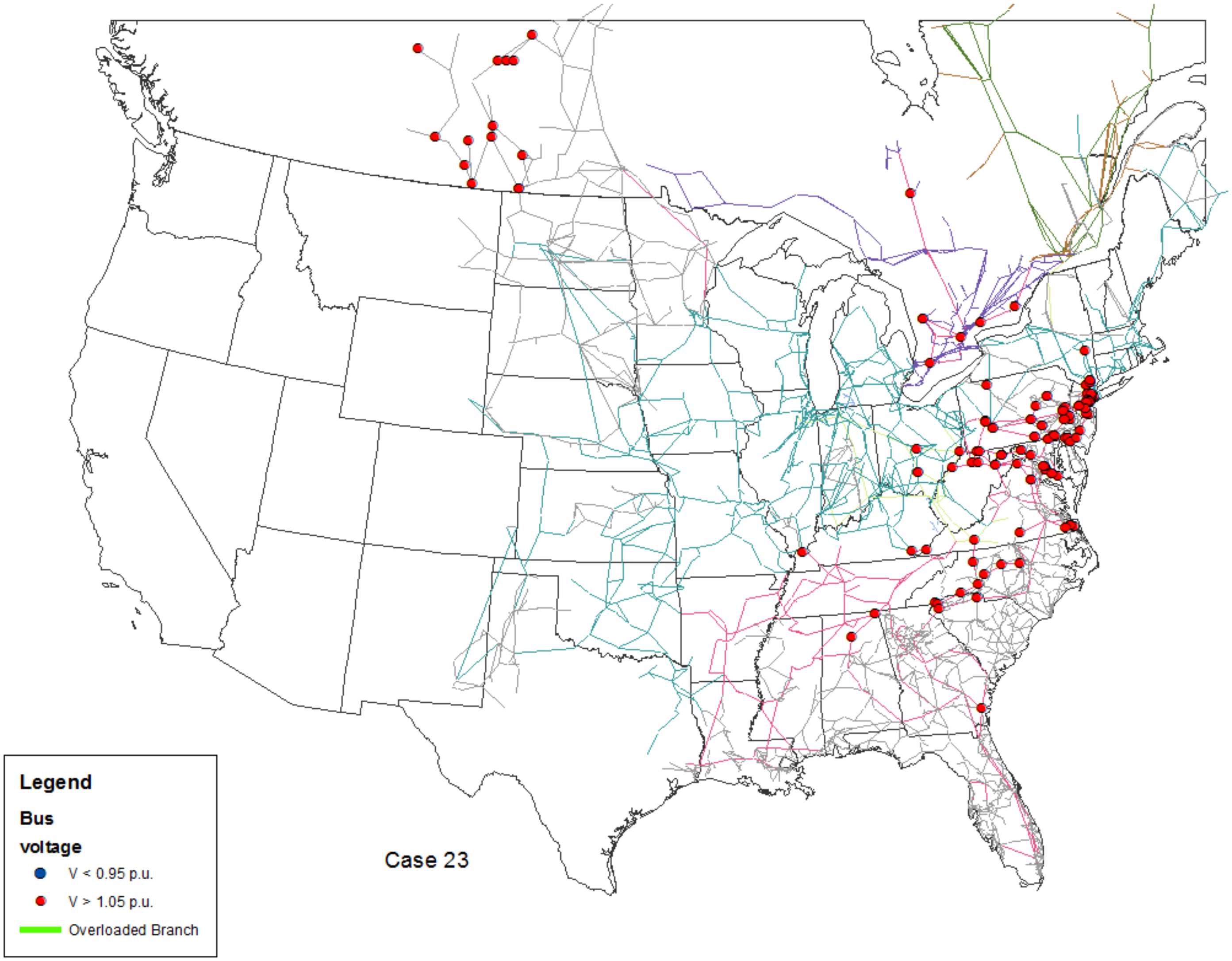

Fig. 3.8. 2013 base case

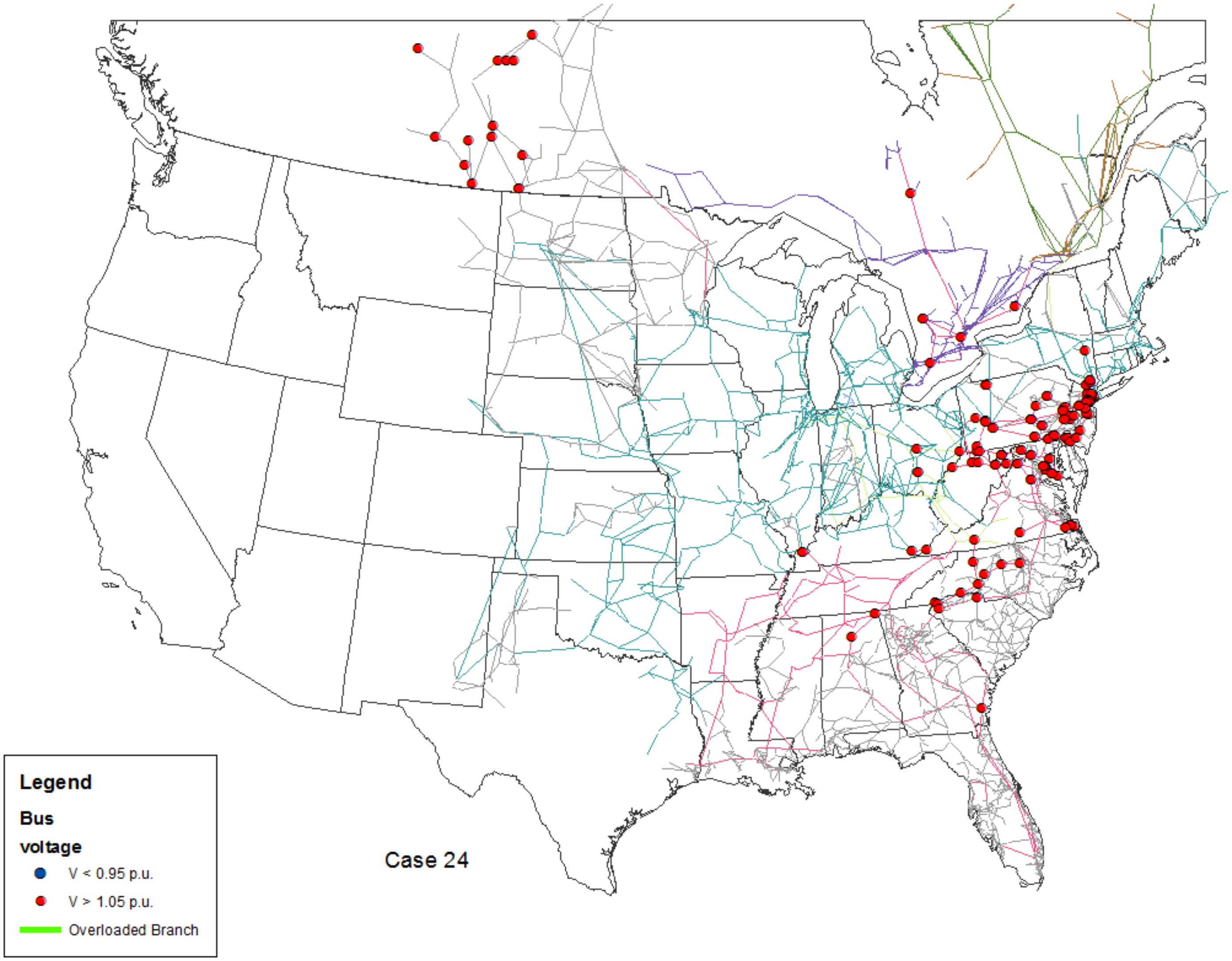

Fig. 3.9. 2013 base case with generators removed

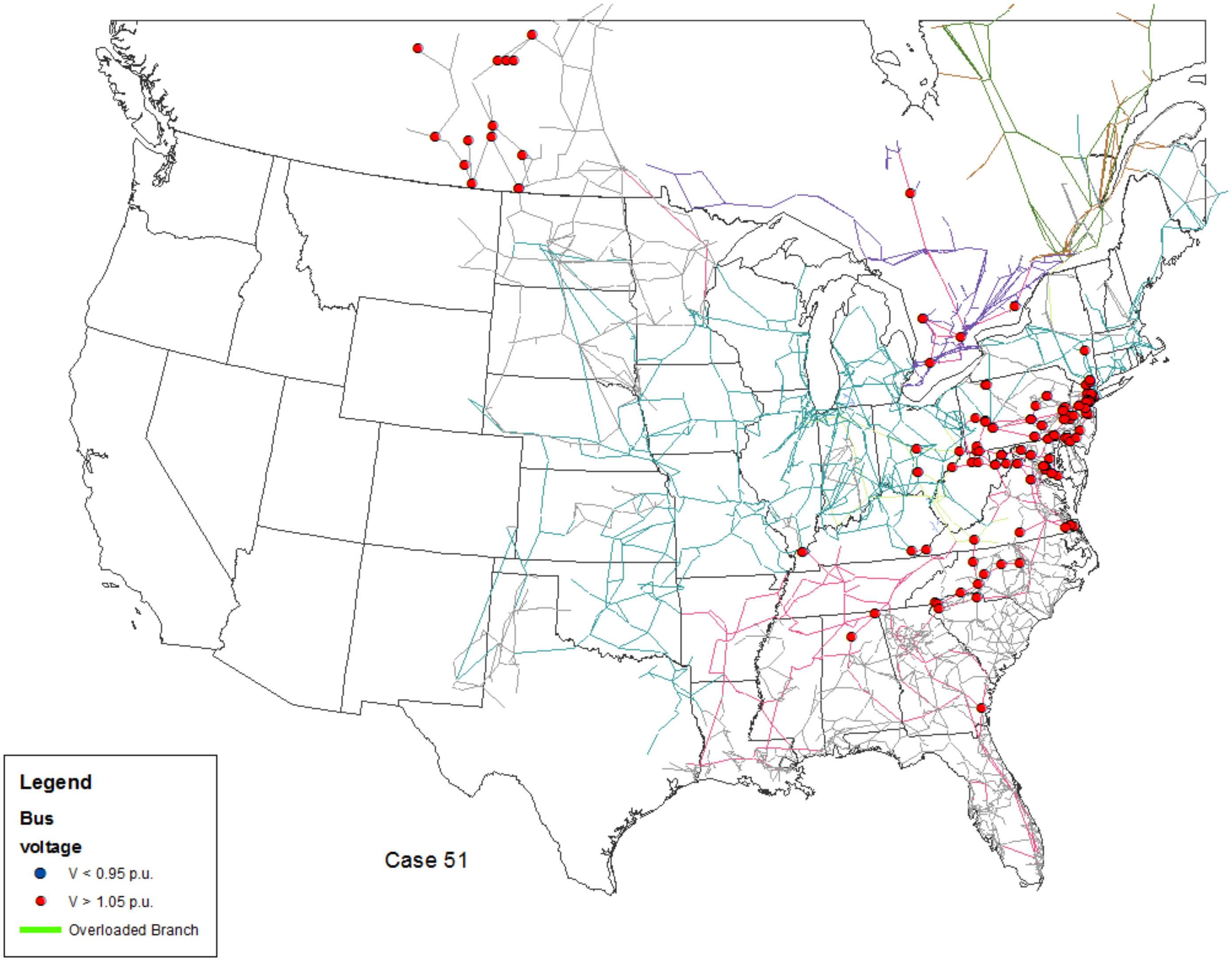

Fig. 3.10. 2013 base case with generators removed, synchronous condensers added

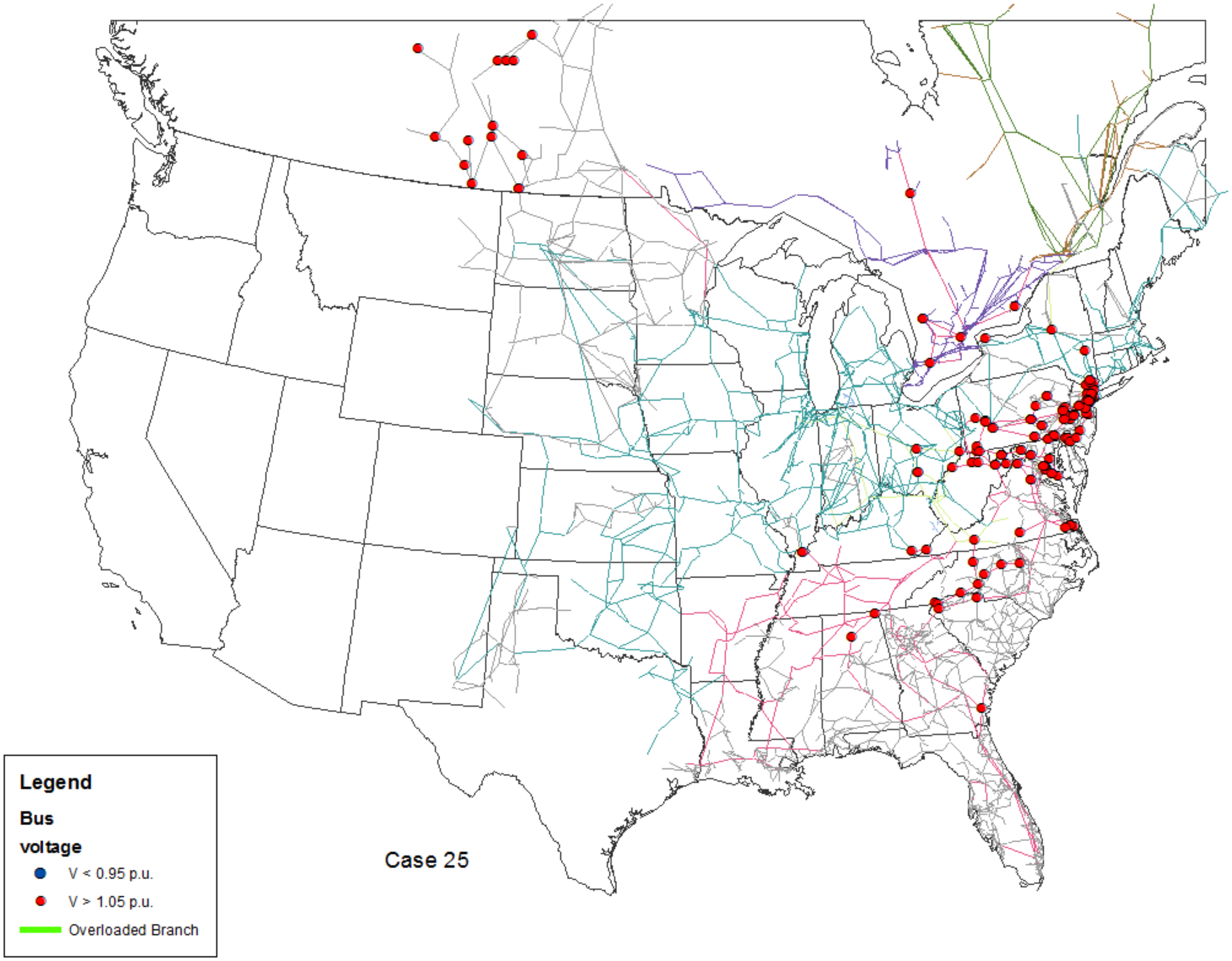

Fig. 3.11. 2013 gas base case

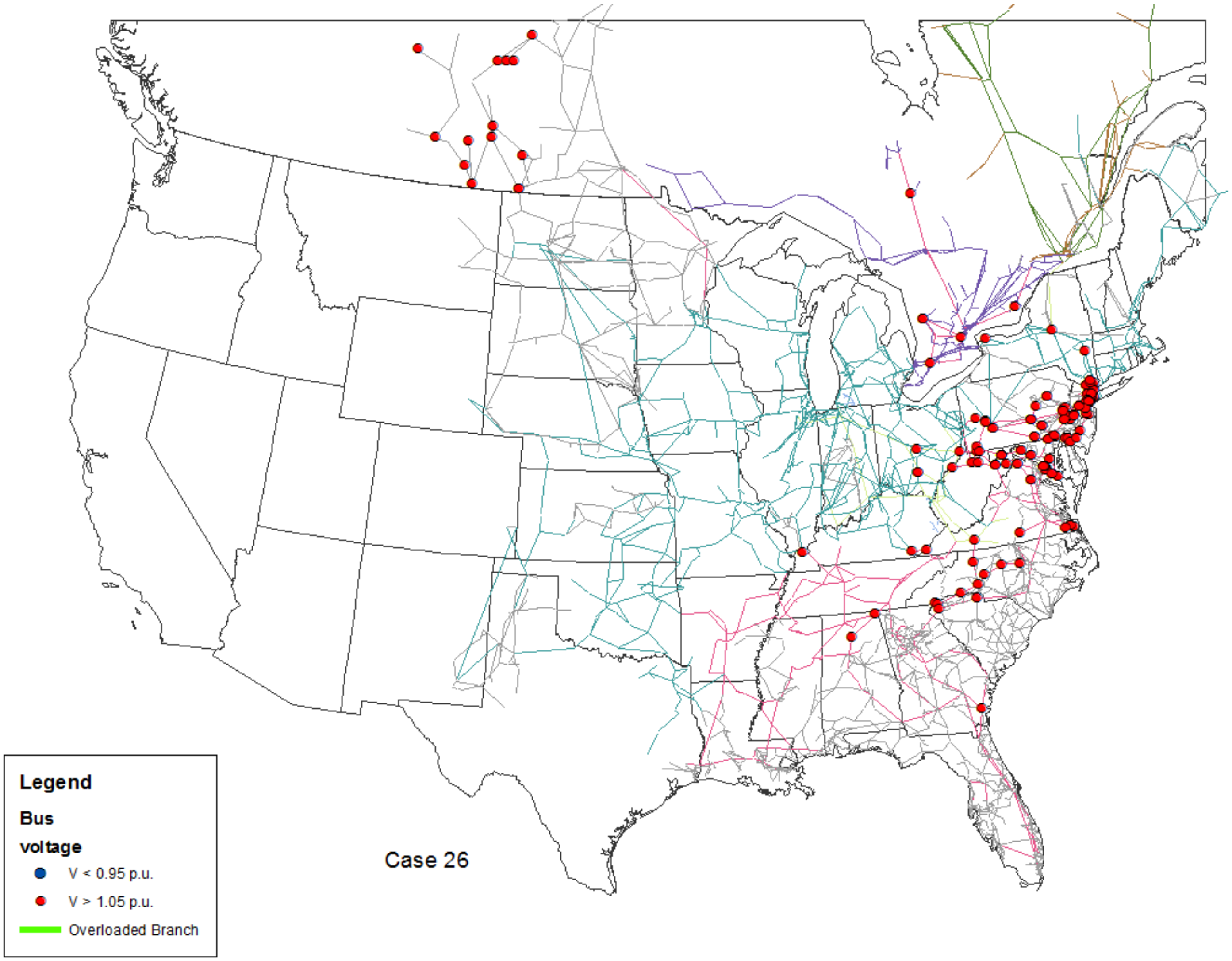

Fig. 3.12. 2013 gas base case with wind

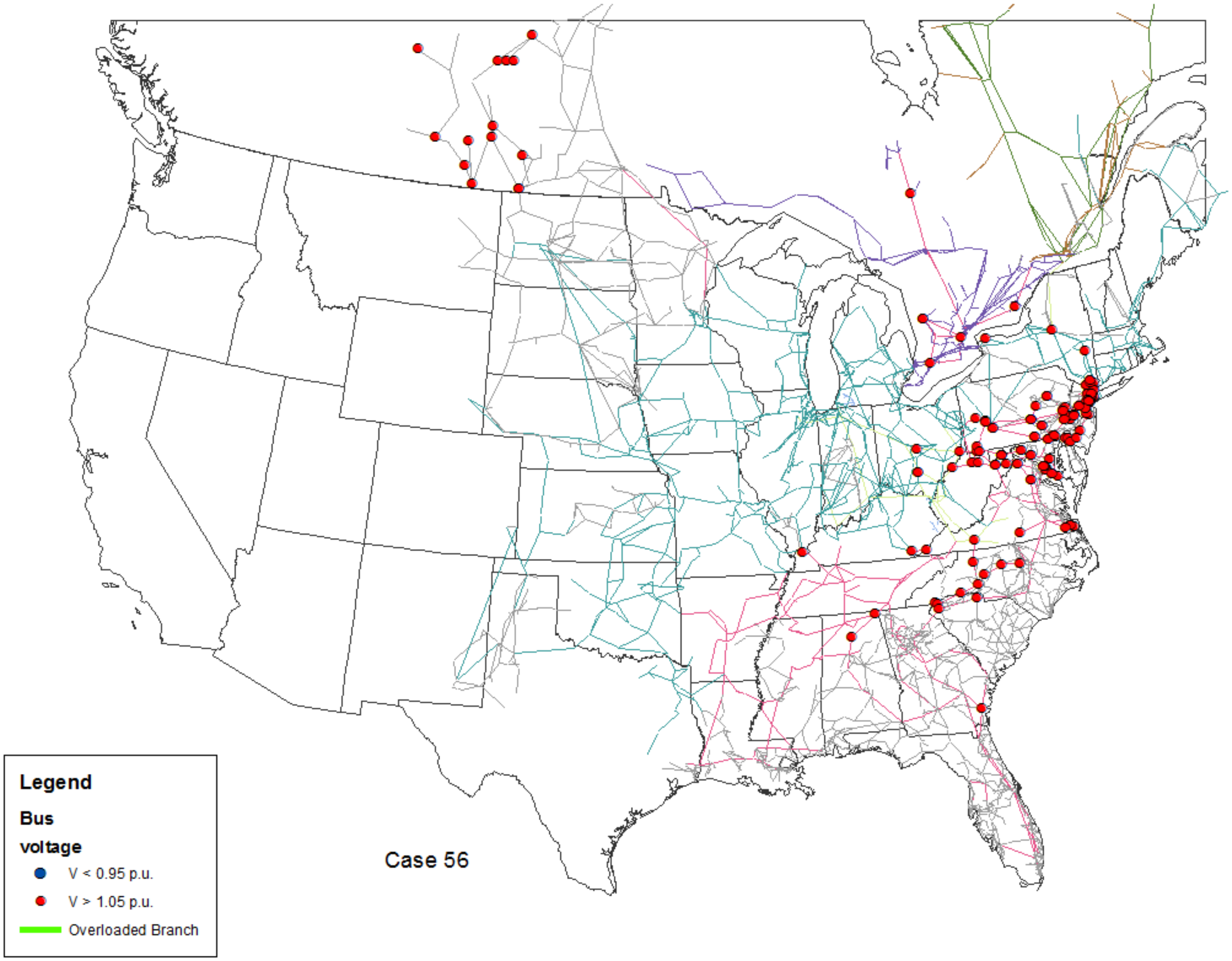

Fig. 3.13. 2013 gas base case with wind and synchronous condensers

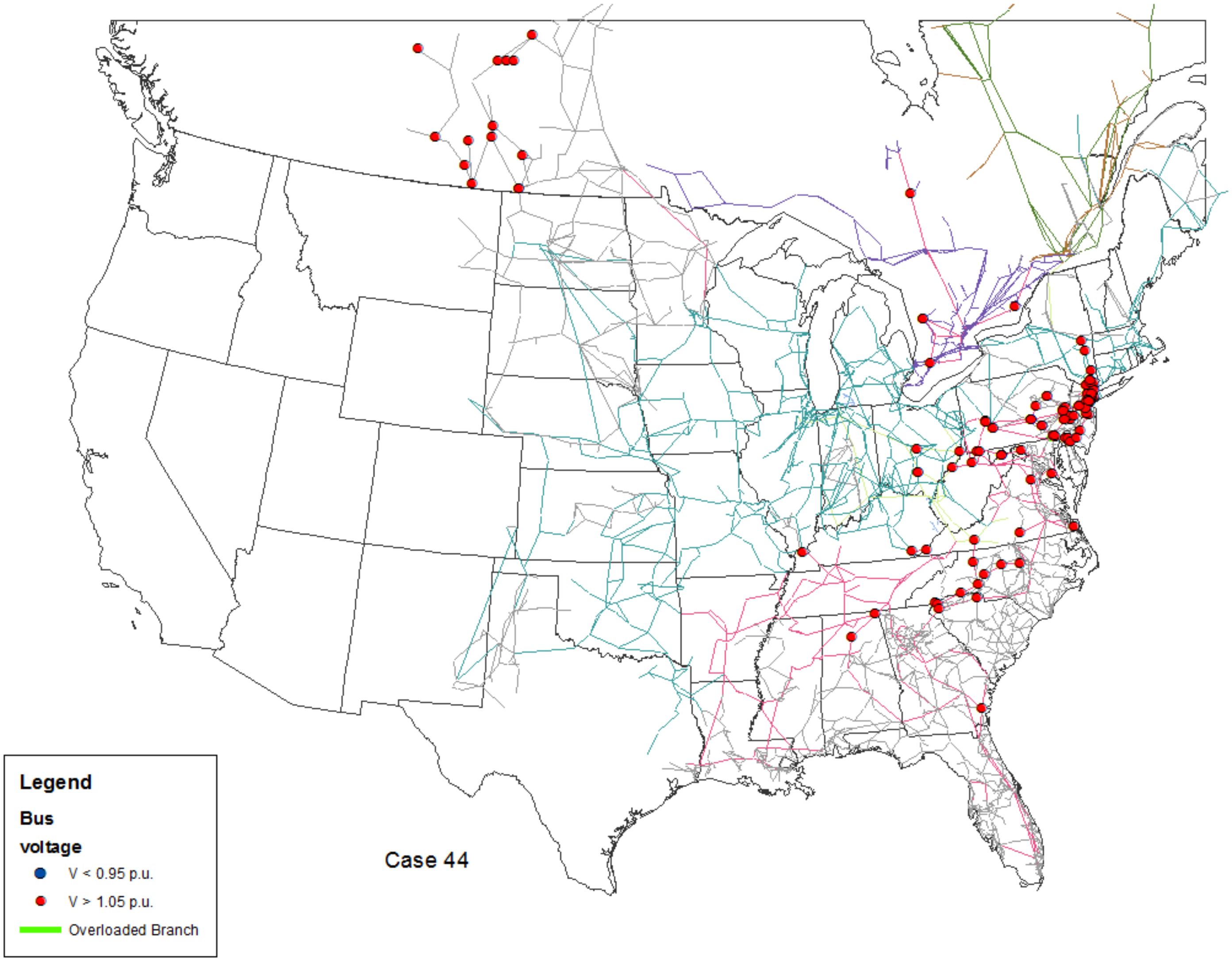

Fig. 3.14. 2013 gas and wind added, nuclear plants removed

3.3 2014

Simulation results for the 2014 base case are shown in Fig. 3.15. This case includes 1.5% load growth from the previous year. Due to convergence issues, Unit 2 of the V.C. Summers Nuclear Power Plant near Jenkinsville, South Carolina was left in the model, even though this generator is not scheduled to begin production until 2017. Sixty-three generators with a capacity of 6,539 MW are due to be deactivated in 2014; the results of the corresponding simulation are shown in Fig. 3.16. The removal of these generators resulted in 14 fewer buses being above their nominal limits. The generation scaling applied to the remaining units to make up for this loss appears to correct the low voltage condition found at two of the buses in the system, and also decreases the flow on four of the overloaded lines down to acceptable levels. Conversion of some of the deactivated units to synchronous condensers had a negligible effect on the system (Fig. 3.17).

