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DEPARTMENT OF ENERGY AND MINERAL ENGINEERING

IMPACT OF INCREASED MARKET PENETRATION OF ELECTRIC VEHICLES ON THE PJM REGIONAL ELECTRIC GRID

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ABSTRACT

This paper analyzes an increased market penetration of electric vehicles in the Classic PJM regional electric grid, and its effect on the dispatch of generators. A unit commitment model was used to create an hour-by-hour generator dispatch schedule for a 168-hour week in PJM. The additional demand placed on the electric grid by increased usage of electric vehicles was modeled using two extreme scenarios and an intermediate scenario. Electric vehicles were assumed to charge within a 13-hour charging window during nighttime hours. Scenario 1 assumed no control algorithm to manage EV demand, and thus resulted in a large spike in demand at the onset of the charging window. Scenario 2 assumed that a perfect control algorithm was present to spread out all EV charging demand across the 13-hour charging window. In reality, a control algorithm implemented through a future smart grid would likely result in an hourly demand curve somewhere in between these two extreme scenarios, thus, an intermediate scenario (Scenario 3) where the EV demand is ramped up and down around the beginning and end of the charging window, respectively, was also analyzed. Three EV market penetrations were analyzed: 0.2, 0.5, and 1.0. When EV demand was added to existing demand in the 168-hour week, the unit commitment model produced an economic dispatch schedule that met demand but raised costs, as expected. Scenario 1 resulted in the highest costs, while significant savings were achieved in Scenario 2 and Scenario 3. As EV market penetration increased, these cost savings became even more pronounced. Scenario 3 had a slight advantage over Scenario 2 in cost savings, but both cut costs significantly from Scenario 1.

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Chapter 1

Introduction

While an uncommon sight on the streets in 2016, electric vehicles (EVs) are poised to sweep the automotive industry in the coming decade. Along with the autonomous vehicle trend in the industry [1], automakers around the world are preparing for the electric vehicle revolution [2]–[5] as technology finally appears ready to support longer-range, reliable, and market friendly electric vehicles [6]. Currently, electric vehicles make up 0.7% of the vehicles on the road in the United States, but this figure is up from effectively 0.0% before 2011 [7], [8]. A number of factors exist that will influence the increased adoption of electric vehicles in the United States, but most predictions have estimated that electric vehicles will grow to between 10% and 50% of the market share in the coming decades [9]–[11].

Much like how gas stations and smoother, safer roads supported the proliferation of petroleum-powered vehicles in the 20th century [12], two infrastructure developments are needed to support the growing electric vehicle market: charging stations and electric transmission and distribution grids. Residential charging stations are currently an option for homeowners, as a standard 230V outlet can provide enough power for an overnight charge [10]. Public charging stations that provide greater power and a faster charge are also becoming more readily available [13], but whether owners will largely charge at home in the future, or via public charging stations, remains unclear.

The second infrastructure improvement needed for adoption of electric vehicles are the transmission and distribution grids. Transmission grids refer to the large, regional electric grids that serve many states and fall under the control of a regional transmission organization (RTO) [14], [15]. An example of a regional transmission grid is the grid served by PJM Interconnection, LLC [16], [17]. That grid itself is part of the larger Eastern Interconnection grid that serves the eastern half of the United States [18]. These large grids comprise of thousands of generators with a variety of generating technologies – coal, gas, oil, wind, solar, nuclear, hydro, biomass, etc. Millions of individual demand points (i.e. customers) are also served in these grids; however, these individual customers are managed by local electric distribution companies discussed below. Electricity flows throughout these grids on very high-voltage transmission lines that can span hundreds of miles between connection points [18]. The RTO in a regional grid controls the dispatch of electric generators to ensure that electricity demand in the grid is met [19]. This dispatch is subject to a number of constraints inherent in the generating technologies and transmission limits. The RTO aims to dispatch the generators in a way that meets demand but also minimizes overall cost [20].