Approximately 1,300 MW of gas-fired generating units are scheduled to be brought online in 2014. The simulation results show that this creates 23 more overvoltage buses (Fig. 3.18) than the scenario where the MATS/CSAPR-affected generators have been removed. The addition of 300 MW of wind power (Fig. 3.19) to the gas base case results in 11 fewer overvoltage buses. Synchronous condenser conversion of deactivated generators causes two additional buses to exceed their nominal voltage compared to the gas/wind case (Fig. 3.20). For the final scenario involving the removal of all nuclear generators, 28 out of the 92 reactors were successfully disabled before the simulation failed to converge. This resulted in several transmission lines in northeastern Maryland being overloaded, as shown in Fig. 3.21.

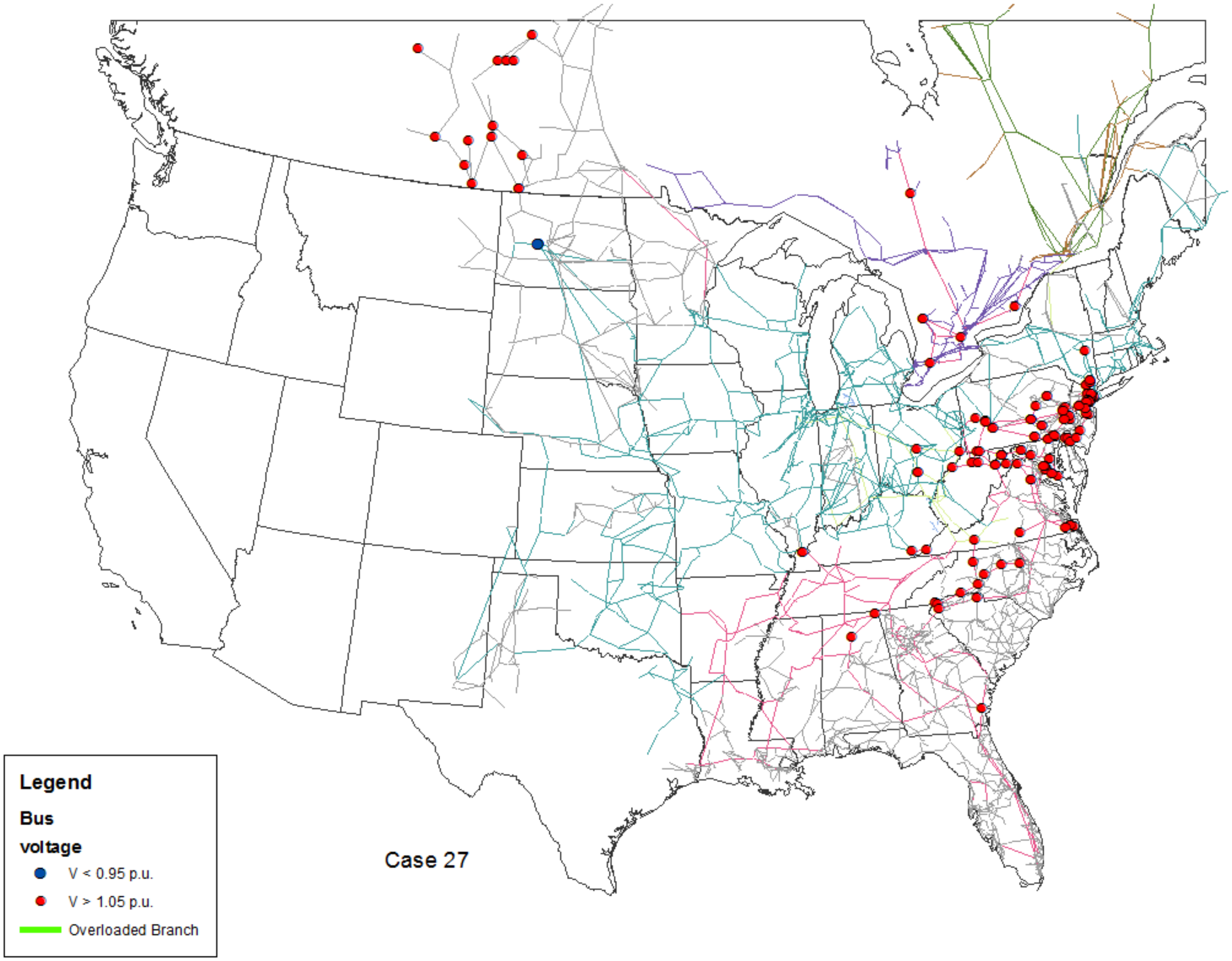

Fig. 3.15. 2014 base case

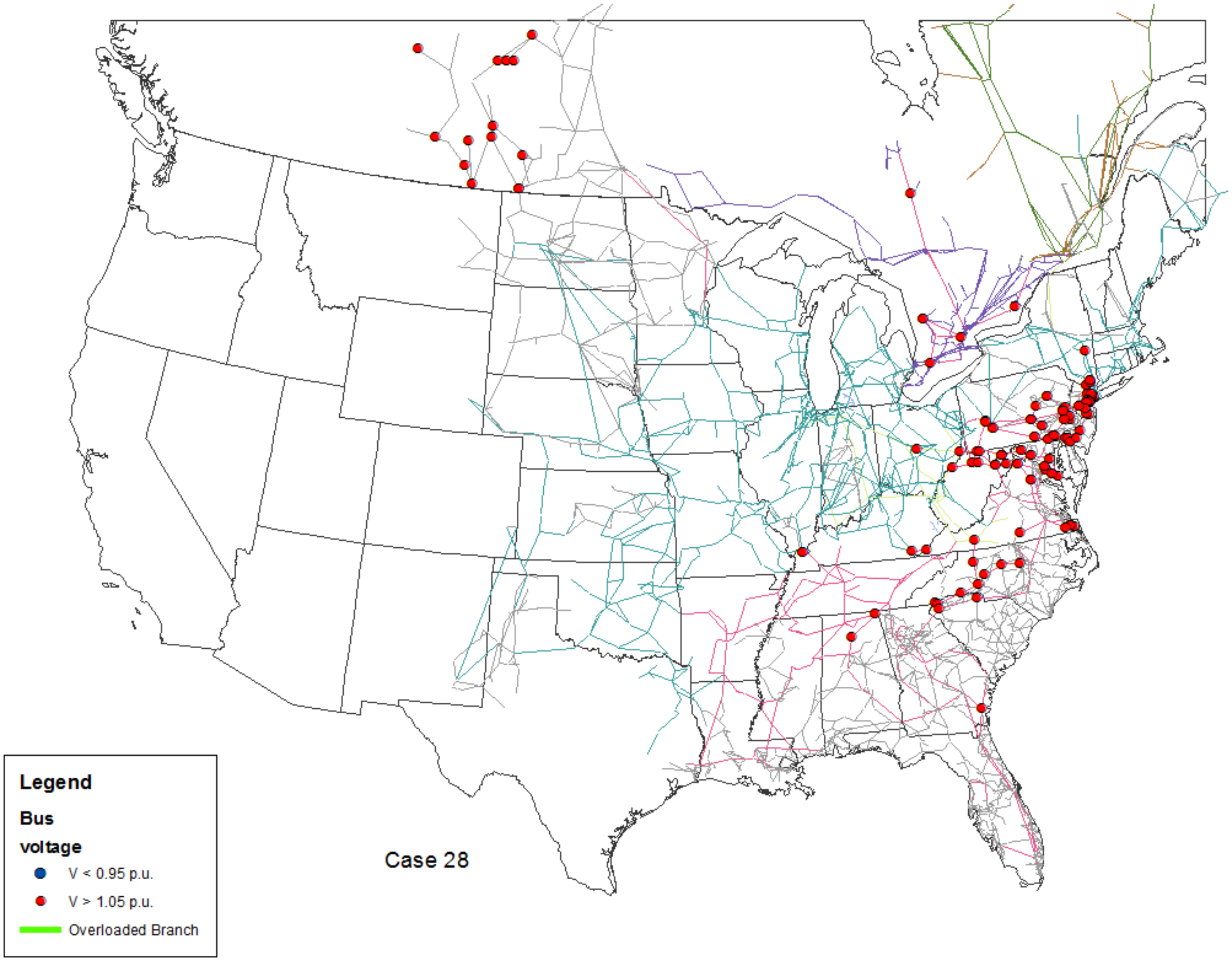

Fig. 3.16. 2014 base case with generators removed

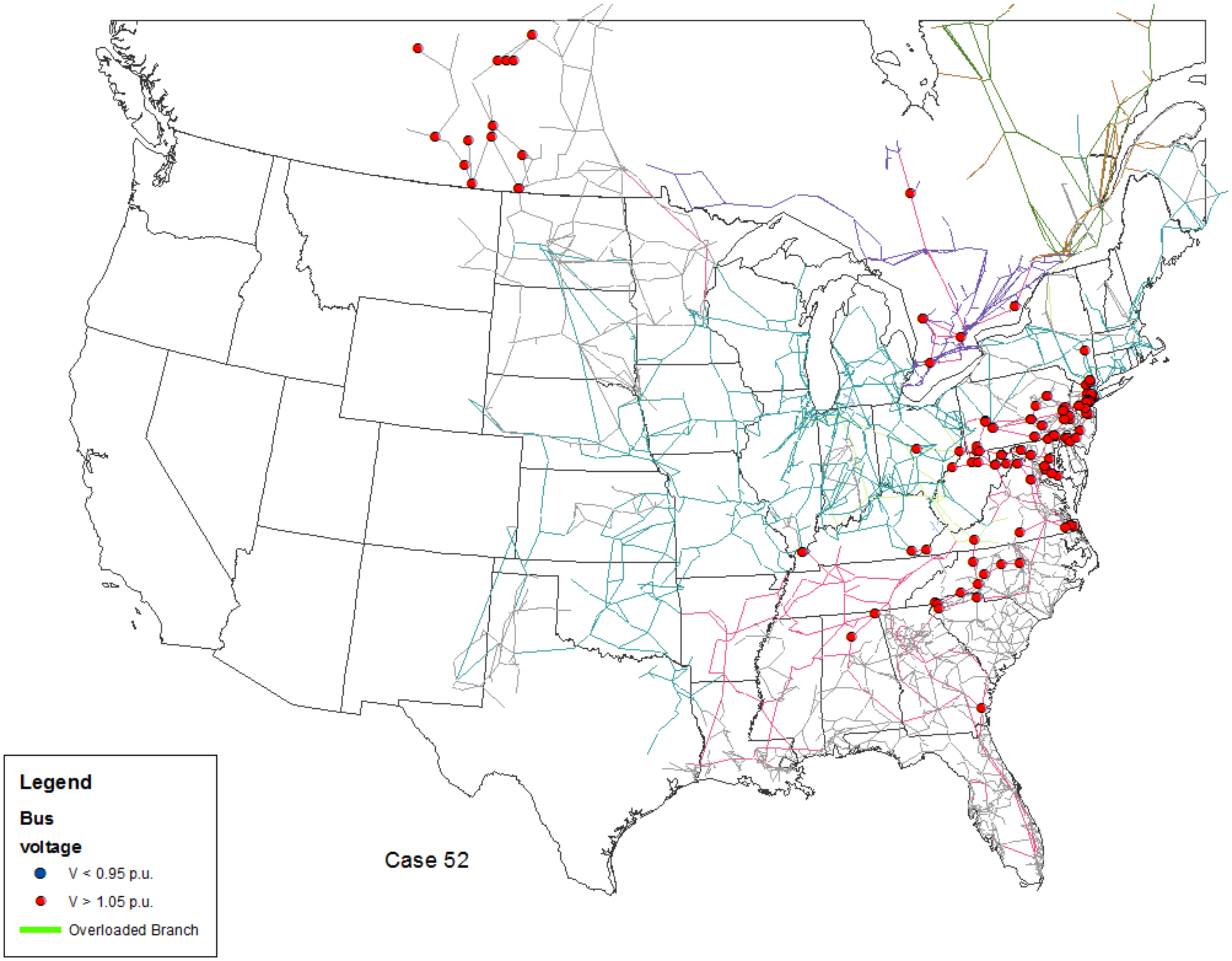

Fig. 3.17. 2014 base case with generators removed, synchronous condensers added

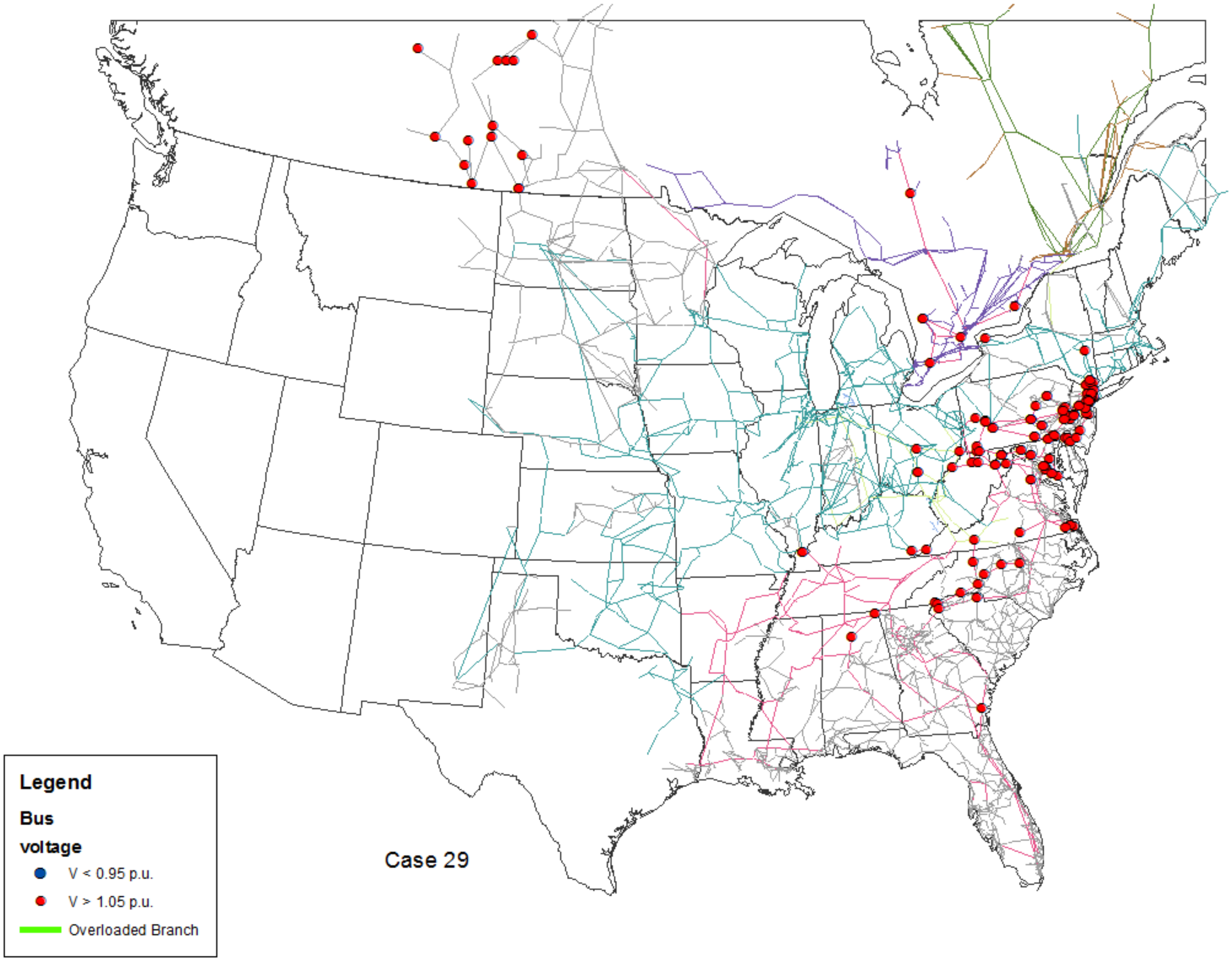

Fig. 3.18. 2014 gas base case

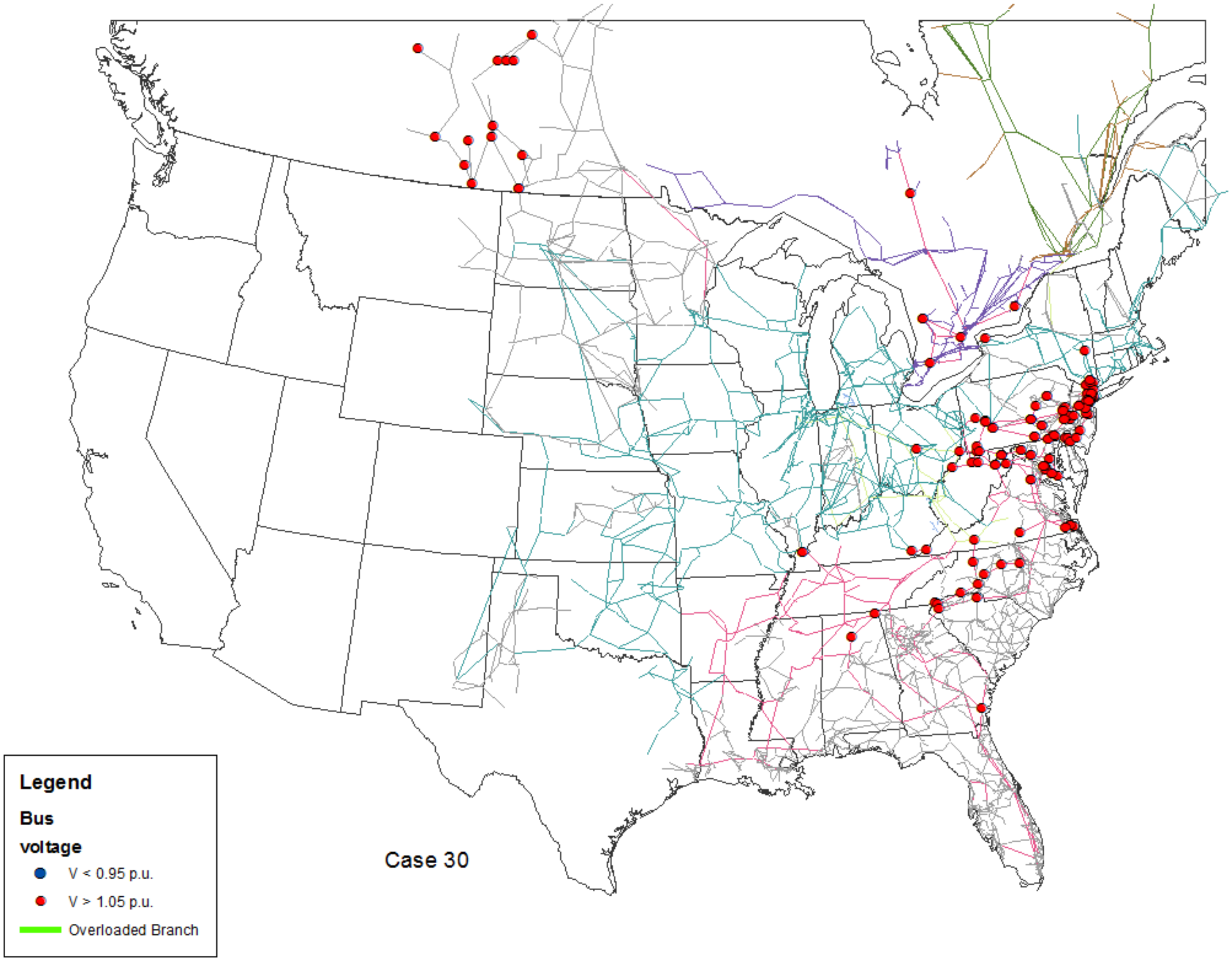

Fig. 3.19. 2014 gas base case with wind generation

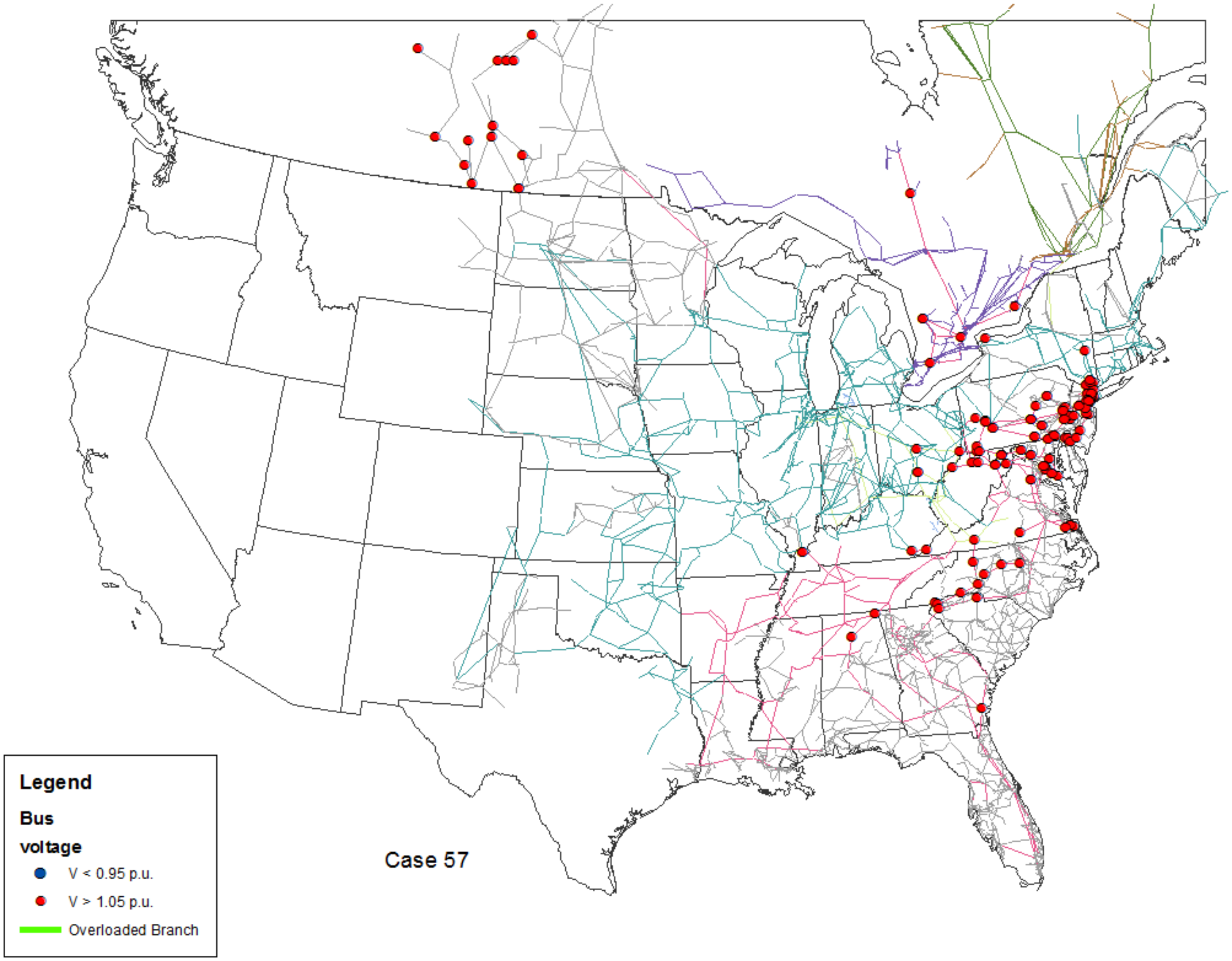

Fig. 3.20. 2014 gas base case with wind generation and synchronous condensers

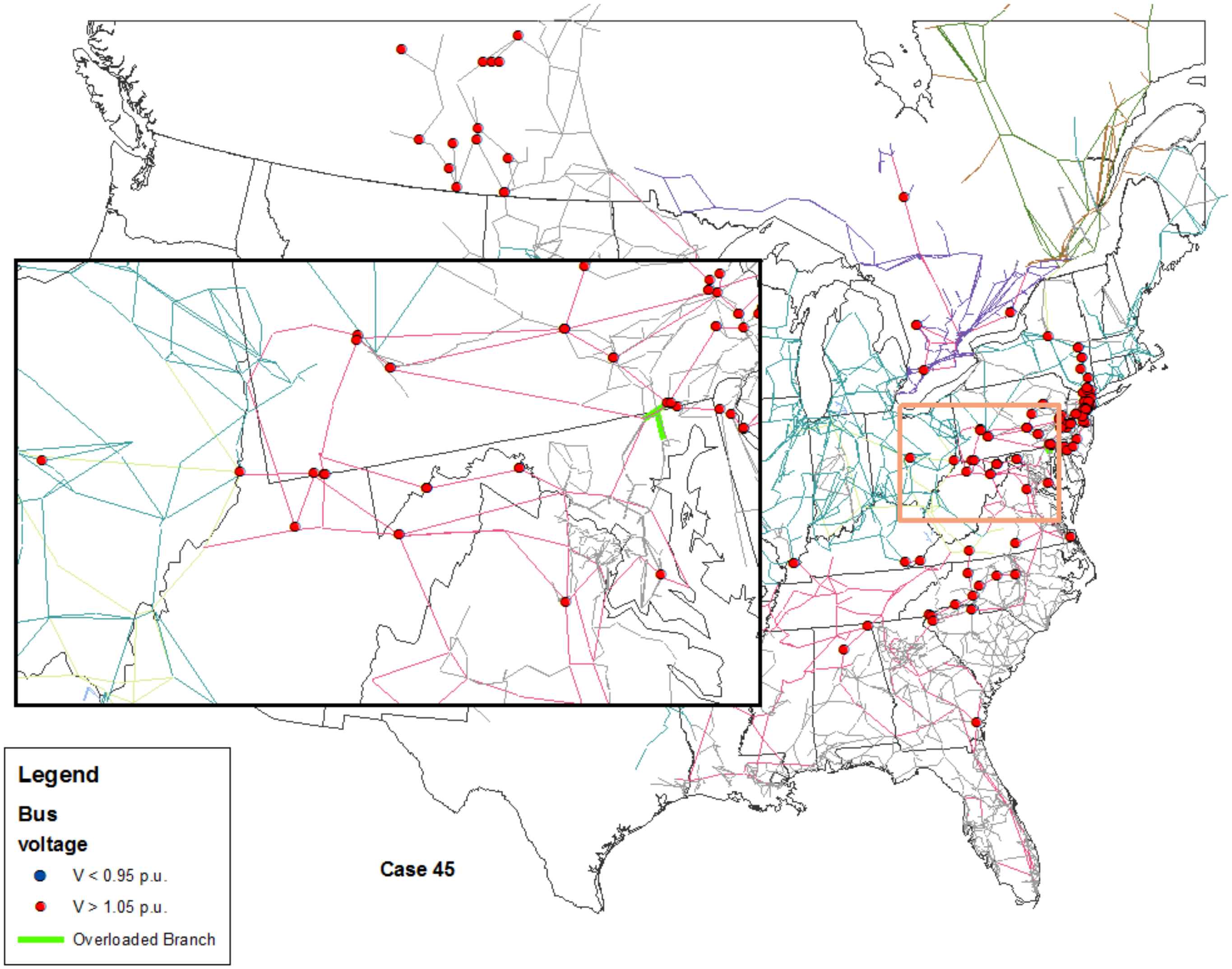

Fig. 3.21. 2014 gas and wind added, nuclear plants removed

3.4 2015

The 2015 scenarios are perhaps the most important ones in this study, since more generators (117) are to be taken offline that year than in the previous three years combined. The 2015 base case (Fig. 3.22) is fairly unremarkable in terms of the number of overvoltage buses (156) and overloaded lines (3). Once the nearly 16,000 MW of MATS/CSAPR-affected generators are removed (Fig. 3.23), two buses in northeastern Ohio drop below allowable voltage levels, and three additional lines become overloaded. It should be noted here that two yet-to-be-built generators (V.C. Summers, Unit 2, and Vogtle, Unit 3) had to be left in the model in order for these cases to converge. By converting several of the generators to synchronous condensers, the bus voltage issues were eliminated (Fig. 3.24).

The addition of 3,859 MW of natural gas-fired generation appears to create some undervoltage issues around the southeastern shore of Lake Erie, and a few overloaded lines in northeastern Maryland (Fig. 3.25), though several of the undervoltage buses are eliminated with the addition of planned wind generation (Fig. 3.26). For these two cases, the newly added generators allowed the previously mentioned Summers and Vogtle units to be successfully removed from the model. Conversion of some of the deactivated generators to synchronous condensers corrected the remaining voltage issues, but did not reduce the number of overloaded lines (Fig. 3.27).

In 2015, the Watts Bar Unit 2 reactor is scheduled to begin operation, the first nuclear reactor to do so in nearly twenty years. Because of its location, the plant does not appear to have much effect on the undervoltage buses and overloaded lines previously noted in the gas and wind cases for this year (Fig. 3.28andFig. 3.29). As before, synchronous condensers were helpful in alleviating some of these problems, as shown inFig. 3.30. Only three nuclear power plants could be removed before the system failed to converge (Fig. 3.31).

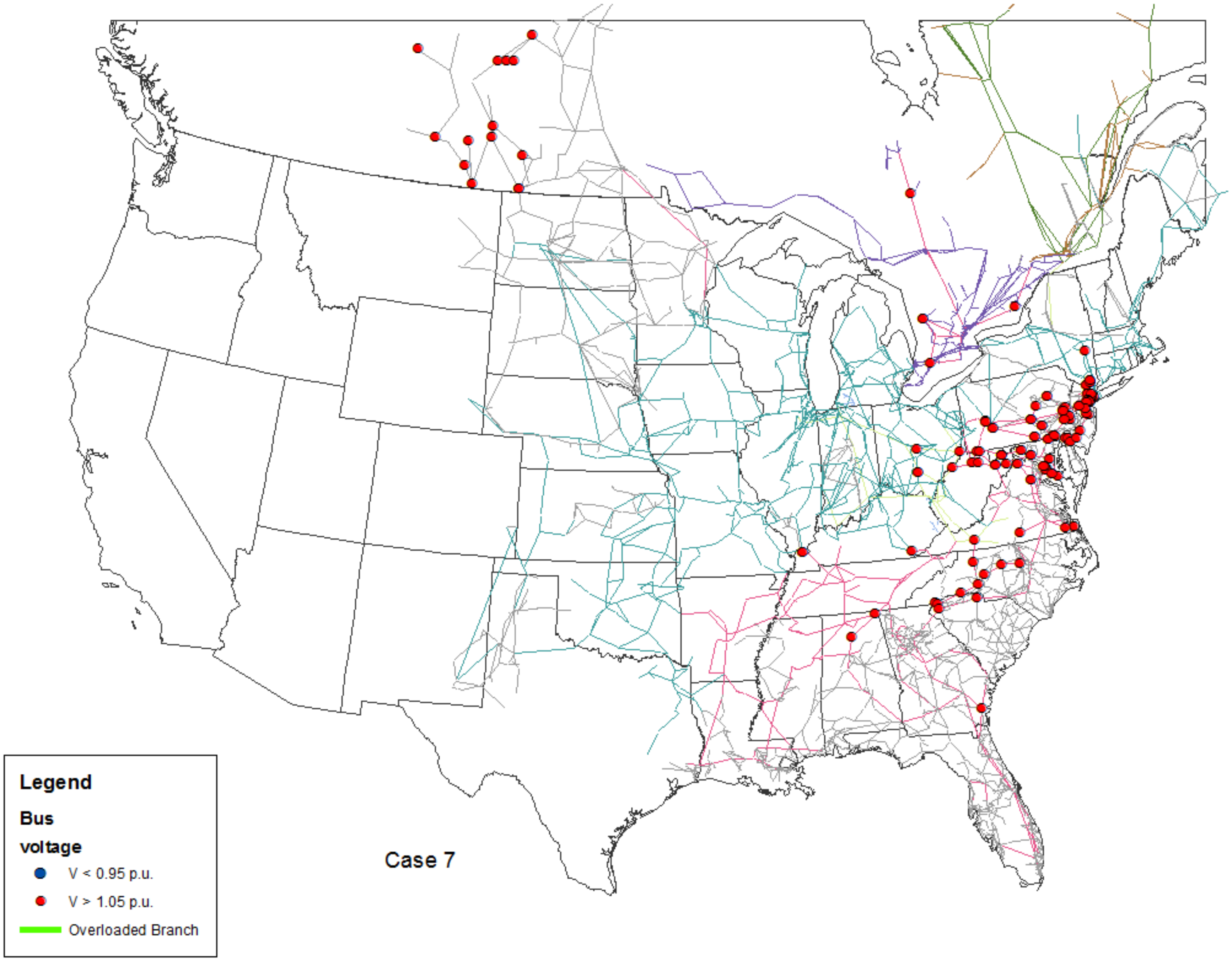

Fig. 3.22. 2015 base case

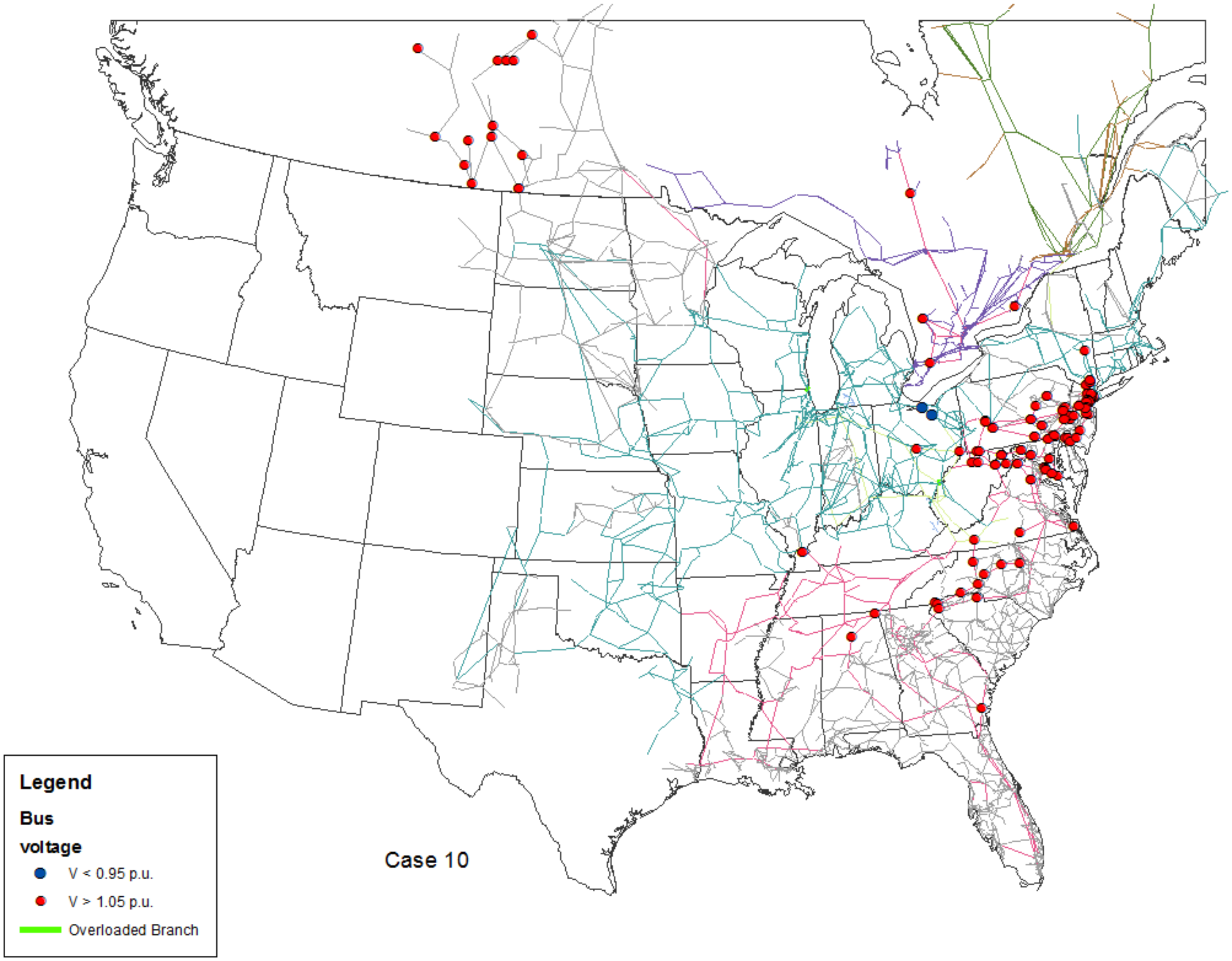

Fig. 3.23. 2015 base case with generators removed

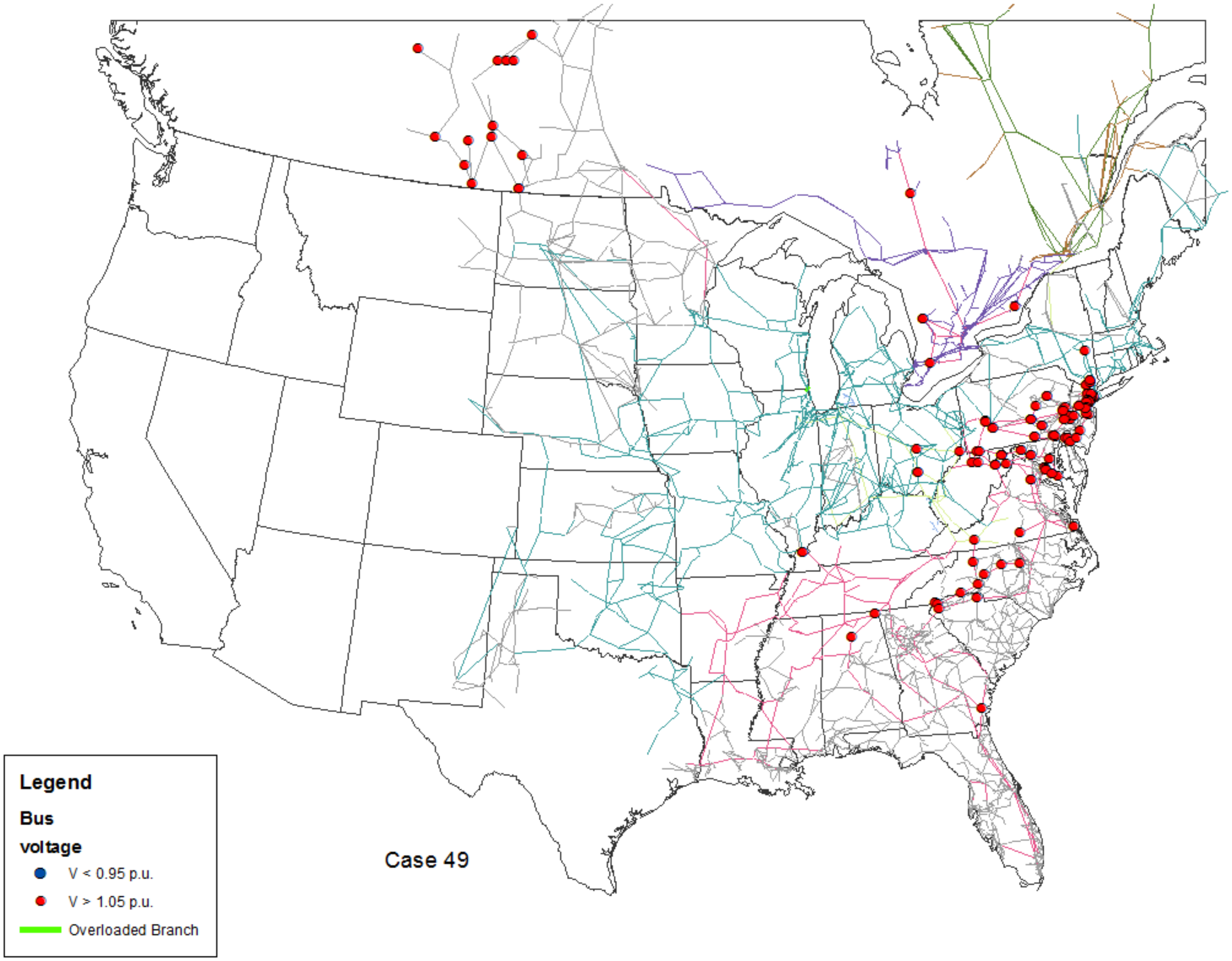

Fig. 3.24. 2015 base case with generators removed, synchronous condensers added

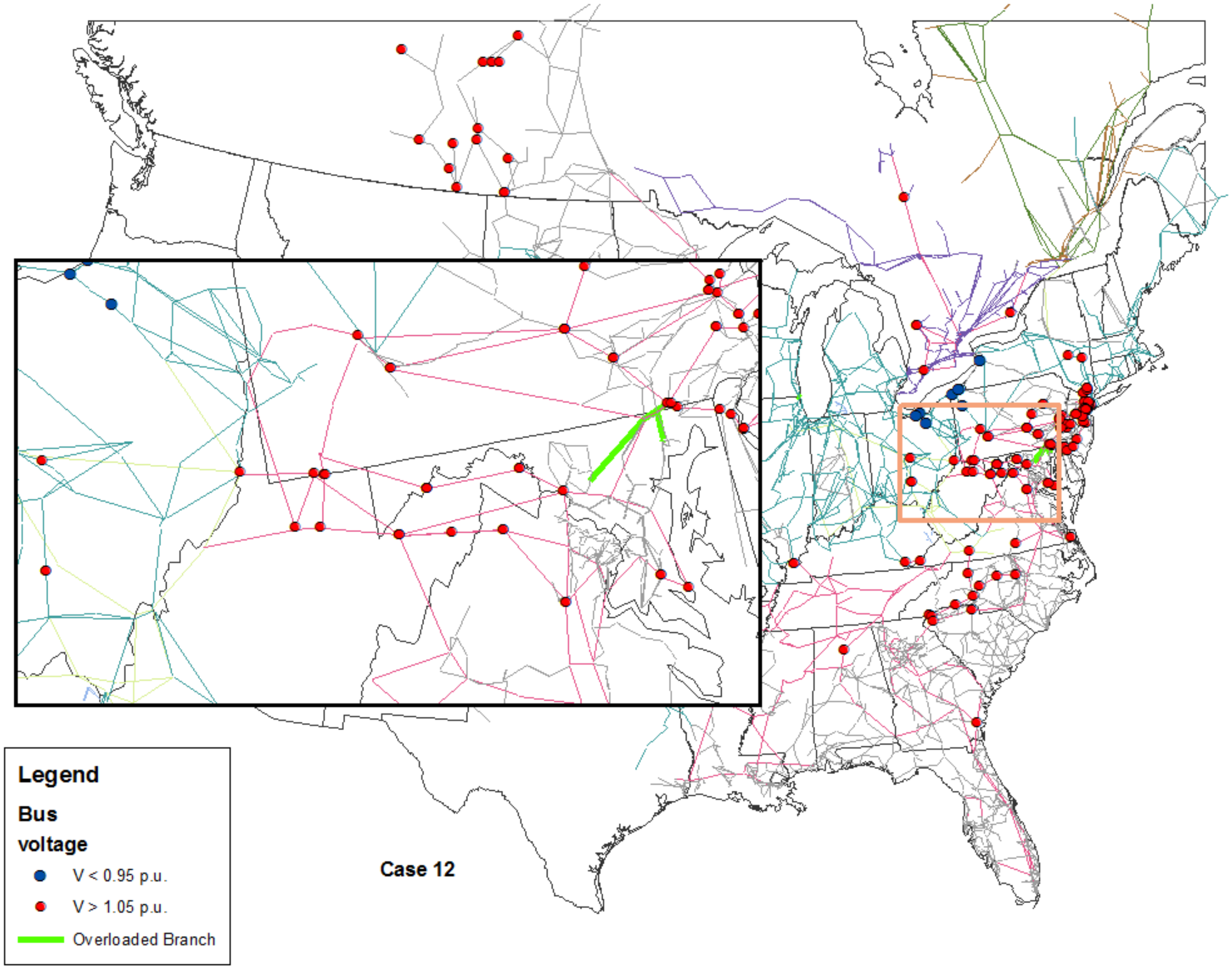

Fig. 3.25. 2015 gas base case

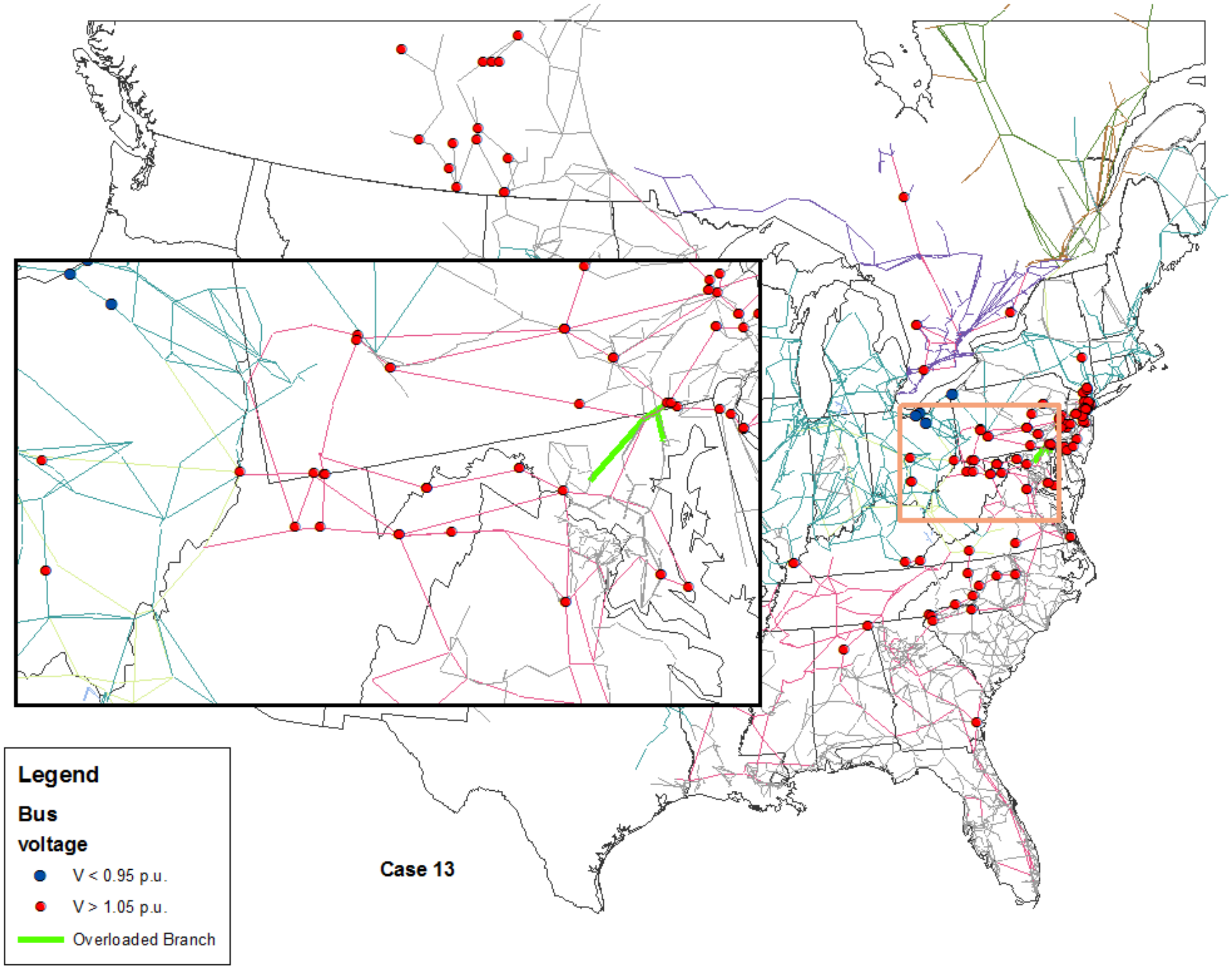

Fig. 3.26. 2015 gas base case with wind

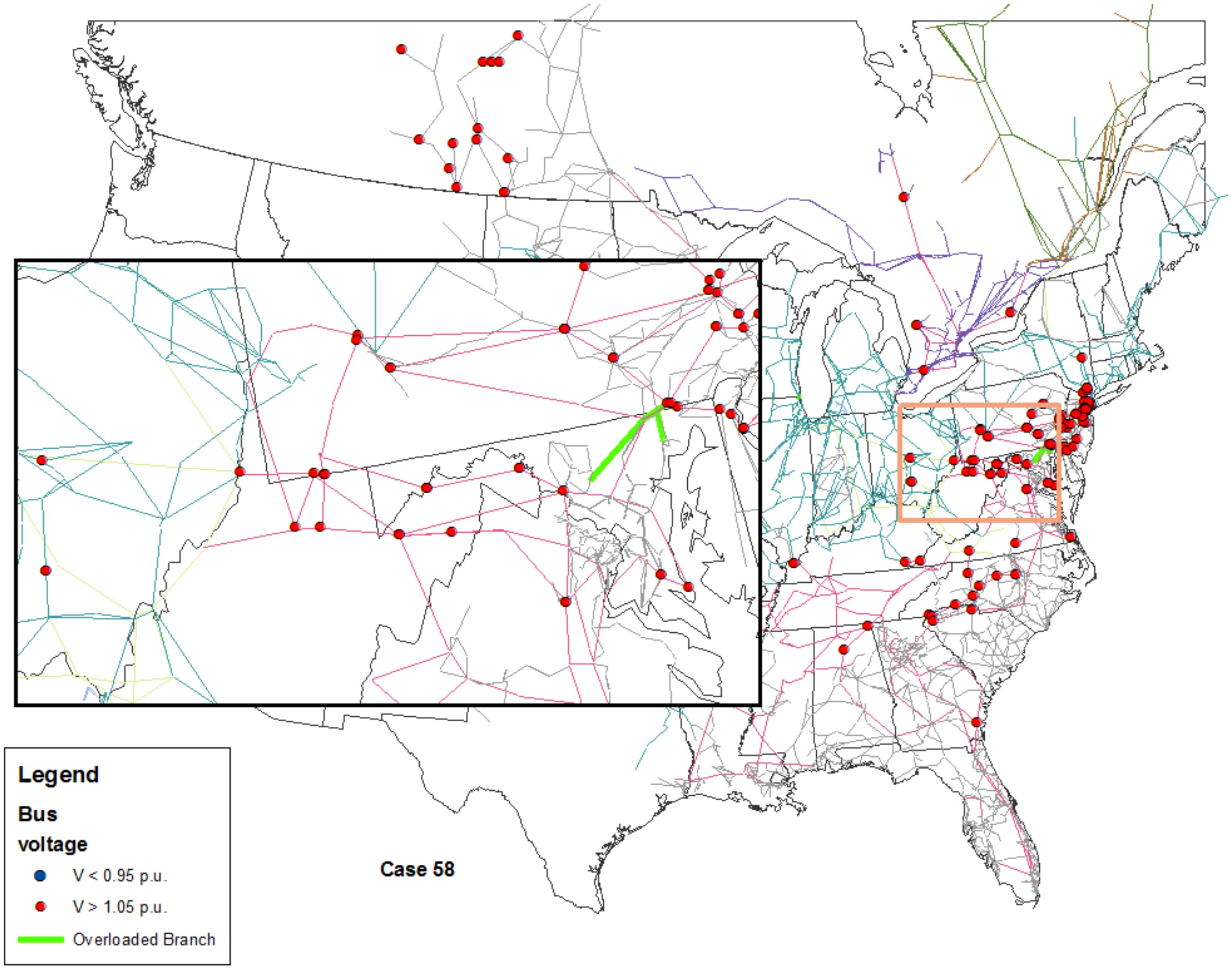

Fig. 3.27. 2015 gas base case with wind generation and synchronous condensers

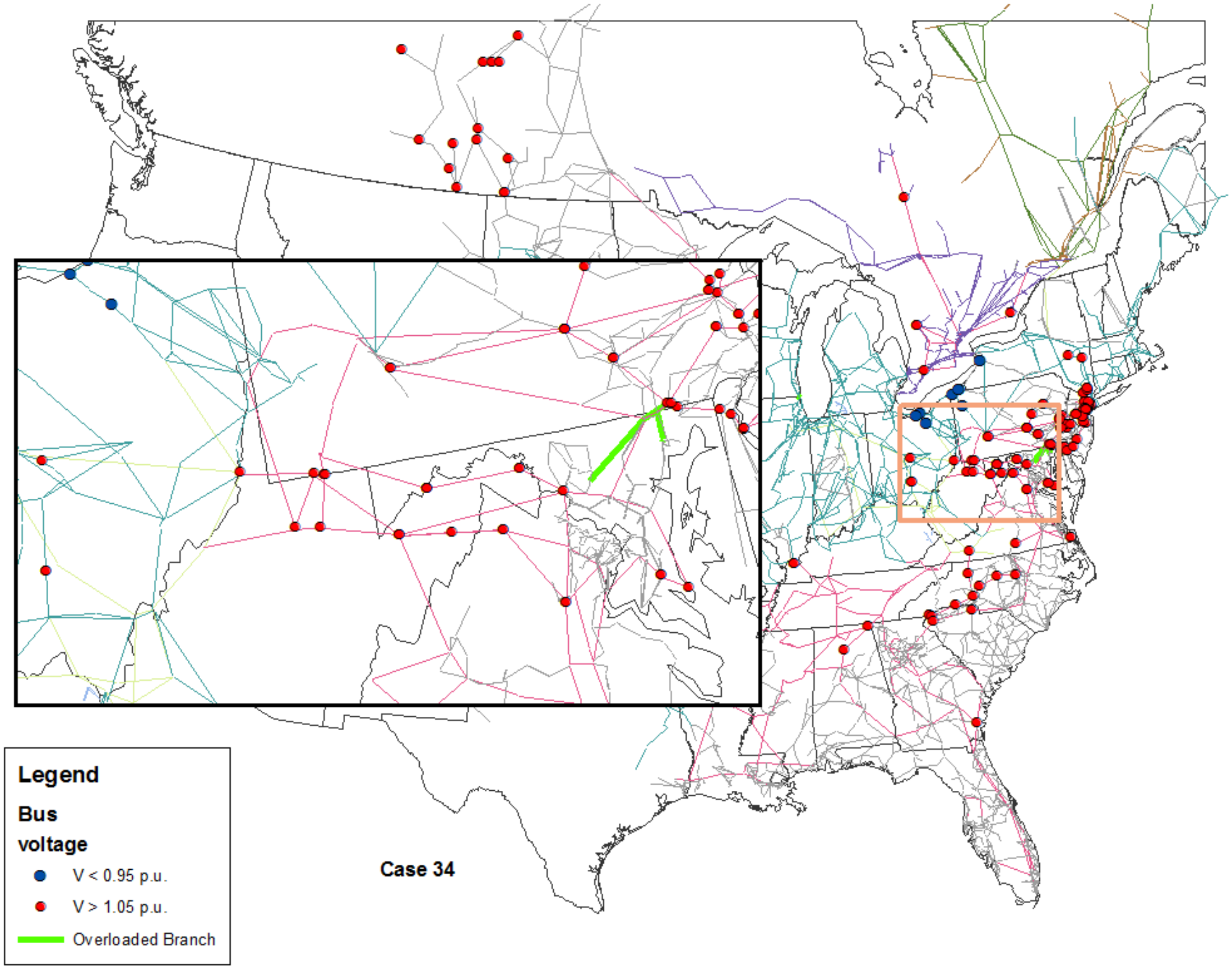

Fig. 3.28. 2015 gas base case with new nuclear units

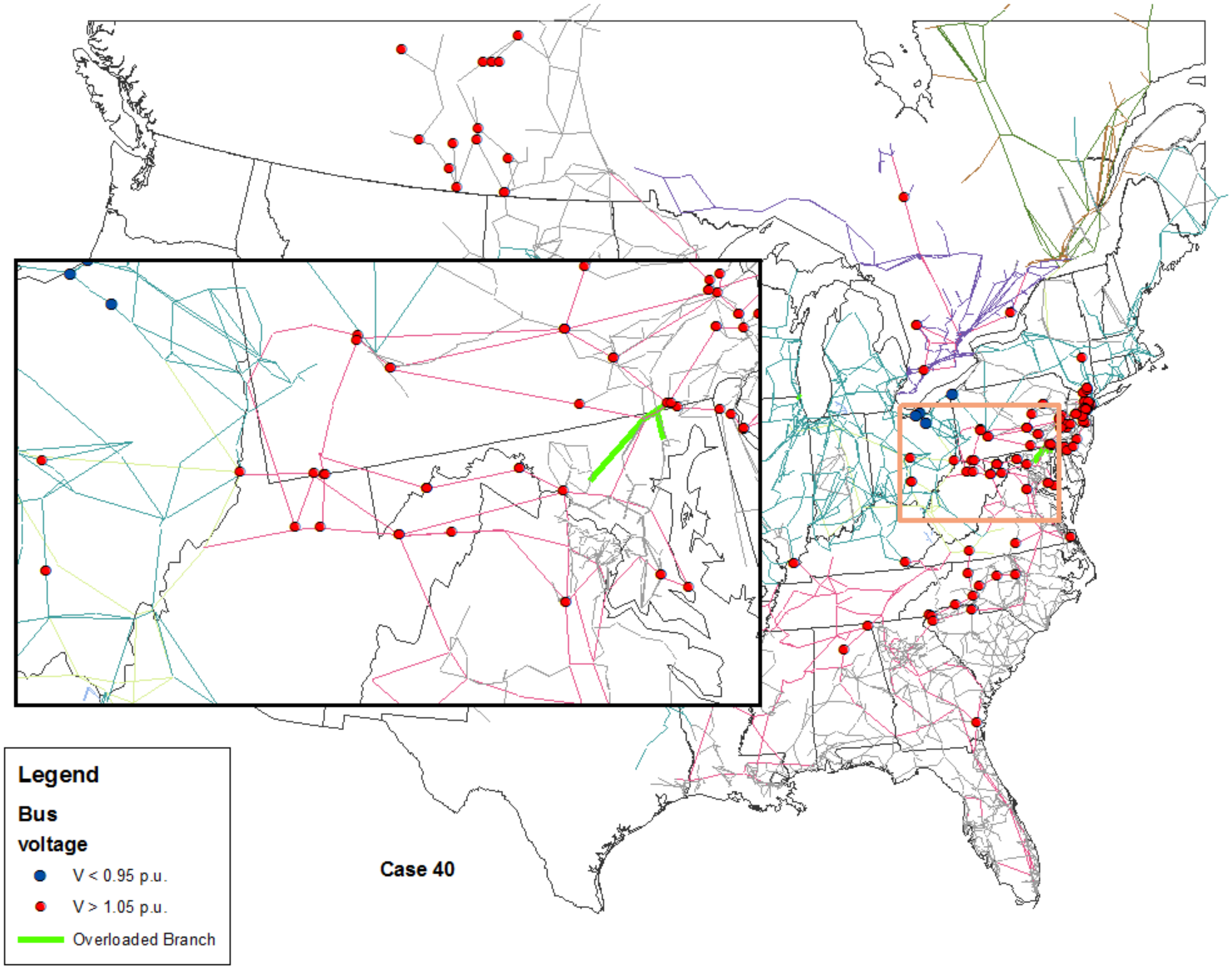

Fig. 3.29. 2015 gas, wind base case with new nuclear units

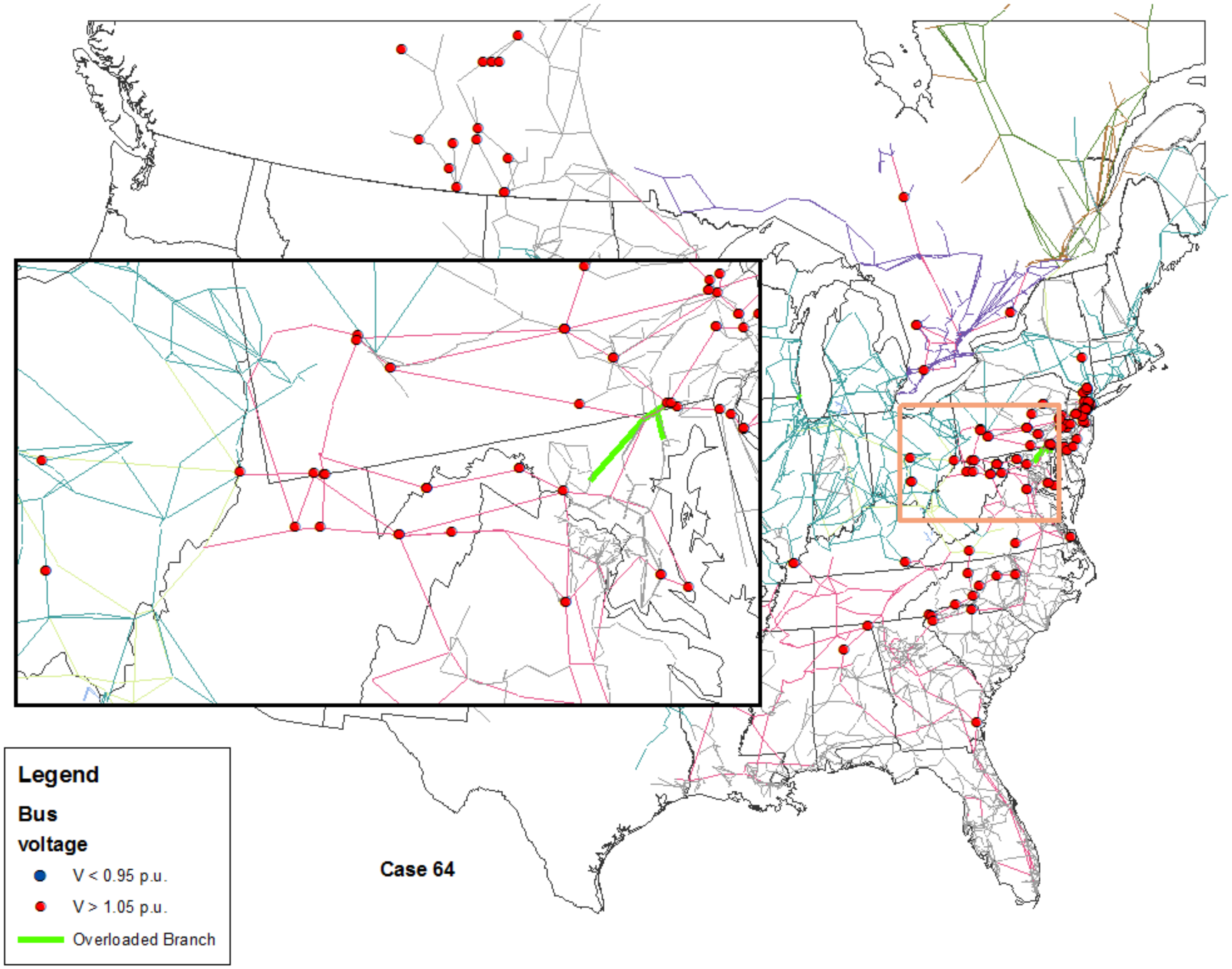

Fig. 3.30. 2015 gas, wind, new nuclear units, and synchronous condensers

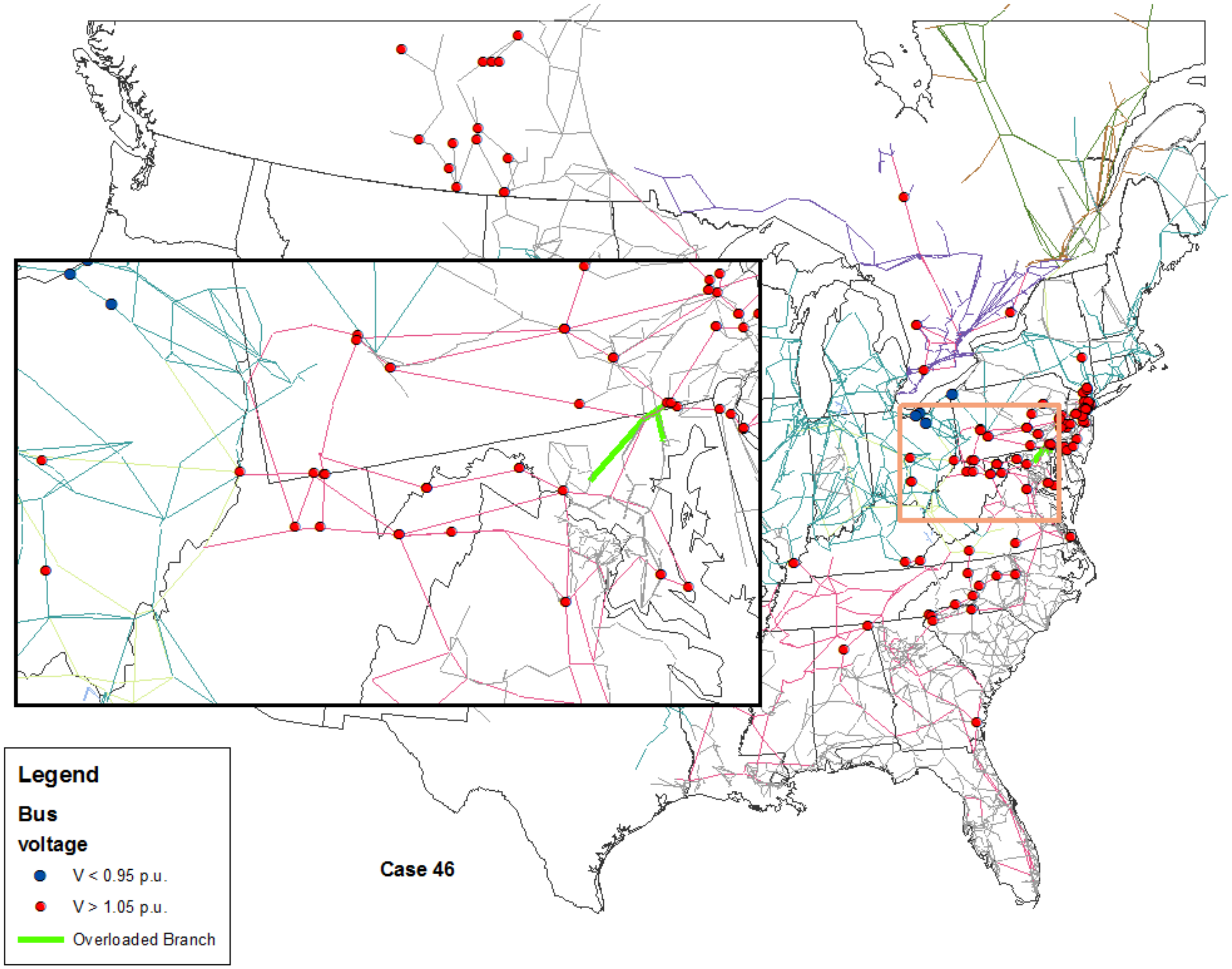

Fig. 3.31. 2015 gas and wind base case, nuclear plants removed

3.5 2016