In contrast, the distribution grid refers to final stage of electric power transmission. In the local distribution grid, electricity is taken from the regional high voltage transmission grid discussed above, transformed into lower voltage electricity, and distributed through a network of transformers and service hookups to individual customers within a smaller locale [21]. The local distribution grid has a completely different set of constraints than the regional grid, including transformer and nodal transmission limits. Therefore, studies on the impact of electric vehicles on electric grids typically focus on either the regional electric grid or the local distribution grid. A number of studies have analyzed an increased market penetration on the local distribution grid in various locales [9], [22]–[34]. This research and analysis of distribution grids in various locales has largely concluded that small increases in the market penetration of EVs, sometimes in the single-digit percentiles, can lead to problems in the local distribution grid when no control algorithm is implemented. This increased demand can manifest in the form of thermal overload, voltage deviation, and phase unbalance in the local distribution systems [23], [35]. When a control algorithm – a program that manages charging of electric vehicles to ensure charging demand is spread evenly across the charging window during off-peak hours, rather than creating a demand spike – is implemented, these studies have found that local distribution grids can handle increased market penetrations that vary between around 20% to upwards of 80% [30].

This study analyzed the increased market penetration of electric vehicles on the PJM grid – specifically, the "Classic PJM" grid, further described in Chapter 2. A number of studies have also analyzed the effect of increased market penetration on various regional transmission grids [10], [28], [32], [36]–[41]. Impact of electric vehicles on regional transmission grids has been less comprehensively researched than the impact on local distribution grids. These studies have concluded that a sizable increase in the market penetration of electric vehicles, similar to the figure used in this study, is attainable if control algorithms are implemented to spread charging demands across the demand valley during the nighttime hours. Such control algorithms may be centrally planned and controlled, or decentralized and implemented at each customer's point of charge [38]. This study analyzed the effect of no control algorithm – where demand spiked when customers plugged in – and the effect of a perfect control algorithm that spreads demand perfectly across the charging window. In reality, individual customers' driving and charging habits will result in a demand scenario somewhere in between these two extremes. This study also used an intermediate scenario that modeled this by ramping up and down EV demand across the charging window, resulting in a smooth demand curve.

Knowing where the regional grid infrastructure stands at the onset of a predicted wave of increased EV market penetration is crucial in the transition from fossil-fuel based vehicles to electric vehicles. The Obama Administration has taken steps to promote this transition to ensure that the United States remains a global leader in automotive innovation [42]. Federal policy aside, the market forces also indicate that electric vehicle adoption is on the horizon, as battery and EV technology continue to get cheaper and oil market futures remain uncertain [43]–[45]. Identification of the limits of current generators in the regional grids across the United States, and research into the technologies – especially green and renewable – that can meet the increased electric demand from electric vehicles, is the crucial next step to take to prepare for the electric vehicle revolution.

Chapter 2

Theory

This study assumed an increased market penetration of electric vehicles by a set decade: the 2030s. The framework used to model an increased electric demand on PJM generators due to increased market penetration of electric vehicles is outlined below. A unit commitment model was modified to accept a realistic demand load from electric vehicles. This extra demand was posited using current data on charging trends and future predictions of market penetration.

Unit Commitment Model

Unit commitment (UC) is a model used in regional electric grid operations to dispatch electric generators while being subject to the constraints of meeting demand while minimizing total costs. Carefully modeled in the unit commitment model, the total costs include fixed startup costs, variable operation and maintenance costs, and fuel costs. A number of other constraints also exist to more realistically model the regional grid, including startup and shutdown times, ramping constraints, and transmission constraints. The unit commitment model produces an hour-by-hour synopsis of which generating technologies across the grid must supply electricity to meet demand [46]. Unit commitment models are usually solved using an algebraic modelling program, such as the General Algebraic Modeling System (GAMS) by GAMS Development Corporation [47]. With reasons discussed below, the transmission constraints are not included in the unit commitment model used in this study.

PJM Electric Power Grid Representation

This study models the electric grid under the control of the PJM Interconnection, LLC regional transmission organization (RTO). PJM, originally named after Pennsylvania, New Jersey, and Maryland [16], now has expanded to and serves all or part of the states of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia [17]. The local distribution grids within PJM are shown in Figure 1. Specifically, this study uses the "Classic PJM" region, which includes 1,172 generators in Pennsylvania, New Jersey, Maryland, Deleware, and the District of Columbia.