Simulation results from the 2016 base case are shown in Fig. 3.32. This case contains 146 overvoltage buses and three overloaded lines. Removal of the 18 MATS/CSAPR-affected generators lowers the bus voltages such that only 126 buses exceed their voltage limits (Fig. 3.33). However, six additional lines become overloaded, most notably in the vicinity of the Kyger Creek Power Plant in West Virginia. This is at least partially due to the fact that the plant serves as the swing bus for the model being used. That is, its power output is adjusted by the power flow program to make up for the overall load-generation mismatch of the system once the remaining generators have been dispatched. For this particular simulation, the swing bus output was very high (8,166 MW), well above the actual 973 MW limit. Because this large amount of power must be sent out through the surrounding transmission lines, it is not surprising that they would become overloaded. Efforts made to lower the swing bus output to a more reasonable value by increasing the remaining generators' outputs generally resulted in a non-convergent model. Many of the subsequent cases for 2016 and 2017 also exhibited this phenomenon, and their results should be interpreted with caution. Application of synchronous condensers to the system (Fig. 3.34) made virtually no difference in the number of out-of-limit bus voltages or overloaded lines.

Undervoltage buses along the southeastern shore of Lake Erie and overloaded lines in northeastern Maryland were again noted once gas-fired generators were introduced into the model (Fig. 3.35). Given that the swing bus output for this case was within reasonable limits, this result likely provides a decent reflection of reality. However, the apparent improvement in bus voltages provided by the added wind generation (Fig. 3.36) may be illusory, since the swing bus output was very high for this simulation. This is also true for the synchronous condenser case (Fig. 3.37), which appeared to show additional improvements in the bus voltages.

Two new nuclear plants (V.C. Summers, Unit 2, and Vogtle, Unit 3) are scheduled to come online in 2016. The results of simulations reflecting these additions (Fig. 3.38, Fig. 3.39, and Fig. 3.40) essentially mirror those of the previous ones where no new nuclear reactors were added. The simulation of a total nuclear shutdown experienced significant difficulties, with only one generator being removed before the model failed to converge (Fig. 3.41).

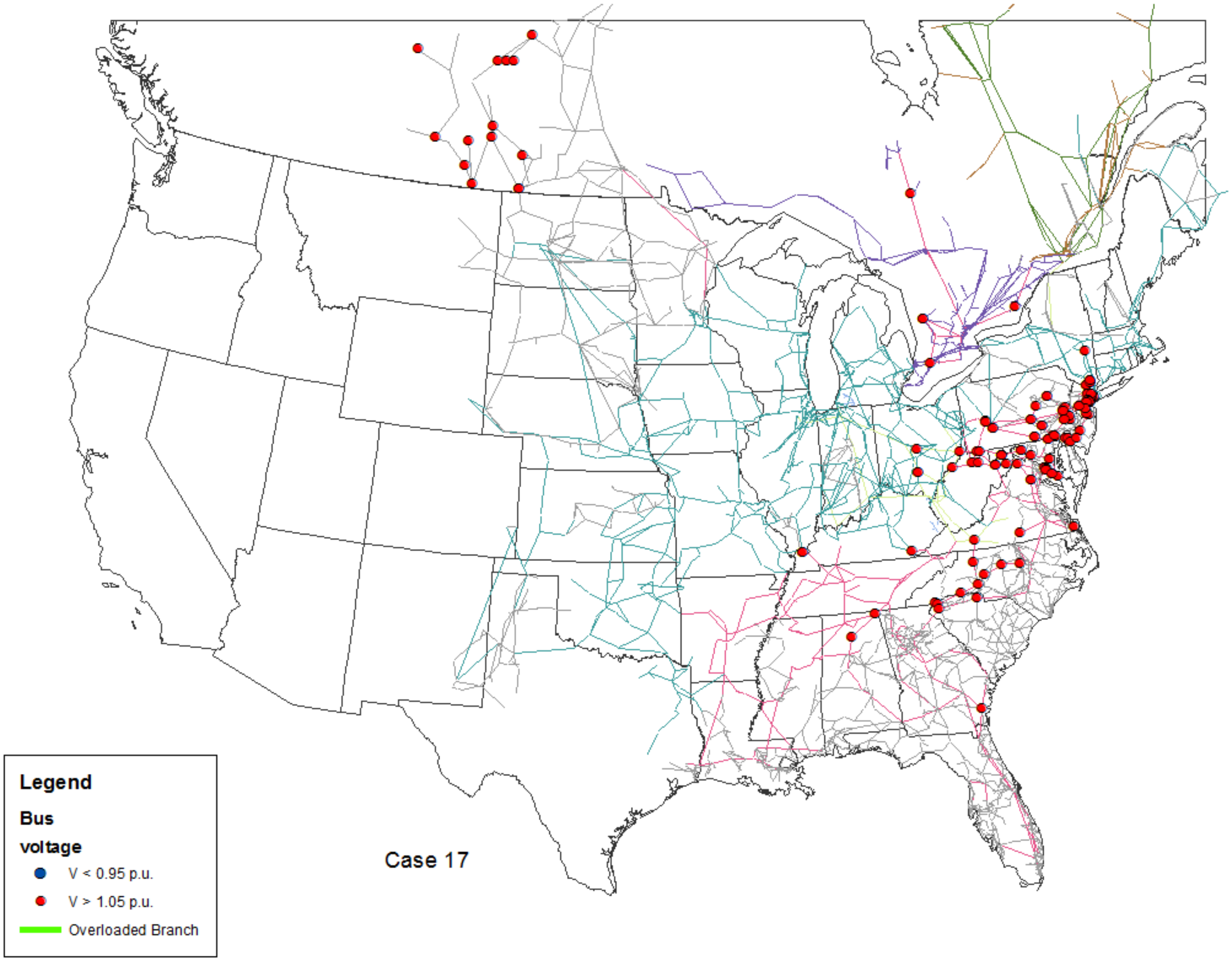

Fig. 3.32. 2016 base case

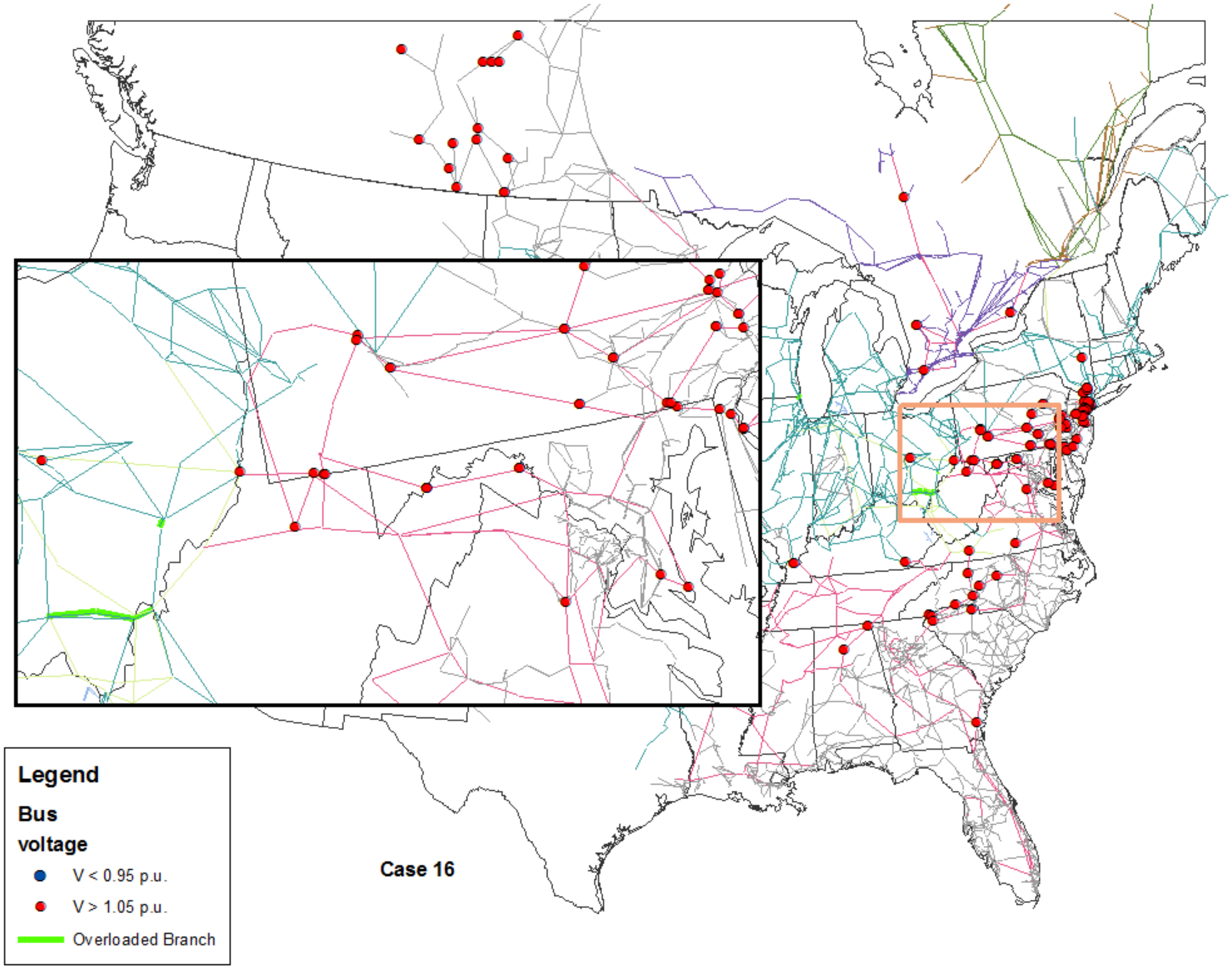

Fig. 3.33. 2016 base case with generators removed

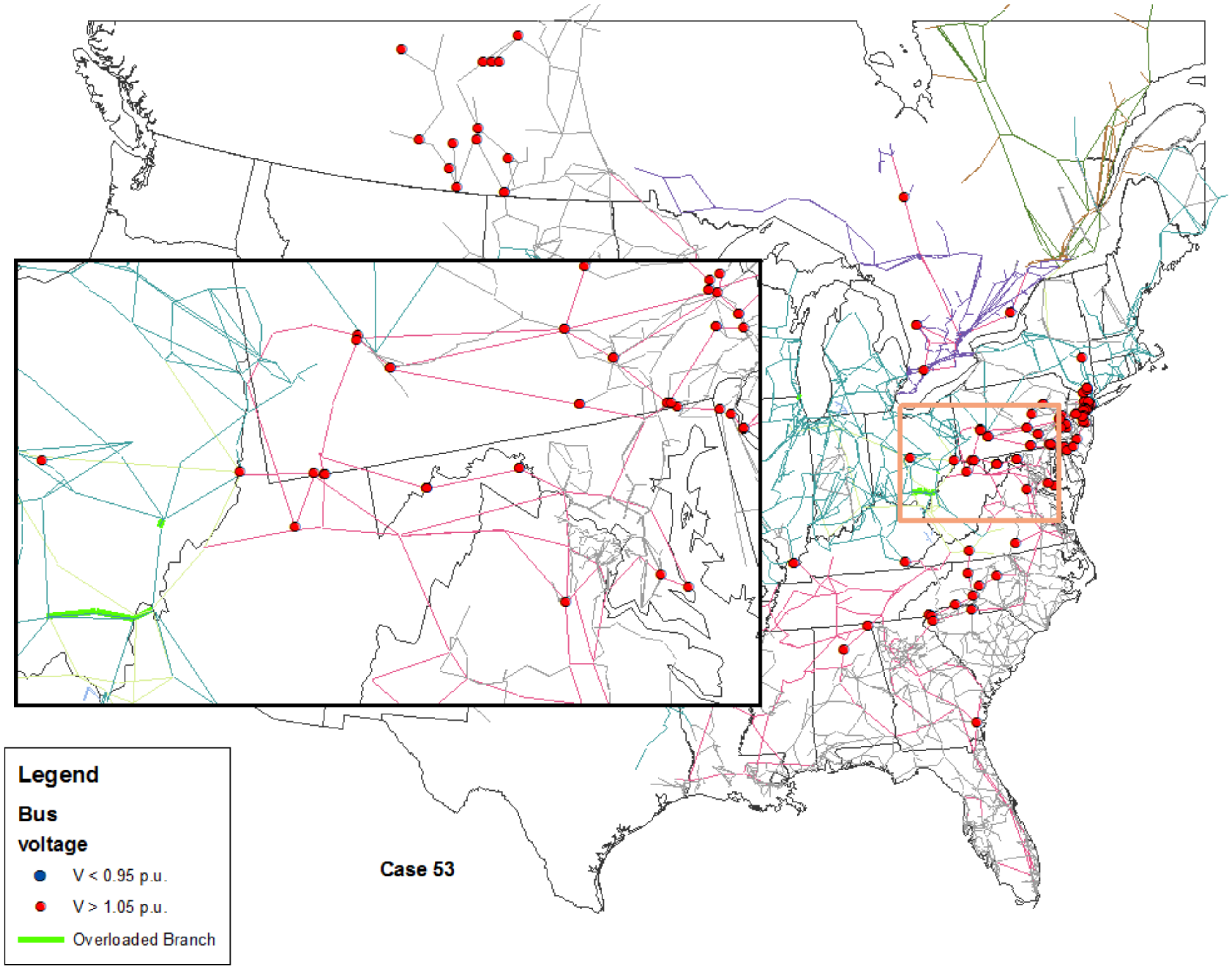

Fig. 3.34. 2016 base case with generators removed, synchronous condensers added

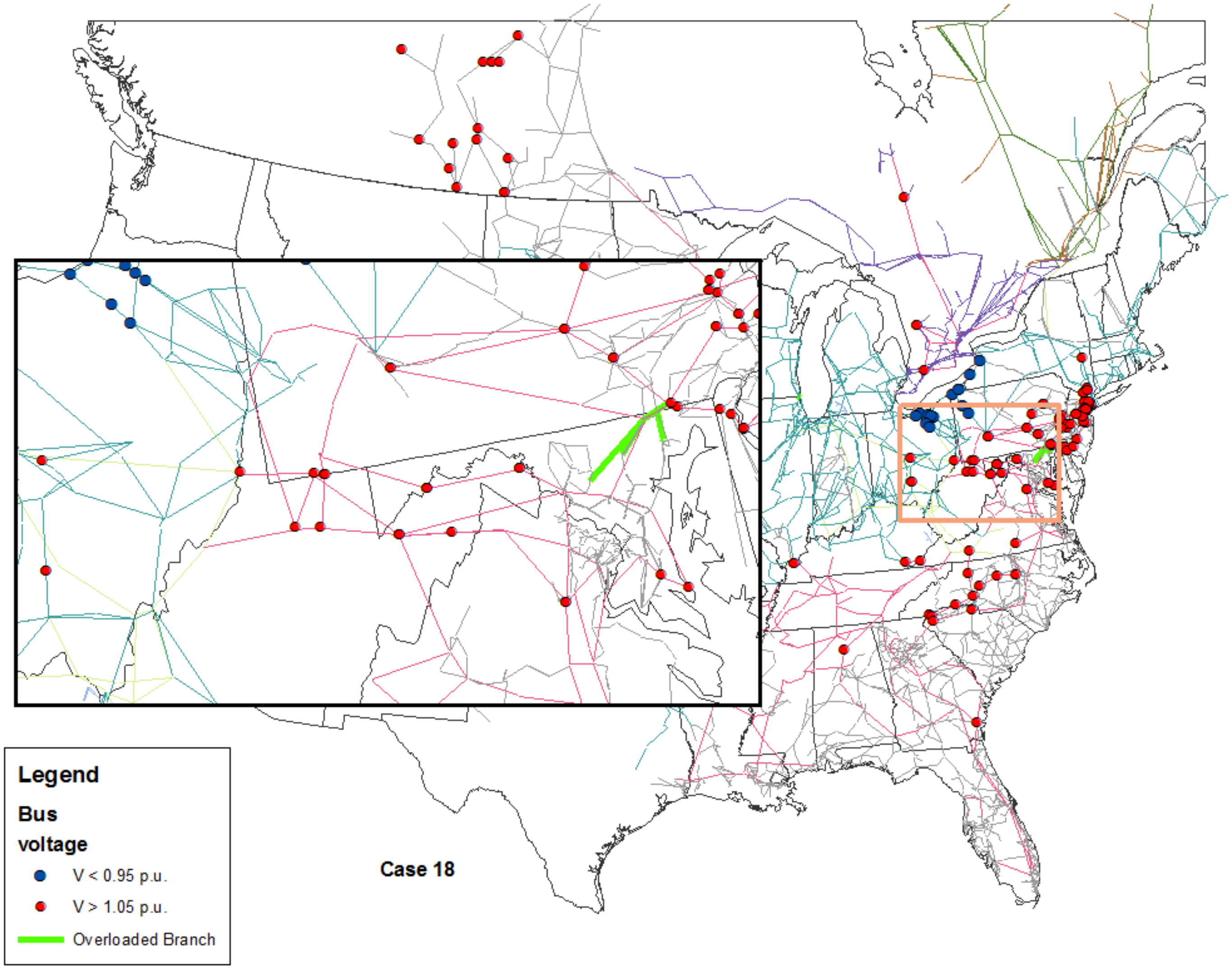

Fig. 3.35. 2016 gas base case

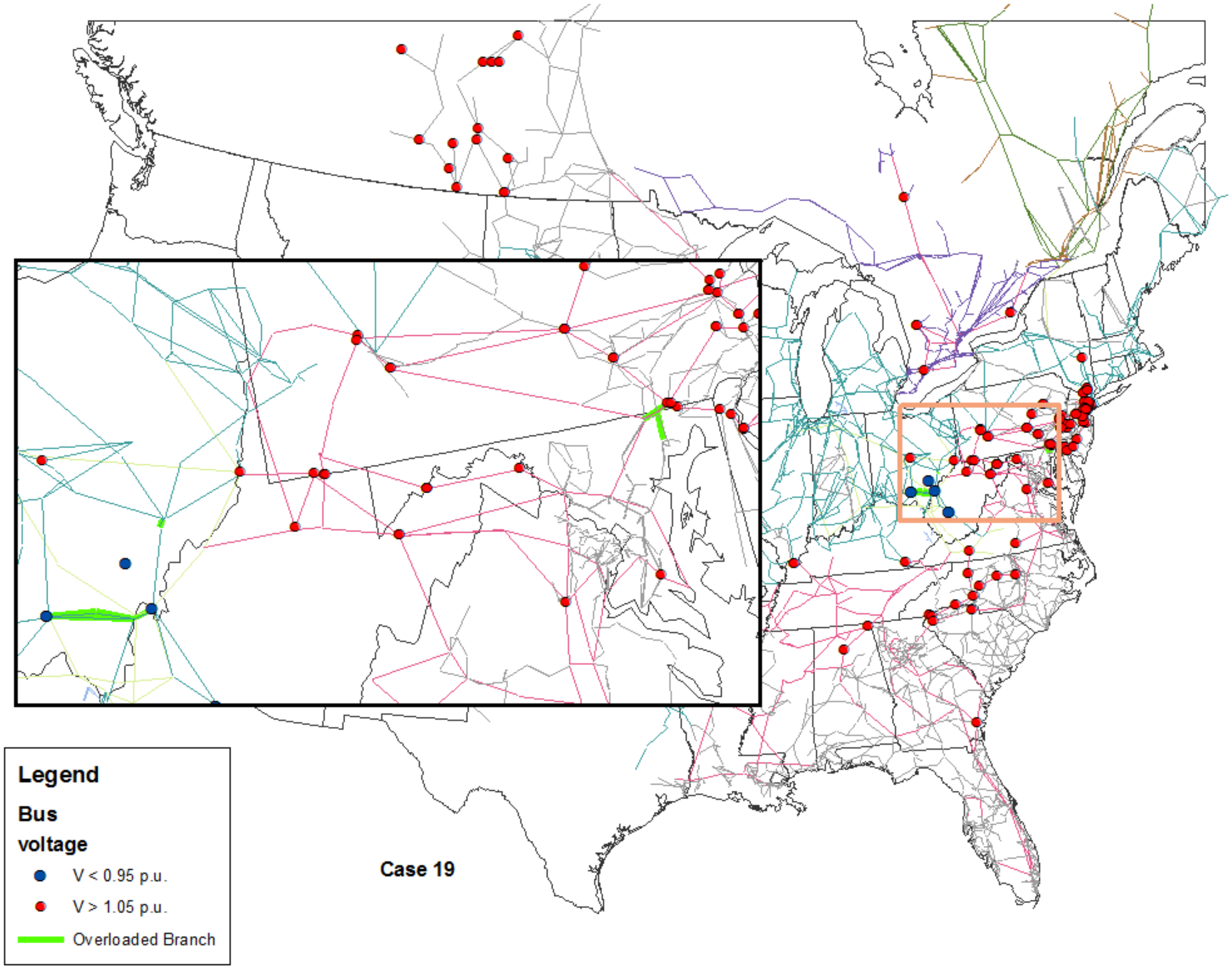

Fig. 3.36. 2016 gas base case with wind

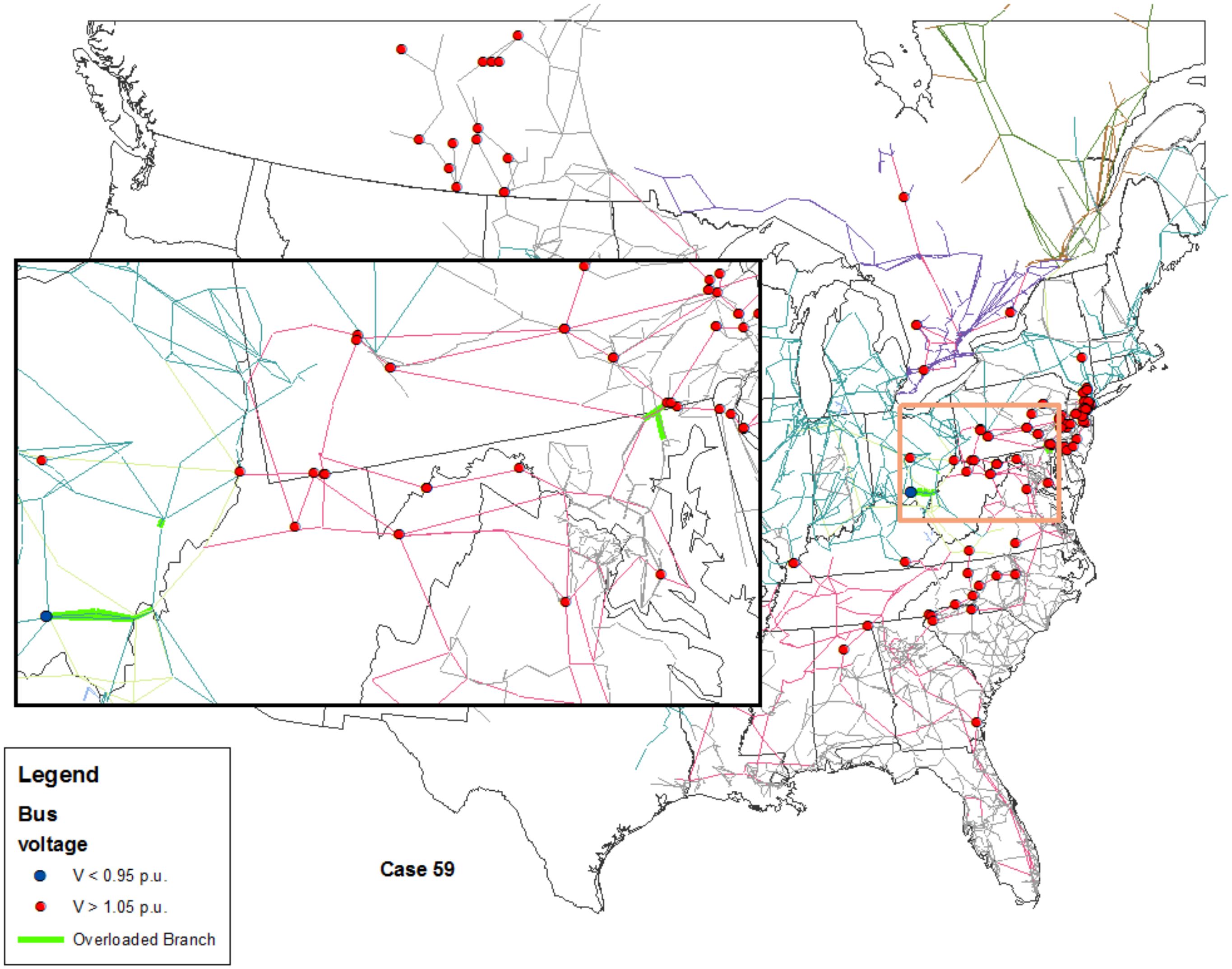

Fig. 3.37. 2016 gas base case with wind generation and synchronous condensers

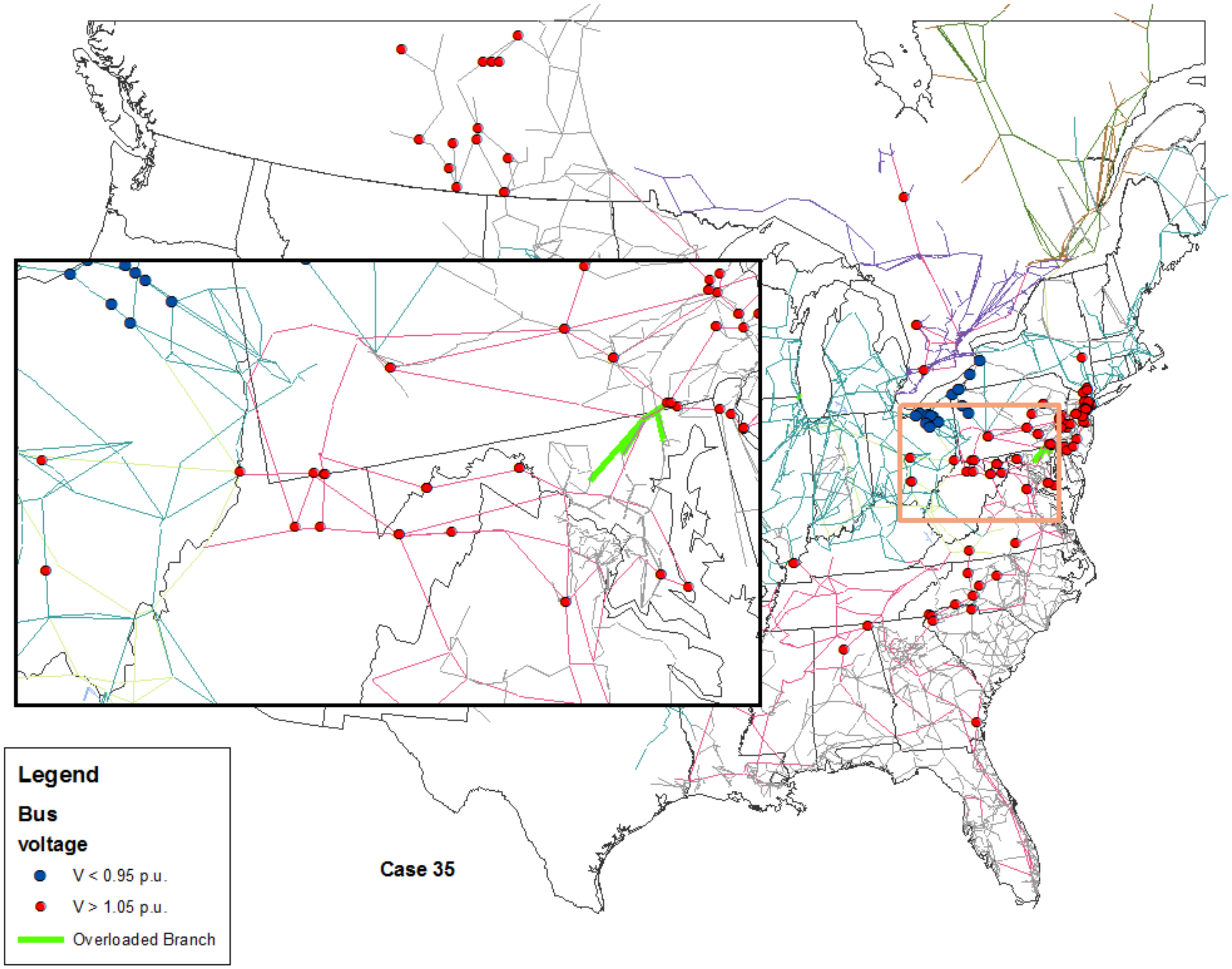

Fig. 3.38. 2016 gas base case with new nuclear units

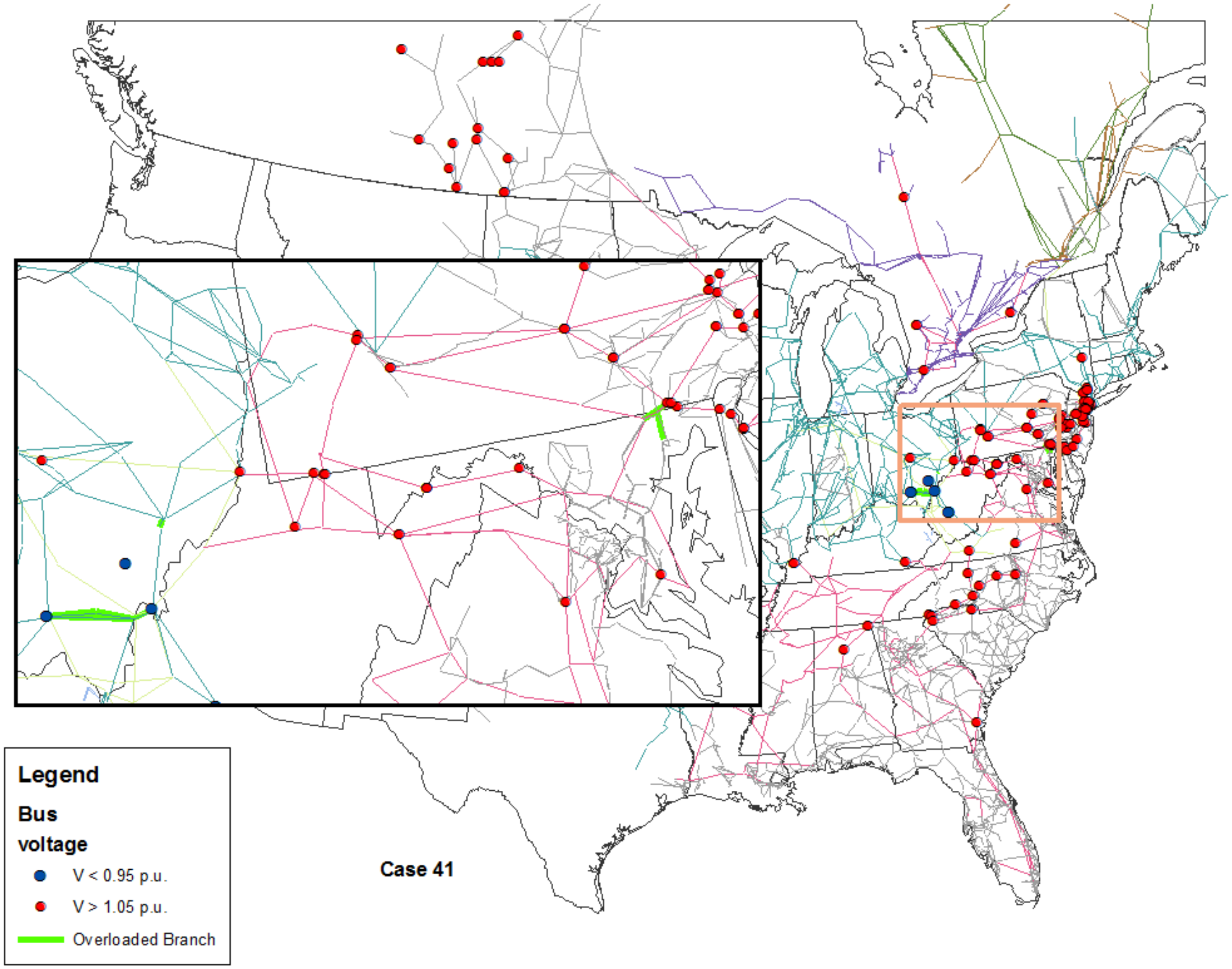

Fig. 3.39. 2016 gas and wind base case with new nuclear units

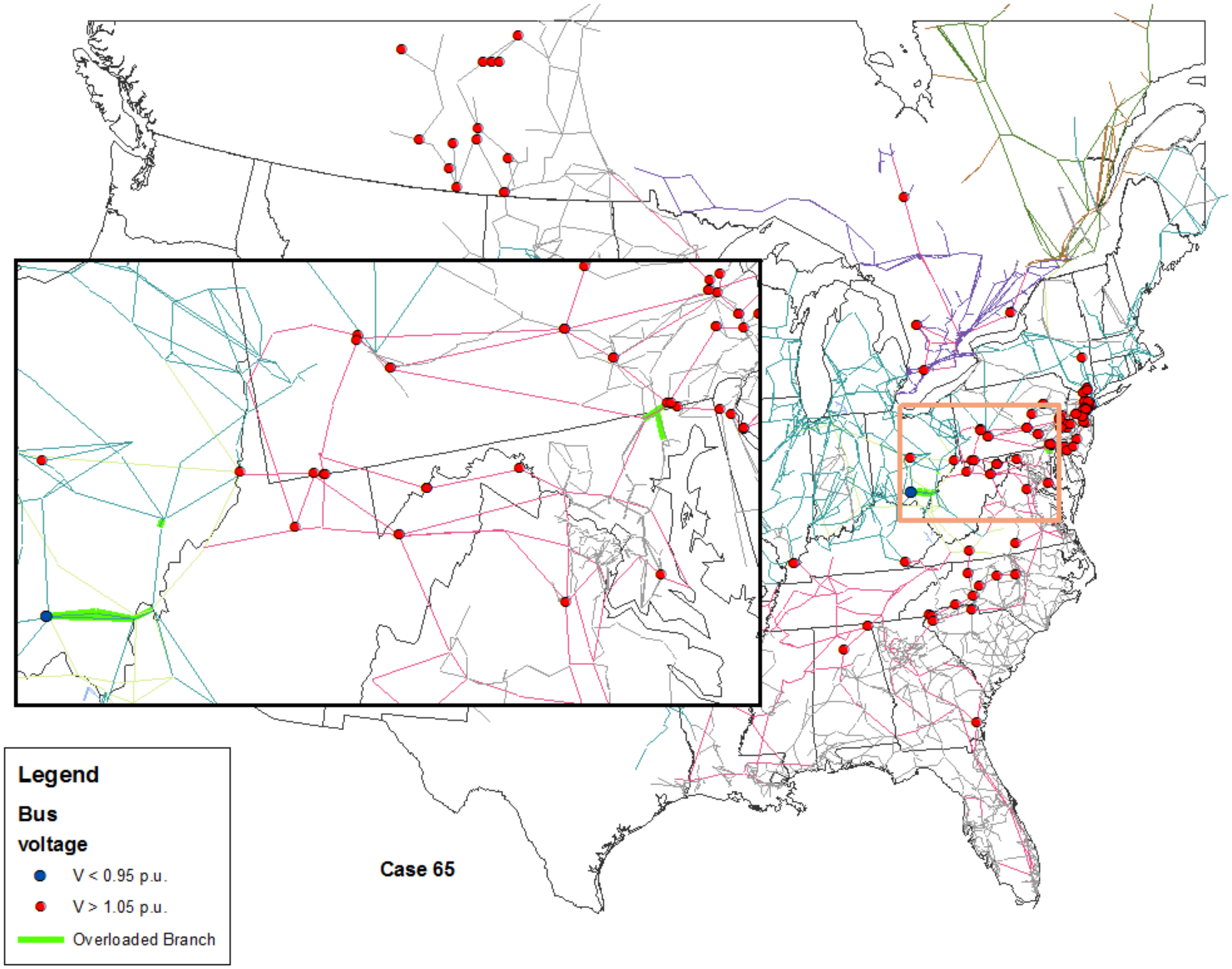

Fig. 3.40. 2016 gas, wind, new nuclear units, and synchronous condensers

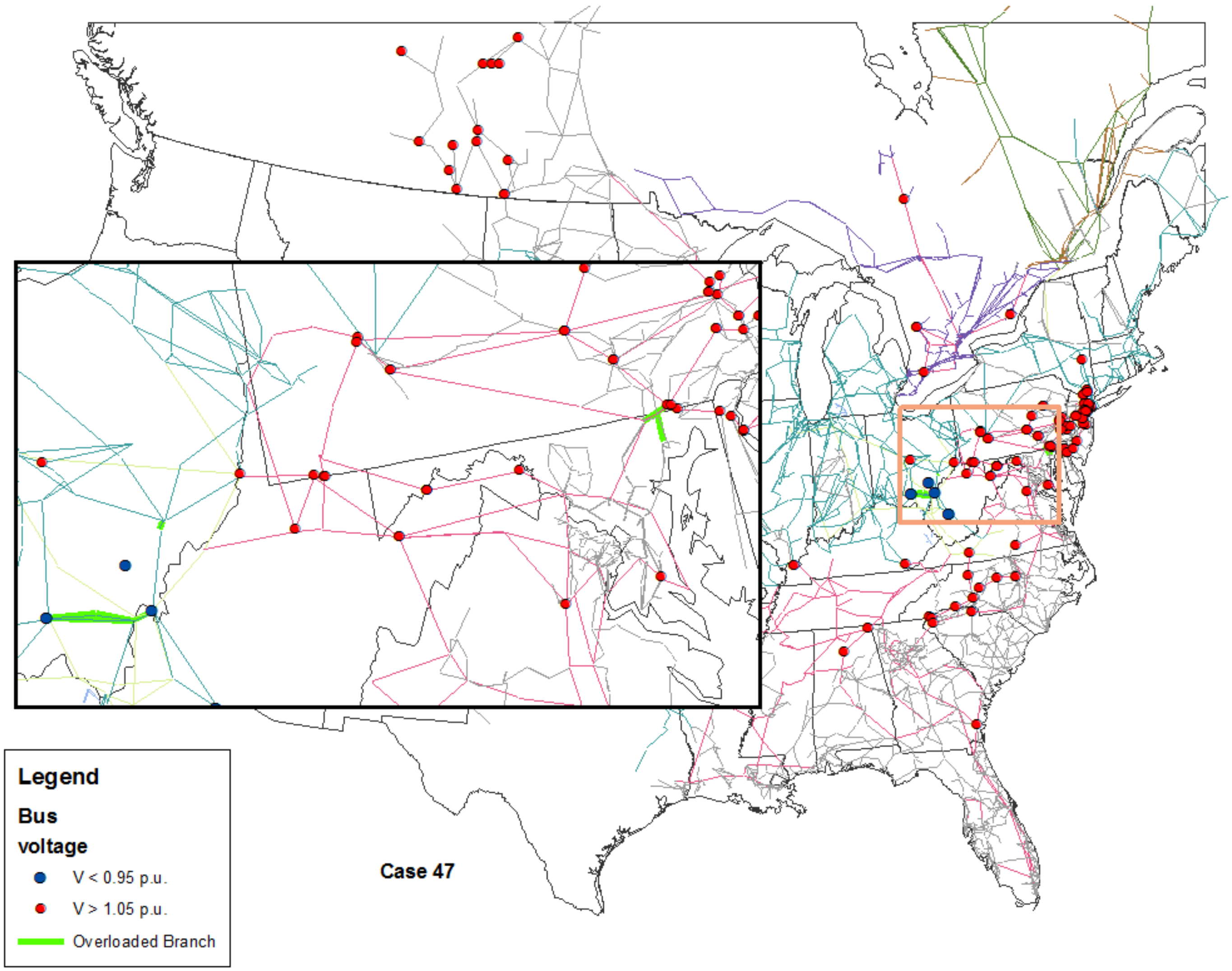

Fig. 3.41. 2016 gas and wind base case, nuclear plants removed

3.6 2017

The results of the 2017 base case simulation are shown in Fig. 3.42, and are similar to the base cases from previous years, however there are many fewer overvoltage buses (134). The swing bus output for this simulation was negative, indicating that it was absorbing rather than delivering real power. Normally, this would not happen in a real system. However, the magnitude of the absorbed power remained within the generator limits, so the results may still have some value. Once the MATS/CSAPR-affected generators were removed, the number of overvoltage buses dropped to 125, and two buses in Manitoba were below their acceptable voltage (Fig. 3.43). Also, four additional lines became overloaded. It should be noted that in this simulation, a large number of generators could not be removed successfully, and the swing bus output was several hundred megawatts above its actual limit. This was also observed for the synchronous condenser case (Fig. 3.44).

While the addition of gas-fired generation seemed to make the case slightly easier to solve, there were still 17 generators that could not be removed (Fig. 3.45). The swing bus output of the solved model was 7,378 MW, well above the actual limits, and this resulted in several additional overloaded lines. The introduction of wind generation (Fig. 3.46) seemed to create some difficulties, resulting in a large swing bus output and corresponding voltage problems. Synchronous condensers did not prove helpful in significantly improving bus voltages or alleviating overloaded lines, and resulted in a large swing bus output (Fig. 3.47).

Only one nuclear reactor (Vogtle, Unit 4) is scheduled to come online in 2017. Compared to the gas base case, the number of out-of-limit buses remained relatively constant, however 7 additional lines became overloaded (Fig. 3.48). As in many of the other 2017 cases, this was due in large part to the high swing bus power output required for the case to converge. Compared to the gas/wind case (Fig. 3.49), there were 9 fewer undervoltage buses and four fewer overloaded lines. Converting some of the removed generators to synchronous condensers appeared to improve the bus voltages in areas where they were too low (Fig. 3.51). For the nuclear shutdown case, the system failed to converge if more than one reactor was removed (Fig. 3.51).