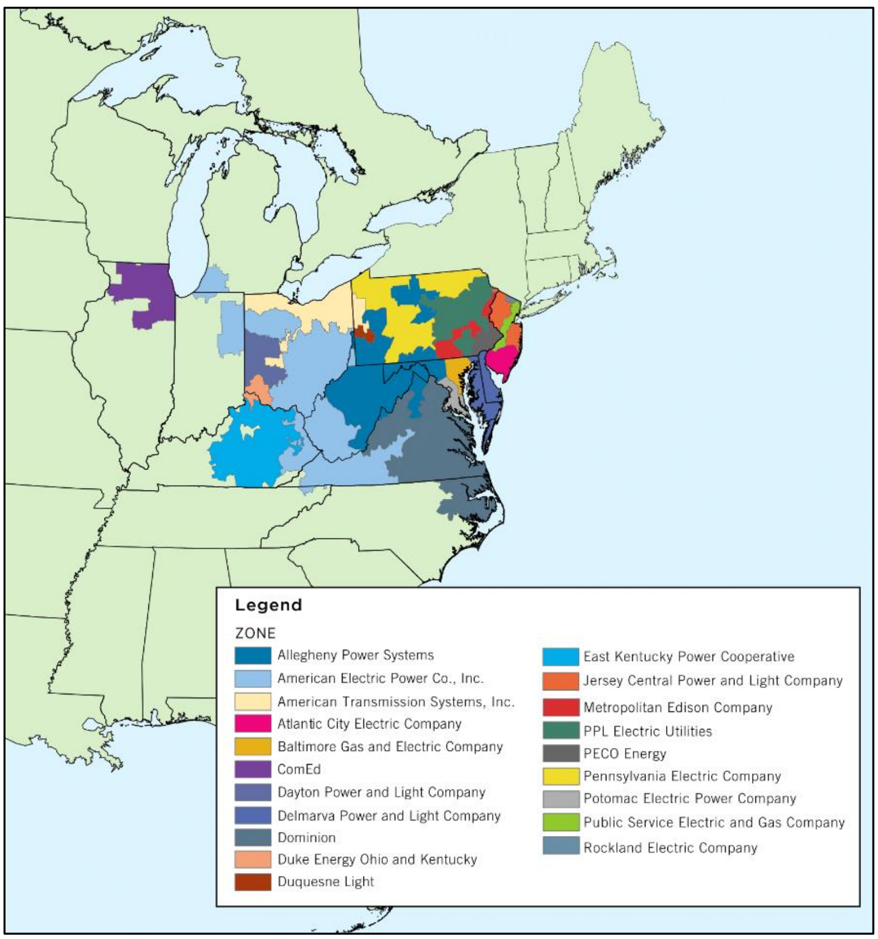

Figure 1: PJM Transmission Distribution Zones [17]

These 1,172 generators each have a minimum output, ramp rate, startup fixed cost, minimum run time, minimum down time, nameplate capacity, fuel cost, variable cost, heat rate, and fuel cost on startup. The wind, solar, and hydro generators have capacity factors. Each of these terms is defined here: The minimum output of each generator is the lowest level of power output maintainable without shutting down completely. Ramp rate, also called ramping limit, refers to how quickly each generator can change its power output. Note that the ramp rate values used in this study are values from 0 to 1 that are multiplied by the generator's total capacity to determine the generator's true ramp rate. Startup fixed cost refers to the cost incurred upon startup of the generator. Minimum run time and minimum down time refer to the minimum number of hours needed for each generator to remain on or off, respectively. Nameplate capacity of each generator is the highest power output attainable. Fuel cost refers to the cost of fuel used in each generating technology, while variable cost refers to the operational and maintenance costs of each generator that very with output. Heat rate is associated with efficiency, and refers to the amount of fuel energy used to generate one unit of electricity. Startup fuel cost refers to the cost of fuel used in plant startup. Capacity factor refers to the percentage (between 0% and 100%, or 0 and 1) of the nameplate capacity that a generator outputs in a specific hour. For example, the capacity factor of solar generators in the nighttime hours is zero because the panels absorb no sunlight. For wind, the capacity factor depends on wind speed but usually falls between 0.01 and 0.3 [48]. An overall operating cost for each generator can be calculated using Equation (1)(1, where $OC_{g,h}$ is the operating cost of each generator in each hour, HR_g is the heat rate of each generator, FC_g is the fuel cost of each generator, and $VC_{g,h}$ is the variable cost of each generator in each hour.

$$OC_{g,h} = \left[HR_g \cdot FC_g\right] + VC_g \tag{1}$$

Generating technologies represented in this database of generators include coal, oil, natural gas, nuclear, hydro, biomass, wind, and solar. Note that several key advantages and disadvantages exist inherently as a property of these different technologies, and perhaps the most significant of these is that renewables such as wind, solar, and hydro have zero fuel cost, startup fixed cost, and minimum output. Conversely, many of the fossil fuel-fired generators have minimum run and down times between eight and sixteen hours. Renewables are limited by their capacity factors, defined above. The capacity factors for solar and wind vary throughout the week. Capacity factor data used in this study for solar and wind are shown in Figure 2 and Figure 3, respectively [49]. The capacity factor for hydro was assumed to be 0.6. The information regarding each generator's properties was taken from [49].