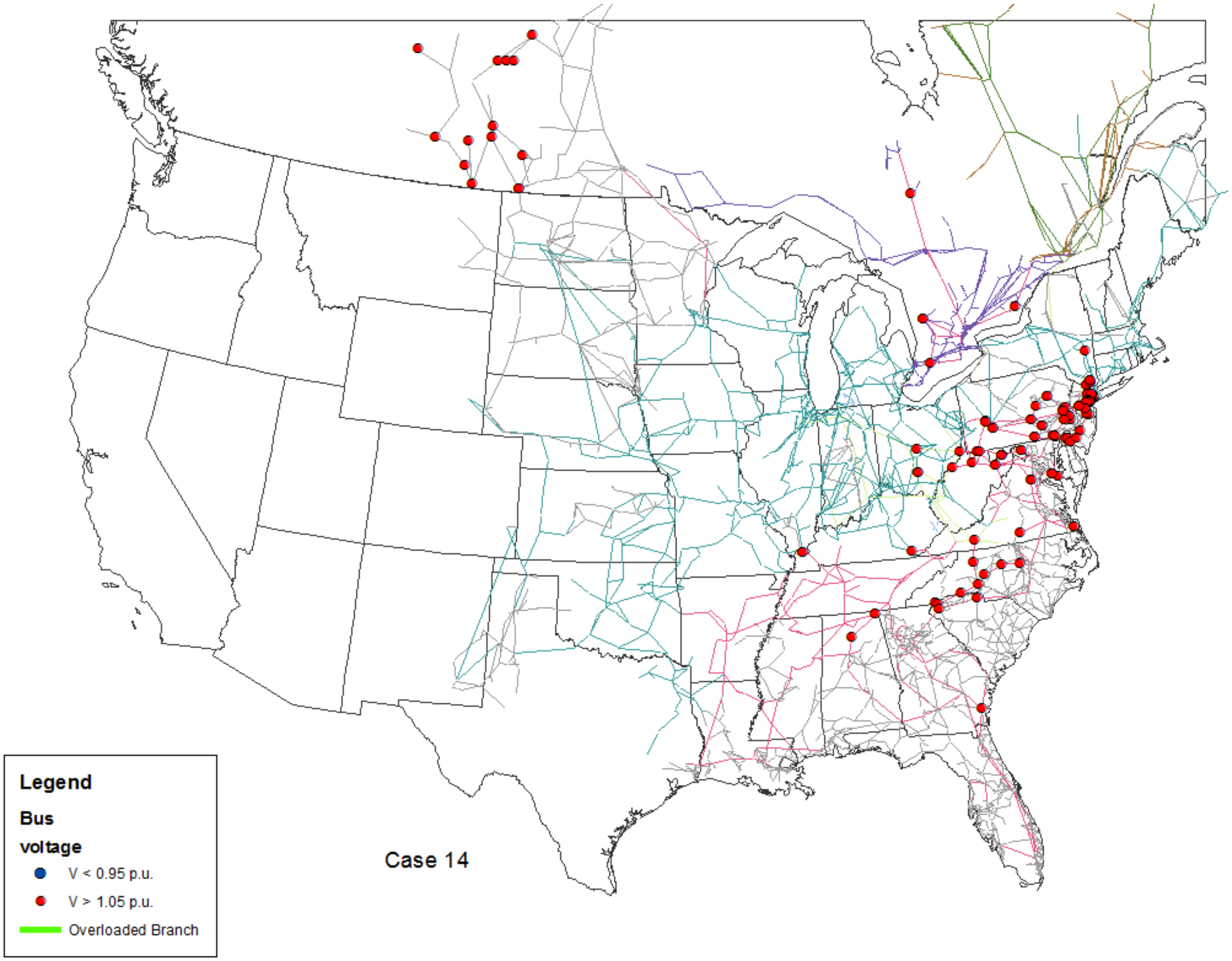

Fig. 3.42. 2017 base case

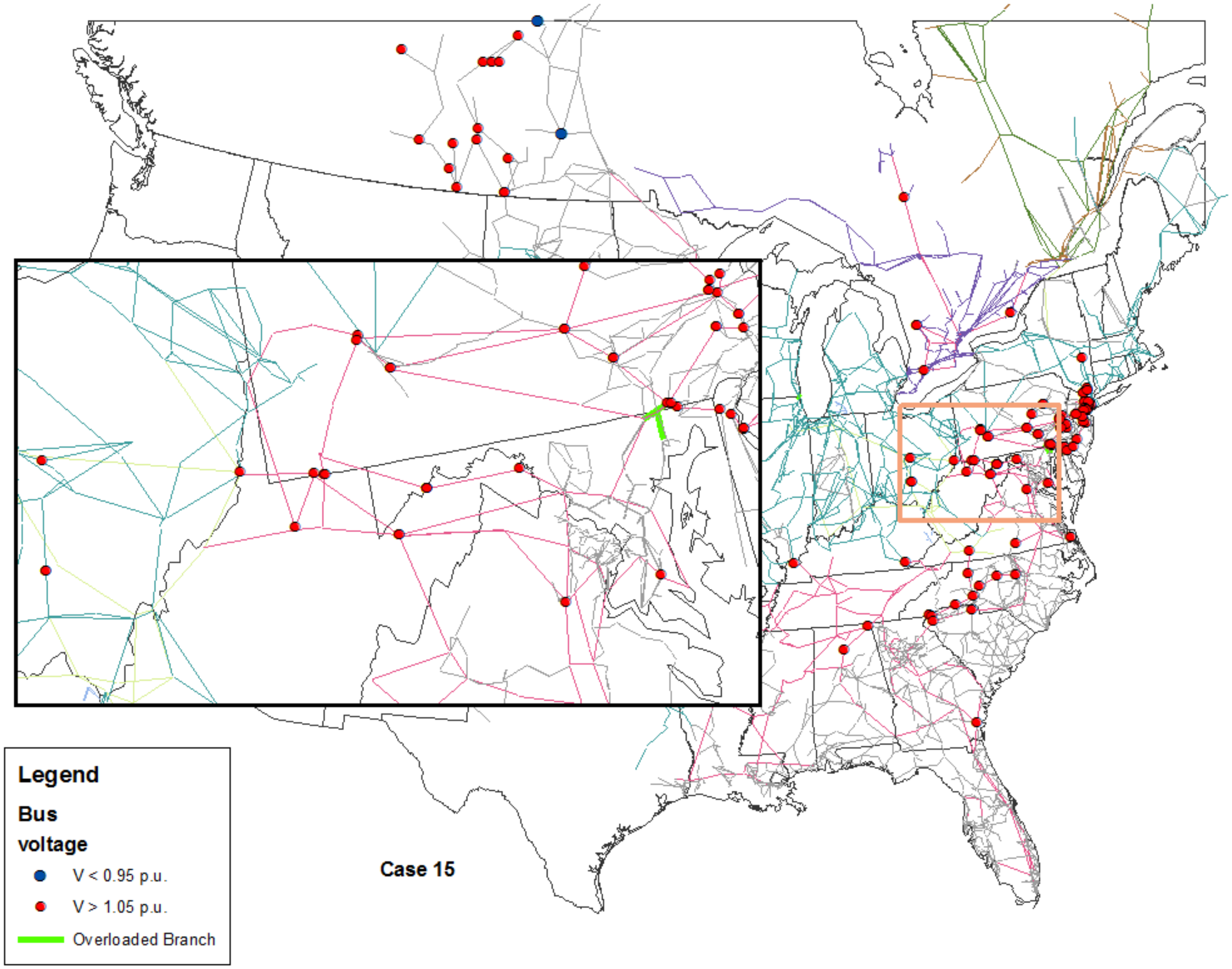

Fig. 3.43. 2017 base case with generators removed

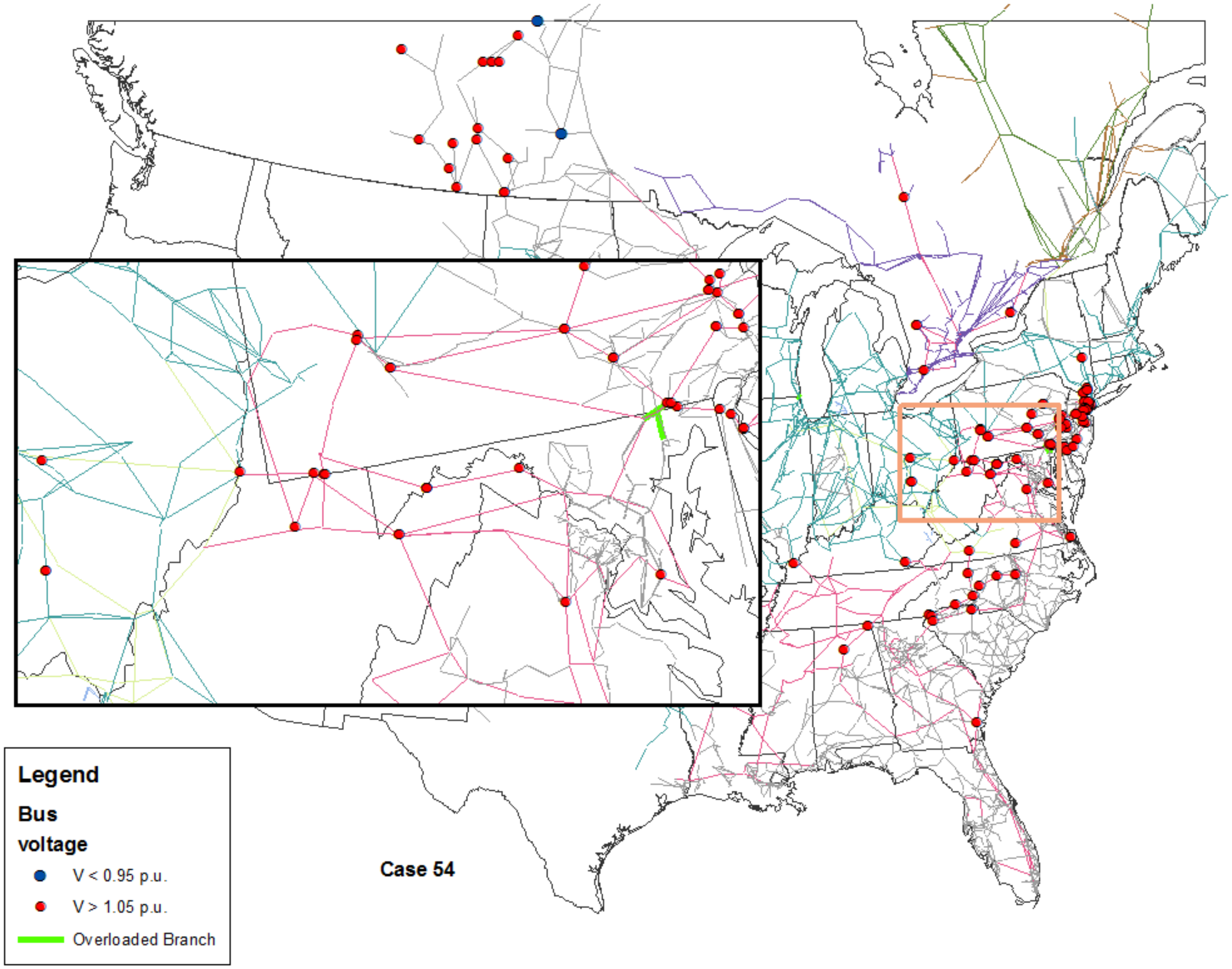

Fig. 3.44. 2017 base case with generators removed, synchronous condensers added

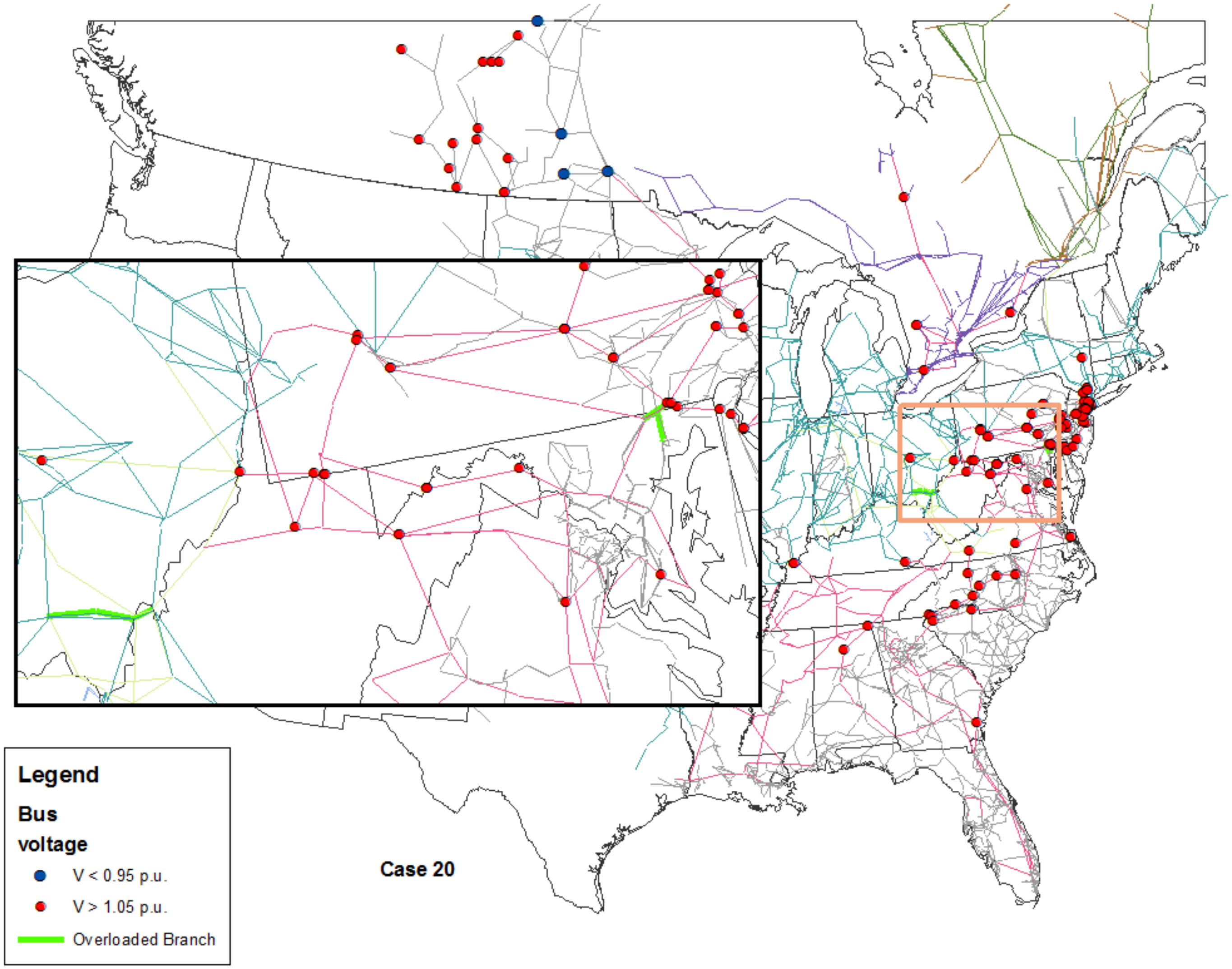

Fig. 3.45. 2017 gas base case

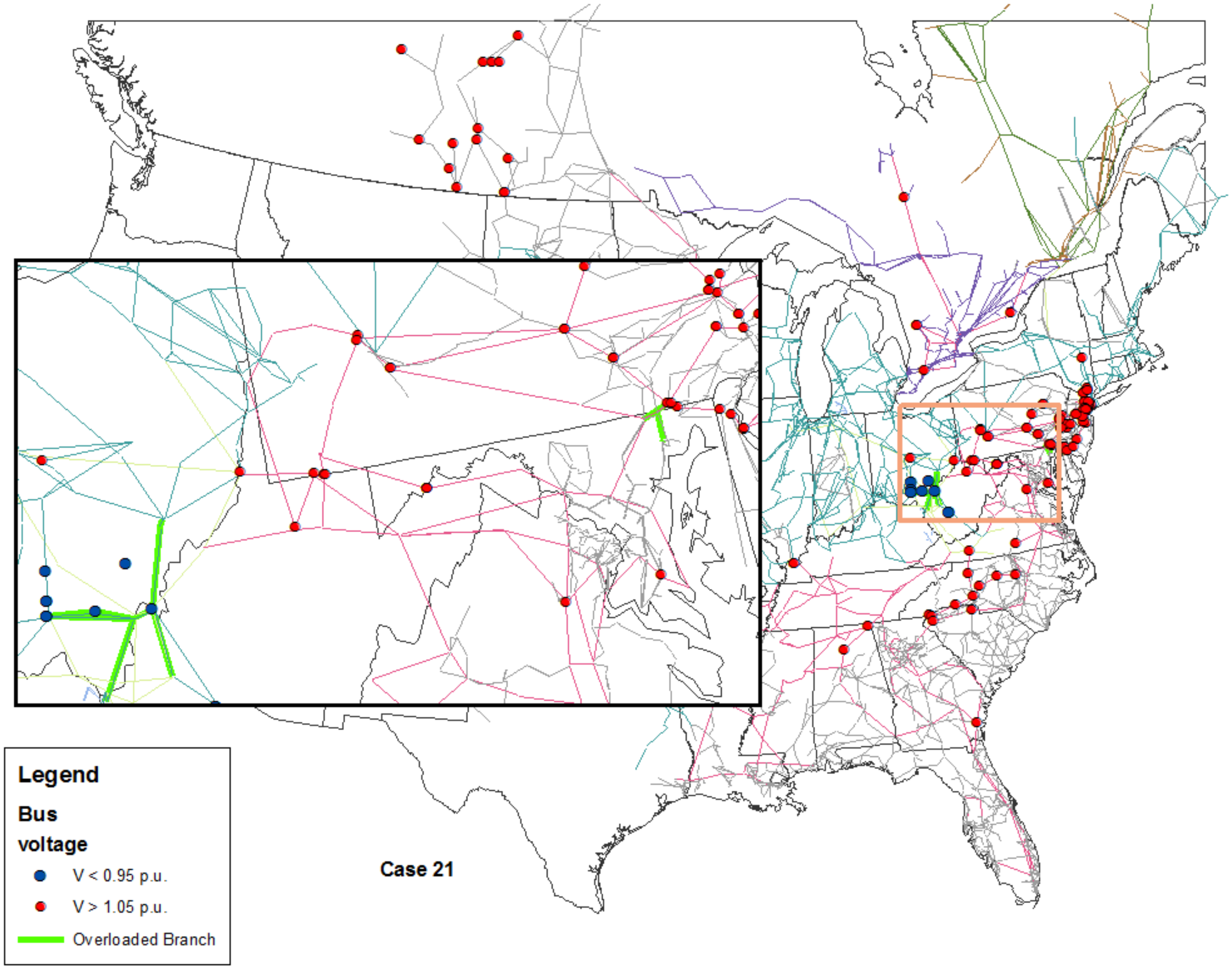

Fig. 3.46. 2017 gas base case with wind

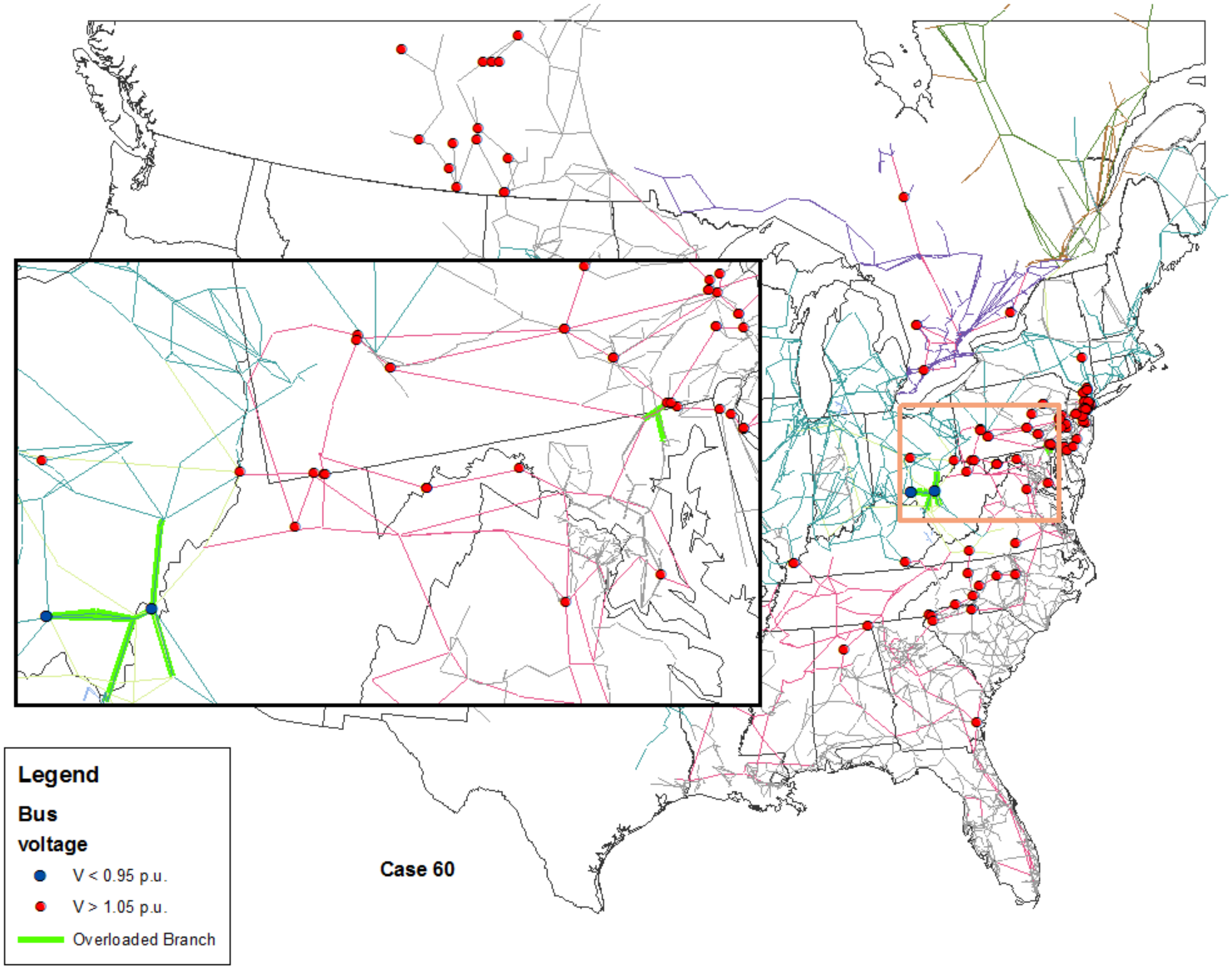

Fig. 3.47. 2017 gas base case with wind generation and synchronous condensers

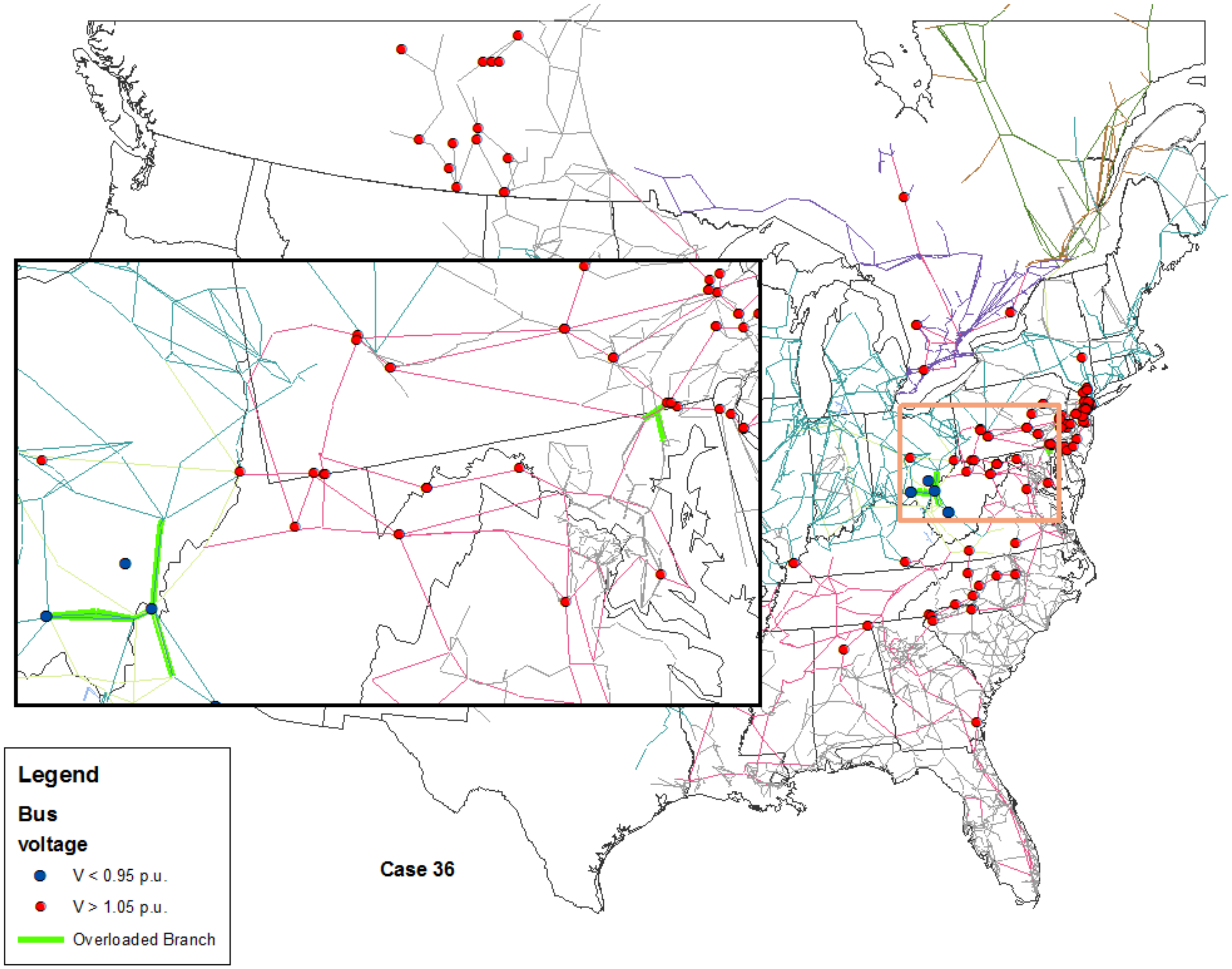

Fig. 3.48. 2017 gas base case with new nuclear units

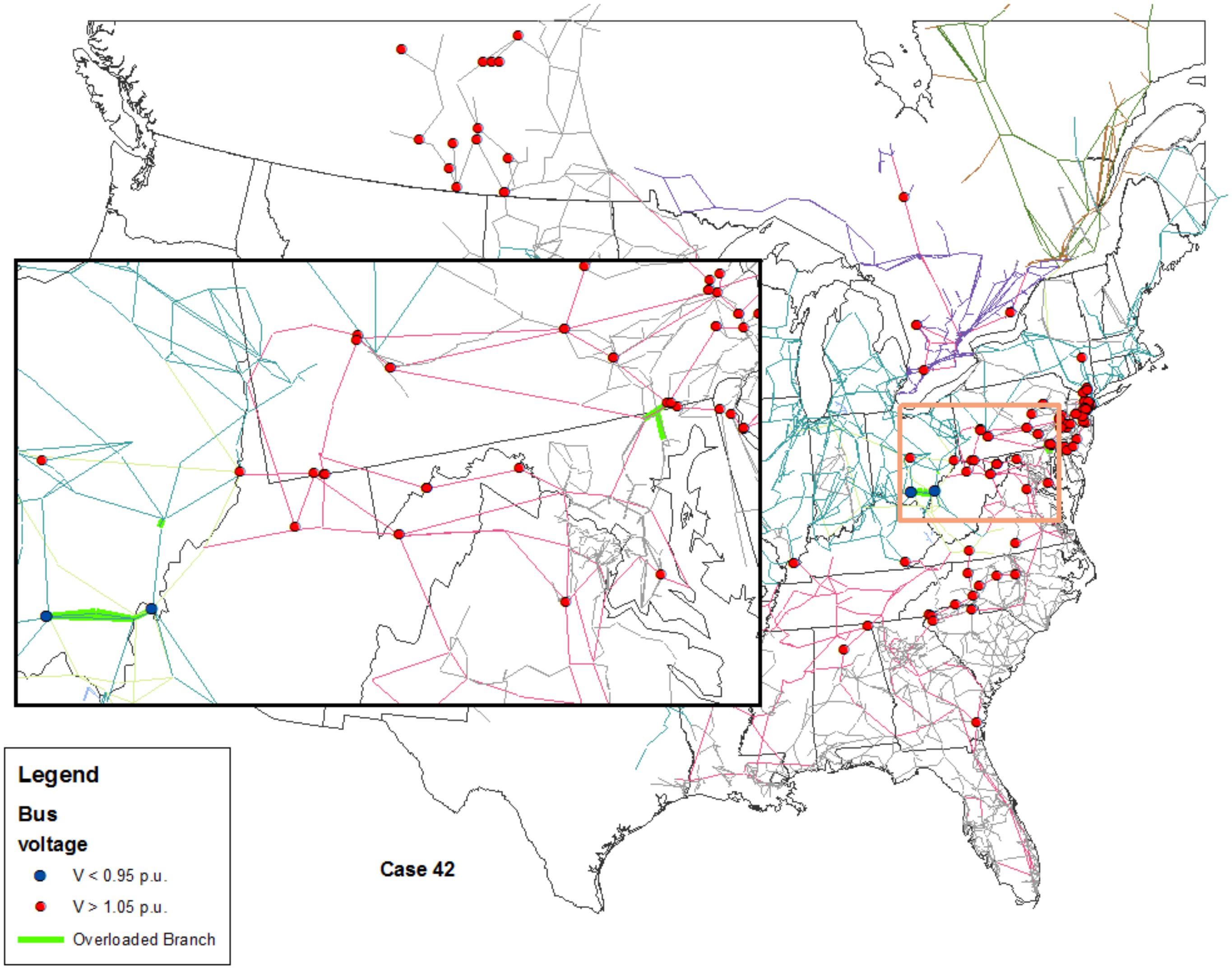

Fig. 3.49. 2017 gas and wind base case with new nuclear units

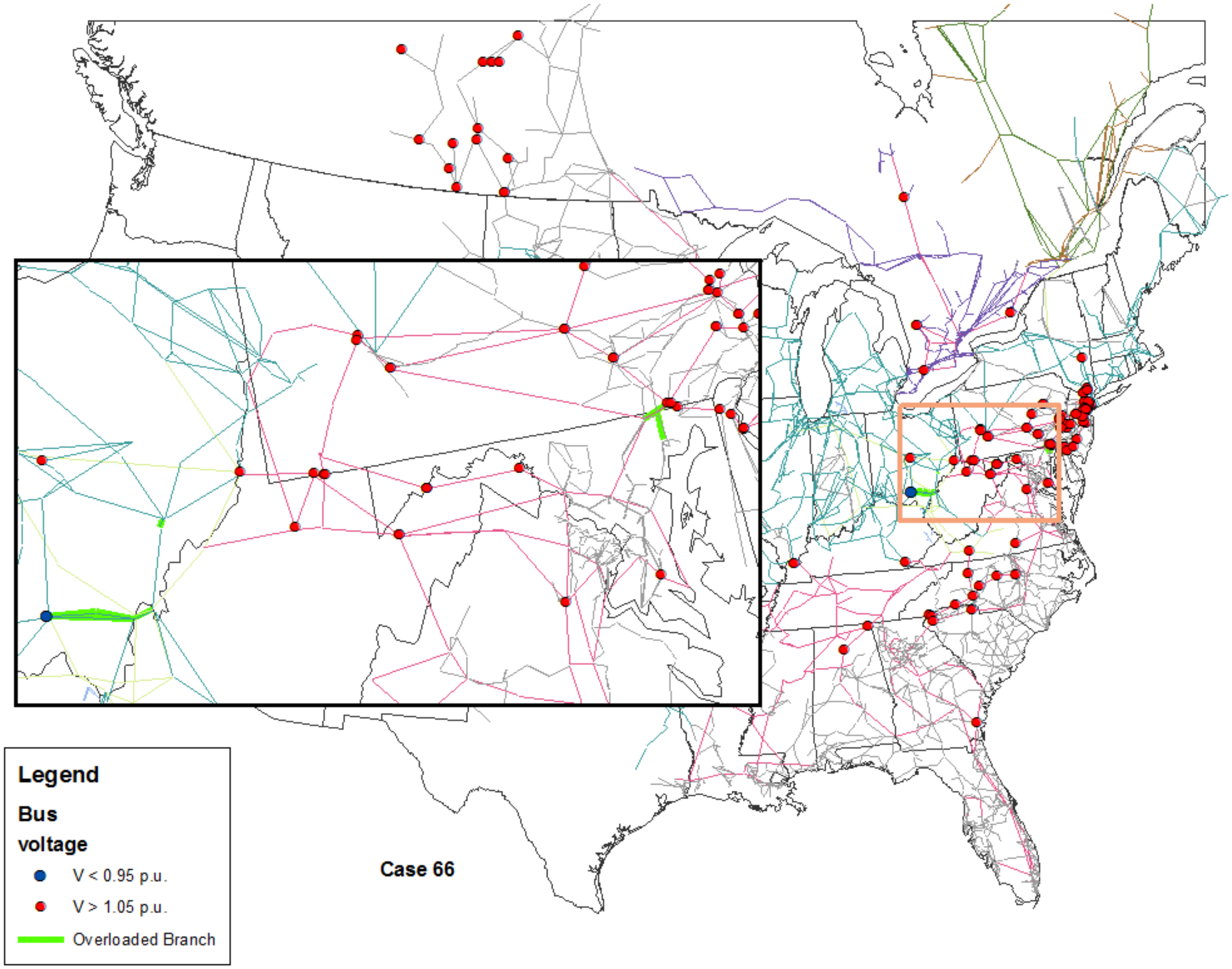

Fig. 3.50. 2017 gas and wind base case with new nuclear units and synchronous condensers

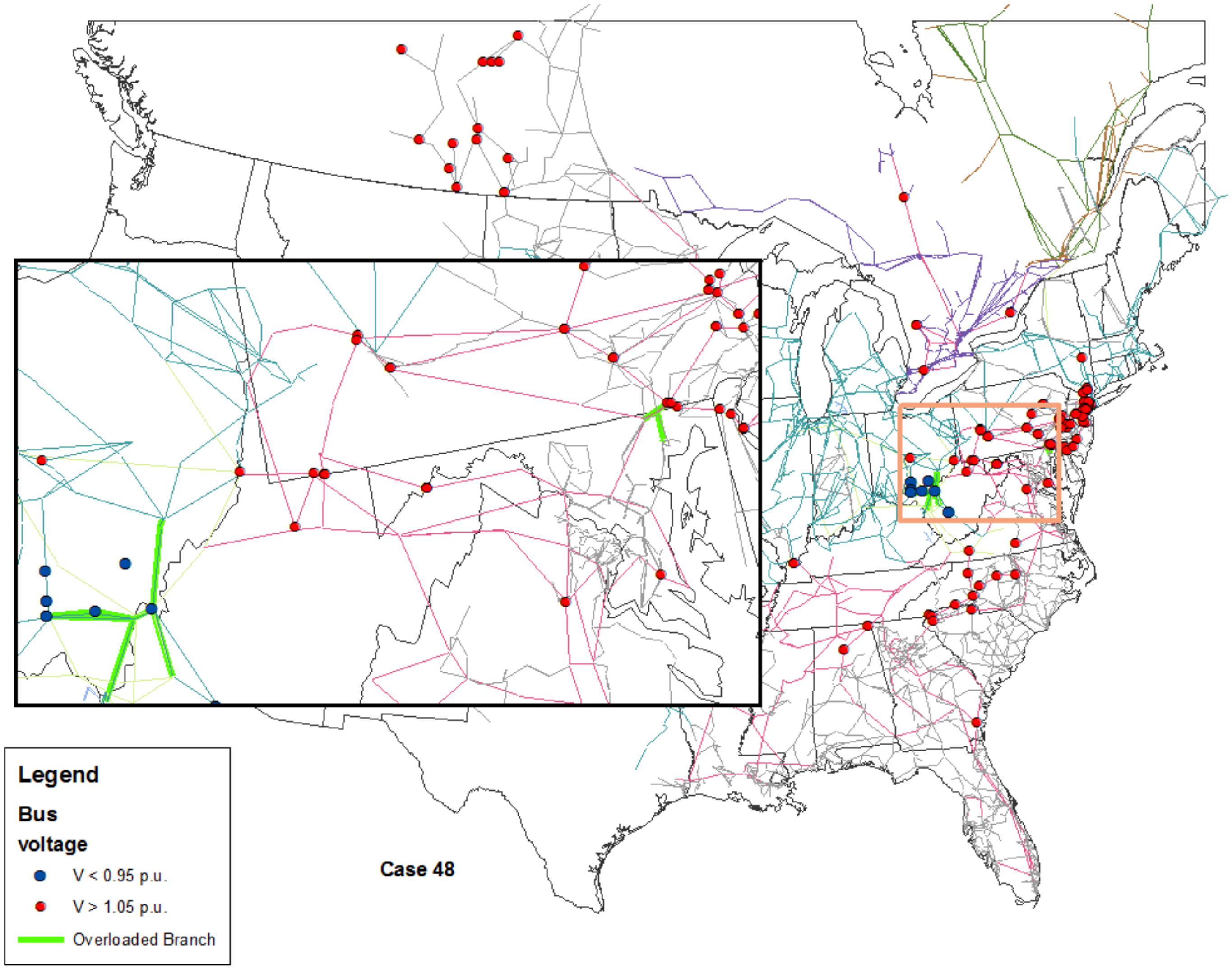

Fig. 3.51. 2017 gas and wind base case, nuclear plants removed

4. CONCLUSIONS

This report has presented a comprehensive study of the impacts of the Cross-State Air Pollution Rule and the Mercury and Air Toxics Standards on the Eastern Interconnection. Sixty power flow cases were constructed using a 29,000-bus PSS/E model. These cases were based upon planned generator deactivations and anticipated construction of new generating capacity, including gas, wind, and nuclear plants. Additionally, several cases were developed to examine what would happen if all nuclear reactors in the EI were to be shut down. The major conclusions of this study are as follows:

It does not appear that there would be widespread voltage stability or line overloading issues in the high-voltage transmission system as a result of MATS and CSAPR. Compared to the overall size of the system, very few buses and lines would be significantly affected in a negative manner. This study did not examine the reliability impacts of these regulations, however, since this has been done by others. Effects of these regulations on dynamic stability were not studied.

Low bus voltages were noted in the northeastern Ohio/Lake Erie region, particularly in 2015. Nearly all simulations in this study required that the Bay Shore and/or Eastlake power plants in this area be set as synchronous condensers in order for the model to converge properly after the MATS/CSAPR generators were removed. Since low bus voltages are indicative of a lack of reactive power, it is likely that remedial measures will need to be taken in this area. The results of this study seem to agree with recent announcements by the owner of the Eastlake plant indicating that some of its generators will need to remain operating for a few more years until additional transmission capacity can be built, while others will be converted to synchronous condensers [24, 25].

Conversion of MATS/CSAPR-affected generators to synchronous condensers is probably not worthwhile, except where previously noted. However, this option may be appropriate for some utilities, depending on their own needs and planning requirements.

Newly added gas-fired generation will not create major voltage stability problems or cause existing transmission lines to be overloaded. In some cases, the introduction of wind power may result in lowered bus voltages due to altered power flows and system operators will need to plan accordingly.

A total shutdown of all nuclear power plants in the Eastern Interconnection could create significant voltage stability issues, not to mention the impact on reserve requirements. Such a scenario is highly unlikely, due to the fact that the United States currently derives about 20% of its electrical energy from nuclear power.

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Appendix A
GENERATORS DEACTIVATED DUE TO MATS/CSAPR IN THE EI

Appendix A. GENERATORS DEACTIVATED DUE TO MATS/CSAPR IN THE EI

Plant Name	Unit ID	Capacity (MW)	Fuel Type	Bus Number	Year	City	State	In model
Philip Sporn	5	220	Coal	242808	2011	Graham Station	WV	1
Philip Sporn	6	220	Coal	242808	2011	Graham Station	WV	1
Albright Power Station 1	1	69	Coal	235564	2012	Albright	WV	1
Albright Power Station 2	1	69	Coal	235565	2012	Albright	WV	1
Albright Power Station 3	1	140	Coal	235566	2012	Albright	WV	1
Alma	3	15	Coal	681543	2012	Alma	WI	0
Alma	2	15	Coal	681543	2012	Alma	WI	0
Alma	1	15	Coal	681543	2012	Alma	WI	0
Bay Shore	Z	641	Coal	238567	2012	Oregon	OH	1
Elrama Power Plant	1	100	Coal	254014	2012	Elrama	PA	0
Elrama Power Plant	4	185	Coal	254010	2012	Elrama	PA	1
Elrama Power Plant	3	125	Coal	254014	2012	Elrama	PA	0
Elrama Power Plant	2	100	Coal	254014	2012	Elrama	PA	0
Hutsonville	4	75	Coal	347272	2012	Hutsonville	IL	1
Hutsonville	3	75	Coal	347271	2012	Hutsonville	IL	1
Meredosia	4	166	Oil	347680	2012	Meredosia	IL	0
Meredosia	5	203	Coal	347680	2012	Meredosia	IL	0
Monticello	2	593	Coal	508337	2012	Mount Pleasant	TX	0
Monticello	1	593	Coal	508337	2012	Mount Pleasant	TX	0
Niles	2	133	Coal	239008	2012	Niles	OH	0
Niles	1	133	Coal	239008	2012	Niles	OH	0
State Line3	L	180	Coal	274679	2012	Hammond	IN	1

State Line3	H	318	Coal	274679	2012	Hammond	IN	1
State Line4	L	100	Coal	274680	2012	Hammond	IN	1
State Line4	H	197	Coal	274680	2012	Hammond	IN	1
Blue Valley	1	51	Coal	548806	2014	Independence	MO	1
Brayton Point	5	435	Natural Gas	129475	2014	Somerset	MA	0
Buck	6	38	Coal	306022	2014	Salisbury	NC	1
Buck	1	38	Coal	306309	2014	Salisbury	NC	0
Buck	7	38	Coal	306309	2014	Salisbury	NC	0
Chamois	1	49	Coal	300019	2014	Chamois	MO	1
Dale	1	75	Coal	341443	2014	Winchester	KY	1
Dale	1	75	Coal	341440	2014	Winchester	KY	1
Dale	1	27	Coal	341436	2014	Winchester	KY	1
Dale	1	27	Coal	341433	2014	Winchester	KY	1
Endicott Station	4	55	Coal	256228	2014	Litchfield	MI	0
James De Young	1	27	Coal	256002	2014	Holland	MI	0
John Sevier	1	176	Coal	100	2014	Rogersville	TN	0
Johnsonville	1	106	Coal	4142	2014	New Johnsonville	TN	1
Johnsonville	1	141	Coal	4148	2014	New Johnsonville	TN	1
Johnsonville	1	106	Coal	4141	2014	New Johnsonville	TN	1
Johnsonville	1	141	Coal	4147	2014	New Johnsonville	TN	1
Johnsonville	1	106	Coal	4146	2014	New Johnsonville	TN	1
Johnsonville	1	106	Coal	4145	2014	New Johnsonville	TN	1
Johnsonville	1	106	Coal	4144	2014	New Johnsonville	TN	1
Johnsonville	1	141	Coal	4150	2014	New Johnsonville	TN	1
Johnsonville	1	106	Coal	4143	2014	New Johnsonville	TN	1

Johnsonville	1	141	Coal	4149	2014	New Johnsonville	TN	1
Lone Star	1	50	Natural Gas	508297	2014	Lone Star	TX	0
Marion	4	170	Coal	350234	2014	Marion	IL	1
New Castle	2A	138	Coal	242940	2014	West Pittsburg	PA	0
New Castle	5	138	Coal	238812	2014	West Pittsburg	PA	0
Philip Sporn	6	41	Coal	242807	2014	Graham Station	WV	1
Philip Sporn	8	41	Coal	242807	2014	Graham Station	WV	1
Philip Sporn	2	105	Coal	242807	2014	Graham Station	WV	1
Philip Sporn	4	105	Coal	242807	2014	Graham Station	WV	1
Philip Sporn	5	41	Coal	242807	2014	Graham Station	WV	1
Philip Sporn	7	41	Coal	242807	2014	Graham Station	WV	1
Philip Sporn	1	105	Coal	242807	2014	Graham Station	WV	1
Philip Sporn	3	105	Coal	242807	2014	Graham Station	WV	1
Plant Mitchell	C	42	Oil	383783	2014	Albany	GA	1
R E Burger	6	47	Coal	238583	2014	Shadyside	OH	0
R E Burger	5	47	Coal	238583	2014	Shadyside	OH	0
Riverbend	8	94	Coal	306154	2014	Mount Holly	NC	0
Riverbend	7	94	Coal	306040	2014	Mount Holly	NC	1
Riverton	Z	54	Coal	547644	2014	Riverton	KS	1
Riverton	39	38	Coal	547469	2014	Riverton	KS	0
Rivesville 5	1	35	Coal	235575	2014	Rivesville	WV	1
Rivesville 6	1	75	Coal	235576	2014	Rivesville	WV	1
Robert A Reid	1	65	Coal	340572	2014	Robards	KY	1
Salem Harbor	1	82	Coal	221125	2014	Salem	MA	0
Salem Harbor	4	476	Coal	221125	2014	Salem	MA	0

Salem Harbor	3	166	Coal	221125	2014	Salem	MA	0
Salem Harbor	2	82	Coal	221125	2014	Salem	MA	0
Sibley	2	54	Coal	541152	2014	Sibley	MO	1
Sibley	1	54	Coal	541153	2014	Sibley	MO	1
Sunbury Generation LP	2B	40	Coal	200021	2014	Shamokin Dam	PA	0
Sunbury Generation LP	2A	40	Coal	200021	2014	Shamokin Dam	PA	0
Sunbury Generation LP	1	128	Coal	209017	2014	Shamokin Dam	PA	1
Sunbury Generation LP4	3	94	Coal	200021	2014	Shamokin Dam	PA	0
Valley	Z	267	Coal	699506	2014	Milwaukee	WI	1
Wabash River	6	387	Coal	251893	2014	Terre Haute	IN	1
Wabash River	5	125	Coal	251892	2014	Terre Haute	IN	1
Wabash River	4	113	Coal	251890	2014	Terre Haute	IN	1
Wabash River	3	123	Coal	251889	2014	Terre Haute	IN	1
Wabash River	2	113	Coal	251888	2014	Terre Haute	IN	1
Willow Island	1	163	Coal	235578	2014	Willow Island	WV	1
Willow Island	1	50	Coal	235577	2014	Willow Island	WV	1
Armstrong	1	163	Coal	235569	2015	Adrian	PA	1
Armstrong	1	163	Coal	235567	2015	Adrian	PA	1
Ashtubula	5	256	Coal	239036	2015	Ashtabula Township	OH	0
Avon Lake	Z	94	Coal	238554	2015	Avon Lake	OH	1
Avon Lake	Z	640	Coal	238555	2015	Avon Lake	OH	1
B.C. Cobb	4	156	Coal	256108	2015	Muskegon	MI	0
B.C. Cobb	2	156	Coal	256108	2015	Muskegon	MI	0
Black Dog	4	180	Coal	603066	2015	Burnsville	MN	0
Black Dog	3	114	Coal	603066	2015	Burnsville	MN	0

Blount Street	8	49	Coal	699168	2015	Madison	WI	0
Blount Street	9	48	Coal	699168	2015	Madison	WI	0
Canadys Steam	1	105	Coal	370812	2015	Walterboro	SC	1
Cape Fear	1	175	Coal	304881	2015	Moncure	NC	1
Cape Fear	1	148	Coal	304880	2015	Moncure	NC	1
Clifton	1	73	Natural Gas	539655	2015	Clifton	KS	1
Clinch River	3L	104	Coal	242904	2015	Cleveland	VA	1
Clinch River	3H	126	Coal	242903	2015	Cleveland	VA	1
Conesville	3	165	Coal	243654	2015	Conesville	OH	1
D.E. Karn	2	260	Coal	256007	2015	Essexville	MI	0
D.E. Karn	1	255	Coal	256007	2015	Essexville	MI	0
Dubuque	4	30	Coal	630290	2015	Dubuque	IA	1
Dubuque	3	35	Coal	630290	2015	Dubuque	IA	1
Eagle Valley	4	56	Coal	249613	2015	Martinsville	IN	0
Eagle Valley	3	43	Coal	249613	2015	Martinsville	IN	0
Eastlake	Z	1257	Coal	238683	2015	Eastlake	OH	1
Frank E. Ratts1	1	117	Coal	248903	2015	Petersburg	IN	1
Frank E. Ratts2	1	117	Coal	248904	2015	Petersburg	IN	1
Glen Gardner	Z	80	Coal	206333	2015	Glen Gardner	NJ	1
Glen Gardner	Z	80	Coal	206331	2015	Glen Gardner	NJ	1
Glen Lyn	6	108	Coal	242651	2015	Glen Lyn	VA	1
Glen Lyn	5	90	Coal	242650	2015	Glen Lyn	VA	1
Glen Lyn	7	127	Coal	242651	2015	Glen Lyn	VA	1
Green River	4	95	Coal	324022	2015	Central City	KY	1
Green River	3	68	Coal	324021	2015	Central City	KY	1

Harllee Branch	2	319	Coal	383692	2015	Milledgeville	GA	1
Harllee Branch	1	262	Coal	383691	2015	Milledgeville	GA	1
Hutchinson Energy Center	T1	51	Natural Gas	533441	2015	Hutchinson	KS	0
Hutchinson Energy Center	T4	77	Natural Gas	533441	2015	Hutchinson	KS	0
Hutchinson Energy Center	T3	56	Natural Gas	533441	2015	Hutchinson	KS	0
Hutchinson Energy Center	T2	55	Natural Gas	533441	2015	Hutchinson	KS	0
J.R. Whiting (All Units)	Z	328	Coal	256368	2015	Erie	MI	1
Kammer	1L	92	Coal	243193	2015	Captina	WV	1
Kammer	1H	108	Coal	243192	2015	Captina	WV	1
Kammer	2L	92	Coal	243195	2015	Oroville	WV	1
Kammer	2H	108	Coal	243194	2015	Oroville	WV	1
Kammer	3L	92	Coal	243197	2015	Captina	WV	1
Kammer	3H	108	Coal	243196	2015	Captina	WV	1
Kanawha	1H	123	Coal	242895	2015	Glasgow	WV	1
Kanawha	1L	72	Coal	242896	2015	Glasgow	WV	1
Kanawha	2L	123	Coal	242898	2015	Glasgow	WV	1
Kanawha	2H	72	Coal	242897	2015	Glasgow	WV	1
Kraft	1	48	Coal	389008	2015	Port Wentworth	GA	1
Lake Shore	18	256	Coal	238637	2015	Cleveland	OH	0
Lawrence Energy Center	4	110	Coal	532853	2015	Lawrence	KS	0
Lawrence Energy Center	3	48	Coal	532853	2015	Lawrence	KS	0
Meramec	2	138	Coal	345140	2015	St. Louis	MO	1
Meramec	L	170	Coal	345156	2015	St. Louis	MO	1
Meramec	1	138	Coal	345132	2015	St. Louis	MO	1

Meramec	L	140	Coal	345148	2015	St. Louis	MO	1
Meramec	H	190	Coal	345156	2015	St. Louis	MO	1
Meramec	H	140	Coal	345148	2015	St. Louis	MO	1
Miami Fort	6	163	Coal	251949	2015	North Bend	OH	1
Muskingum River	A	70	Coal	243045	2015	Beverly	OH	1
Muskingum River	4	92	Coal	242940	2015	Beverly	OH	1
Muskingum River	3	92	Coal	243045	2015	Beverly	OH	1
Muskingum River	D	113	Coal	242940	2015	Beverly	OH	1
Muskingum River	2	120	Coal	242940	2015	Beverly	OH	1
Muskingum River	C	112	Coal	243045	2015	Beverly	OH	1
Muskingum River	1	120	Coal	243045	2015	Beverly	OH	1
Muskingum River	B	70	Coal	242940	2015	Beverly	OH	1
New Castle	4	96	Coal	238812	2015	West Pittsburg	PA	0
P H Glatfelter	Z	36	Coal	204639	2015	Spring Grove	PA	1
Picway	1	100	Coal	243522	2015	Lockbourne	OH	0
Portland	Z	172	Coal	204661	2015	Mt. Bethel	PA	1
Portland	Z	255	Coal	204651	2015	Mt. Bethel	PA	1
Potomac River	5	110	Coal	314053	2015	Alexandria	VA	0
Potomac River	4	110	Coal	314053	2015	Alexandria	VA	0
Potomac River	3	110	Coal	314053	2015	Alexandria	VA	0
Potomac River	2	88	Coal	314053	2015	Alexandria	VA	0
Potomac River	1	88	Coal	314053	2015	Alexandria	VA	0
Quindaro	T3	46	Natural Gas	530592	2015	Kansas	KS	0
Quindaro	T2	56	Natural Gas	530592	2015	Kansas	KS	0
R Gallagher	1	140	Coal	251857	2015	New Albany	IN	1

R Gallagher	3	140	Coal	251859	2015	New Albany	IN	1
R. Paul Smith	11	75	Coal	235509	2015	Williamsport	MD	0
R. Paul Smith	9	35	Coal	235509	2015	Williamsport	MD	0
Rumford Cogeneration	7	43	Coal	204614	2015	Rumford	ME	0
Rumford Cogeneration	6	43	Coal	204614	2015	Rumford	ME	0
Scholz	2	49	Coal	386752	2015	Sneeds	FL	1
Scholz	1	49	Coal	386751	2015	Sneeds	FL	1
Shawville 1	Z	125	Coal	200715	2015	Shawville	PA	1
Shawville 2	2	125	Coal	200722	2015	Shawville	PA	1
Shawville 3	3	188	Coal	200665	2015	Shawville	PA	1
Shawville 4	4	188	Coal	200666	2015	Shawville	PA	1
Tanners Creek	3	153	Coal	243233	2015	Lawrenceburg	IN	1
Tanners Creek	C	145	Coal	243233	2015	Lawrenceburg	IN	1
Tanners Creek	4	215	Coal	243233	2015	Lawrenceburg	IN	1
Tecumseh Energy Center	Z	74	Coal	532671	2015	Tecumseh	KS	1
Titus	3	75	Coal	204512	2015	Birsboro	PA	0
Titus	2	75	Coal	204512	2015	Birsboro	PA	0
Titus	1	75	Coal	204512	2015	Birsboro	PA	0
Titus	5	18	Coal	204512	2015	Birsboro	PA	0
Titus	4	18	Coal	204512	2015	Birsboro	PA	0
WC Beckjord	4	163	Coal	251936	2015	New Richmond	OH	1
WC Beckjord	3	125	Coal	251935	2015	New Richmond	OH	1
WC Beckjord	2	113	Coal	251934	2015	New Richmond	OH	1
WC Beckjord	1	115	Coal	251939	2015	New Richmond	OH	1
WC Beckjord	6	461	Coal	251938	2015	New Richmond	OH	1
WC Beckjord	5	245	Coal	251937	2015	New Richmond	OH	1

Weatherspoon	A	49	Coal	304924	2015	Lumberton	NC	1
Weatherspoon	A	79	Coal	304927	2015	Lumberton	NC	1
Weatherspoon	A	49	Coal	304925	2015	Lumberton	NC	1
Welsh 2	1	528	Coal	509405	2015	Pittsburg	TX	1
WPS Power Niagara	1	53	Coal	135415	2015	Niagara Falls	NY	0
Yates	1	99	Coal	383641	2015	Newnan	GA	1
Yorktown	2	188	Coal	315091	2015	Yorktown	VA	1
Yorktown	1	188	Coal	315090	2015	Yorktown	VA	1
Cane Run	5	209	Coal	324011	2016	Louisville	KY	1
Cane Run	4	163	Coal	324010	2016	Louisville	KY	1
Cane Run	6	272	Coal	324012	2016	Louisville	KY	1
Chesapeake	J	16	Coal	315101	2016	Chesapeake	VA	1
Chesapeake	G	24	Coal	315100	2016	Chesapeake	VA	1
Chesapeake	B	19	Coal	315099	2016	Chesapeake	VA	1
Chesapeake	D	24	Coal	315099	2016	Chesapeake	VA	1
Chesapeake	H	24	Coal	315100	2016	Chesapeake	VA	1
Chesapeake	F	16	Coal	315099	2016	Chesapeake	VA	1
Chesapeake	I	16	Coal	315101	2016	Chesapeake	VA	1
Chesapeake 1	1	113	Coal	315094	2016	Chesapeake	VA	1
Chesapeake 2	2	113	Coal	315095	2016	Chesapeake	VA	1
Chesapeake 3	3	185	Coal	315096	2016	Chesapeake	VA	1
Chesapeake 4	4	239	Coal	315097	2016	Chesapeake	VA	1
Green River	1	75	Coal	324144	2016	Central City	KY	0
Green River	2	114	Coal	324144	2016	Central City	KY	0
Northeast Station	3	473	Coal	510396	2016	Oologah	OK	0
Tyrone	3	135	Coal	324042	2016	Versailles	KY	1

Appendix B
PLANNED GAS-FIRED POWER PLANTS IN THE EI

Appendix B. PLANNED GAS-FIRED POWER PLANTS IN THE EI

Plant Name	Unit ID	Capacity (MW)	Fuel Type	Bus Number	Year	City	State	In Model
Astoria Energy II	T4	156	Natural Gas	126295	2011	Astoria	NY	0
Astoria Energy II	T3	156	Natural Gas	126295	2011	Astoria	NY	0
Astoria Energy II	T2	228	Natural Gas	126295	2011	Astoria	NY	0
Bear Garden	S1	254	Natural Gas	315193	2011	New Canton	VA	1
Bear Garden	G2	170	Natural Gas	315192	2011	New Canton	VA	1
Bear Garden	G1	165	Natural Gas	315191	2011	New Canton	VA	1
Buck	10	163	Natural Gas	306119	2011	Salisbury	NC	0
Buck	11	163	Natural Gas	306119	2011	Salisbury	NC	0
Cane Island	4	160	Natural Gas		2011	Intercession City	FL	0
Fremont Energy Center	2	175	Natural Gas	238602	2011	Fremont	OH	1
Fremont Energy Center	3	325	Natural Gas	238603	2011	Fremont	OH	1
Fremont Energy Center	1	175	Natural Gas	238601	2011	Fremont	OH	1
Gillette SBMC	G3	7	Natural Gas		2011	Boston	MA	0
Greenland Energy Center	1	148	Natural Gas	200581	2011	Jacksonville	FL	0
Greenland Energy Center	2	148	Natural Gas	200581	2011	Jacksonville	FL	0
Hunlock Power Station	5	49	Natural Gas	234251	2011	Hunlock Creek	PA	0
Hunlock Power Station	6	49	Natural Gas	234251	2011	Hunlock Creek	PA	0
Kleen Energy Systems Project	ST	274	Natural Gas		2011	Middletown	CT	0
Kleen Energy Systems Project	U1	177	Natural Gas		2011	Middletown	CT	0
Kleen Energy Systems Project	U2	177	Natural Gas		2011	Middletown	CT	0
Marshfield Utilities Gas Plant	M1	55	Natural Gas	699244	2011	Marshfield	WI	0
Oneida Energy	E1	1	Natural Gas	699359	2011	Green Bay	WI	0
Richmond	A	200	Natural Gas	304978	2011	Hamlet	NC	1
Richmond	B	200	Natural Gas	304978	2011	Hamlet	NC	1
Richmond	C	252	Natural Gas	304978	2011	Hamlet	NC	1
Teche	4	33	Natural Gas	335567	2011	Baldwin	LA	0
West County Energy Center	3A	232	Natural Gas		2011	Loxahatchee	FL	0
West County Energy Center	ST	523	Natural Gas		2011	Loxahatchee	FL	0
West County Energy Center	3C	232	Natural Gas		2011	Loxahatchee	FL	0
West County Energy Center	3B	244	Natural Gas		2011	Loxahatchee	FL	0
York Energy Center	G4	188	Natural Gas	200122	2011	Peach Bottom	PA	0
York Energy Center	G2	122	Natural Gas	200122	2011	Peach Bottom	PA	0
York Energy Center	G3	122	Natural Gas	200122	2011	Peach Bottom	PA	0

York Energy Center	G1	113	Natural Gas	200122	2011	Peach Bottom	PA	0
Bayonne Energy Center	T1	57	Natural Gas	126285	2012	Bayonne	NJ	0
Bayonne Energy Center	T4	57	Natural Gas	126285	2012	Bayonne	NJ	0
Bayonne Energy Center	T2	57	Natural Gas	126285	2012	Bayonne	NJ	0
Bayonne Energy Center	T5	57	Natural Gas	126285	2012	Bayonne	NJ	0
Bayonne Energy Center	T3	57	Natural Gas	126285	2012	Bayonne	NJ	0
Bayonne Energy Center	T6	57	Natural Gas	126285	2012	Bayonne	NJ	0
Bayonne Energy Center	T8	57	Natural Gas	126285	2012	Bayonne	NJ	0
Bayonne Energy Center	T7	57	Natural Gas	126285	2012	Bayonne	NJ	0
Cleveland County Generating Facility	1	180	Natural Gas	306578	2012	Grover	NC	1
Cleveland County Generating Facility	4	180	Natural Gas	306581	2012	Grover	NC	1
Cleveland County Generating Facility	3	180	Natural Gas	306580	2012	Grover	NC	1
Cleveland County Generating Facility	2	180	Natural Gas	306579	2012	Grover	NC	1
Dan River	3	263	Natural Gas	306572	2012	Eden	NC	1
Dan River	2	163	Natural Gas	306571	2012	Eden	NC	1
Dan River	1	163	Natural Gas	306570	2012	Eden	NC	1
Deer Creek Station	1	300	Natural Gas	659285	2012	Elkton	SD	1
Dresden Energy Facility	1S	223	Natural Gas	246770	2012	Dresden	OH	1
Dresden Energy Facility	1B	158	Natural Gas	246770	2012	Dresden	OH	1
Dresden Energy Facility	1A	158	Natural Gas	246770	2012	Dresden	OH	1
Elkins Generating Center	C	20	Natural Gas	506983	2012	Elkins	AR	0
Howard Down	11	56	Natural Gas	228207	2012	Vineland	NJ	0
Jack McDonough	5A	240	Natural Gas	383962	2012	Smyrna	GA	1
Jack McDonough	5	373	Natural Gas	383961	2012	Smyrna	GA	1
Jack McDonough	6B	240	Natural Gas	383885	2012	Smyrna	GA	1
Jack McDonough	6	375	Natural Gas	383883	2012	Smyrna	GA	1
Jack McDonough	4A	240	Natural Gas	383879	2012	Smyrna	GA	1
Jack McDonough	6A	240	Natural Gas	383884	2012	Smyrna	GA	1
Jack McDonough	4	380	Natural Gas	383878	2012	Smyrna	GA	1
Jack McDonough	4B	240	Natural Gas	383880	2012	Smyrna	GA	1
JackMcDonough	5B	240	Natural Gas	383963	2012	Smyrna	GA	1
John Sevier	3	165	Natural Gas	4323	2012	Rogersville	TN	1
John Sevier	2	165	Natural Gas	4322	2012	Rogersville	TN	1
John Sevier	4	383	Natural Gas	4324	2012	Rogersville	TN	1
John Sevier	1	165	Natural Gas	4321	2012	Rogersville	TN	1
New Haven Harbor	3	44	Natural Gas		2012	New Haven	CT	0
New Haven Harbor	2	44	Natural Gas		2012	New Haven	CT	0

New Haven Harbor	4	44	Natural Gas		2012	New Haven	CT	0
Oneida Energy	E3	1	Natural Gas	699359	2012	Green Bay	WI	0
Oneida Energy	E2	1	Natural Gas	699359	2012	Green Bay	WI	0
PSEG Kearny Generating Station	33	44	Natural Gas	217000	2012	Kearny	NJ	0
PSEG Kearny Generating Station	31	44	Natural Gas	217000	2012	Kearny	NJ	0
PSEG Kearny Generating Station	42	44	Natural Gas	217000	2012	Kearny	NJ	0
PSEG Kearny Generating Station	41	44	Natural Gas	217000	2012	Kearny	NJ	0
PSEG Kearny Generating Station	34	44	Natural Gas	217000	2012	Kearny	NJ	0
PSEG Kearny Generating Station	32	44	Natural Gas	217000	2012	Kearny	NJ	0
Warren F Sam Beasley Generation Station	2	50	Natural Gas	232002	2012	Smyrna	DE	0
Waterloo	13	6	Natural Gas	348776	2012	Waterloo	IL	0
Big Bend	T5	56	Natural Gas		2013	Apollo Beach	FL	0
CPV Valley Energy Center	1	281	Natural Gas	148998	2013	Wawayanda	NY	1
CPV Valley Energy Center	1	175	Natural Gas	148997	2013	Wawayanda	NY	1
CPV Valley Energy Center	1	175	Natural Gas	148996	2013	Wawayanda	NY	1
Gowanus Gas Turbines Generating	SS	90	Natural Gas	126277	2013	Brooklyn	NY	0
H L Culbreath Bayside Power Station	8	56	Natural Gas		2013	Tampa Bay	FL	0
H L Culbreath Bayside Power Station	7	56	Natural Gas		2013	Tampa Bay	FL	0
Hamlet Generating Facility	S6	56	Natural Gas	304355	2013	Hamlet	NC	0
Wayne County	A	170	Natural Gas	304960	2013	Goldsboro	NC	1
Wayne County	A	170	Natural Gas	304956	2013	Goldsboro	NC	1
Wayne County	A	170	Natural Gas	304957	2013	Goldsboro	NC	1
Wayne County	A	170	Natural Gas	304959	2013	Goldsboro	NC	1
Wayne County	A	170	Natural Gas	304958	2013	Goldsboro	NC	1
West Deptford Energy Station	1	308	Natural Gas	219121	2013	West Deptford	NJ	0
Big Bend	T6	56	Natural Gas		2014	Apollo Beach	FL	0
Garrison Energy Center LLC	T1	150	Natural Gas	232003	2014	Dover	DE	0
Towantic Energy LLC	G1	165	Natural Gas	126281	2014	Oxford	CT	0
Towantic Energy LLC	G2	161	Natural Gas	126281	2014	Oxford	CT	0
Towantic Energy LLC	G1	161	Natural Gas	126281	2014	Oxford	CT	0
West Deptford Energy Station	2	308	Natural Gas	219121	2014	West Deptford	NJ	0
Zion Energy Center	G4	152	Natural Gas	270940	2014	Zion	IL	0

Zion Energy Center	G5	152	Natural Gas	270940	2014	Zion	IL	0
CPV Warren, LLC	1	180	Natural Gas	235110	2015	Front Royal	VA	0
CPV Warren, LLC	2	180	Natural Gas	235110	2015	Front Royal	VA	0
CPV Warren, LLC	1	105	Natural Gas	235110	2015	Front Royal	VA	0
CPV Warren, LLC	2	105	Natural Gas	235110	2015	Front Royal	VA	0
Cricket Valley Energy	1	346	Natural Gas	126294	2015	Dover	NY	0
Cricket Valley Energy	2	346	Natural Gas	126294	2015	Dover	NY	0
Cricket Valley Energy	3	346	Natural Gas	126294	2015	Dover	NY	0
Garrison Energy Center LLC	T2	150	Natural Gas	232003	2015	Dover	DE	0
Gibson County Generation Station	1	371	Natural Gas	141	2015	Rutherford	TN	0
Lima Energy	T2	240	Natural Gas	242909	2015	Lima	OH	0
Lima Energy	T1	240	Natural Gas	242909	2015	Lima	OH	0
Live Oaks Power Plant	1A	170	Natural Gas	386039	2015	Brunswick	GA	1
Live Oaks Power Plant	1B	170	Natural Gas	386040	2015	Brunswick	GA	1
Live Oaks Power Plant	1	250	Natural Gas	386038	2015	Brunswick	GA	1
Nearman Creek	T5	45	Natural Gas	542976	2015	Kansas City	KS	0
Tampa Electric Co NA 2	1	56	Natural Gas		2015	Tampa Bay	FL	0
Washington Parish Energy Center	T1	215	Natural Gas	336130	2015	Bogalusa	LA	0
Washington Parish Energy Center	G1	172	Natural Gas	336130	2015	Bogalusa	LA	0
Washington Parish Energy Center	G2	172	Natural Gas	336130	2015	Bogalusa	LA	0
Stony Brook	3A	289	Natural Gas	137455	2016	Ludlow	MA	0
Tampa Electric Co NA 2	2	56	Natural Gas		2016	Tampa Bay	FL	0
Trigen Trenton Energy	2	1	Natural Gas	219200	2016	Trenton	NJ	0
Trigen Trenton Energy	1	1	Natural Gas	219200	2016	Trenton	NJ	0
Elk Mound	Z	90	Natural Gas	680516	2017	Elk Mound	WI	1
Tampa Electric Co NA 2	3	56	Natural Gas		2017	Tampa Bay	FL	0
Tampa Electric Co NA 2	4	56	Natural Gas		2018	Tampa Bay	FL	0
Polk	8	366	Natural Gas		2019	Mulberry	FL	0
Arvah B Hopkins	T5	46	Natural Gas	380218	2020	Tallahassee	FL	0

Appendix C
PLANNED WIND POWER PLANTS IN THE EI

Appendix C. PLANNED WIND POWER PLANTS IN THE EI

Plant Name	Unit ID	Capacity (MW)	Fuel Type	Bus Number	Year	City	State	In Model
Bishop Hill Energy LLC	1	200	Wind	636672	2012	Galva	IL	0
Blue Canyon Windpower VI LLC	1	100	Wind	521129	2012	Lawton	OK	1
Cimarron Windpower II	1	131	Wind	531469	2012	Cimarron	KS	0
Crossroads Wind Farm	98	227	Wind	515407	2012	Canton	OK	0
Ironwood Wind	2	167	Wind	531469	2012	Ford County	KS	0
Marble River Wind Farm	G1	200	Wind	137200	2012	Clinton	NY	0
Meadow Lake Wind Farm V LLC	N1	100	Wind	249524	2012	Brookston	IN	0
Post Rock Wind Power Project LLC	1	201	Wind	530592	2012	Ellsworth County	KS	0
Prairie Rose Wind Farm	R1	200	Wind	602039	2012	Jasper	MN	0
Bingham Wind	1	127	Wind		2013	Bingham	ME	0
Black Prairie Wind Farm LLC	N2	200	Wind	270673	2013	McLean County	IL	0
Blackstone Wind Farm IV	G2	100	Wind	270852	2013	Pontiac	IL	0
Lexington Chenoa Wind Farm II LLC	G1	100	Wind	270673	2013	Lexington	IL	0
Lexington Chenoa Wind Farm LLC	G2	200	Wind	270673	2013	Lexington	IL	0
Number Nine Wind Farm	G1	200	Wind		2013	Bridgewat er	ME	0
Oakfield Wind Project	2	149	Wind		2013	Oakfield	ME	0
Waverly Wind Farm LLC	G1	200	Wind	532797	2013	Waverly	KS	0
Black Prairie Wind Farm LLC	N1	200	Wind	270673	2014	McLean County	IL	0
Simpson Ridge Wind Farm LLC	N1	100	Wind		2014	Hanna	WY	0

Appendix D
Planned Nuclear Power Plants in the EI

Appendix D. PLANNED NUCLEAR POWER PLANTS IN THE EI

Plant Name	Unit ID	Capacity (MW)	Fuel Type	Bus Number	Year	City	State	In Model
Watts Bar, Unit 2	2	1270	Nuclear	4022	2015	Spring City	TN	1
Virgil C. Summer, Unit 2	2	1100	Nuclear	370835	2016	Jenkinsville	SC	1
Vogtle Electric Generating Plant, Unit 3	3	1100	Nuclear	383753	2016	Waynesboro	GA	1
Vogtle Electric Generating Plant, Unit 4	4	1100	Nuclear	380115	2017	Waynesboro	GA	0