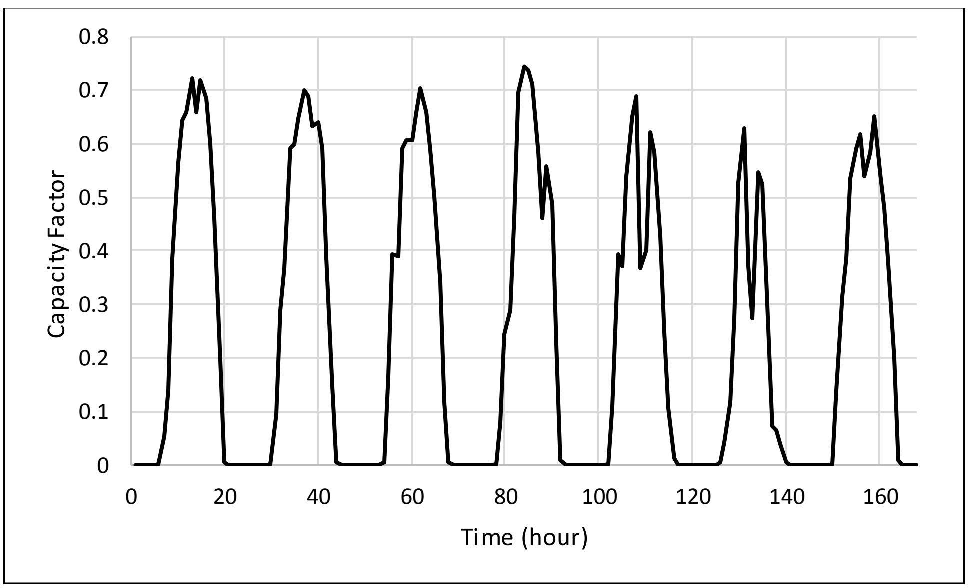

Figure 2: Capacity Factor Data for Solar

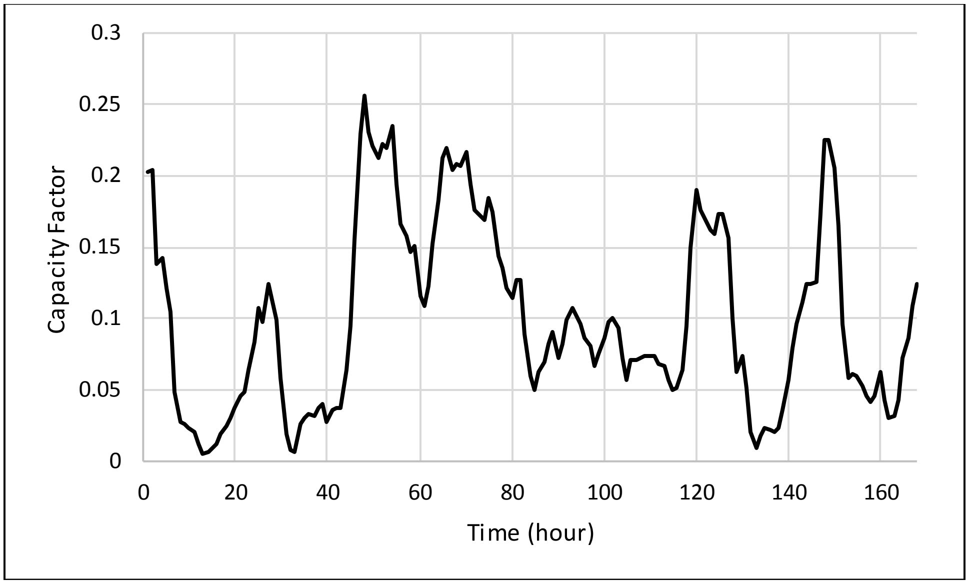

Figure 3: Capacity Factor Data for Wind

Integrating Electric Demand Loads

Typical electric demands in a regional electric grid region follow a cyclic daily curve that peaks in the late afternoon and reaches the lowest point around 3:00 am. Demand loads will differ by region of the country, weather, season, and weekday. This study used hourly demand loads for a 168-hour week, taken from a two-week sample of demand loads in the PJM region in the summer of 2012, from [50]. The demand curve used for this study represents the demand for a typical summer week in the Classic PJM region, and is shown in Figure 4.

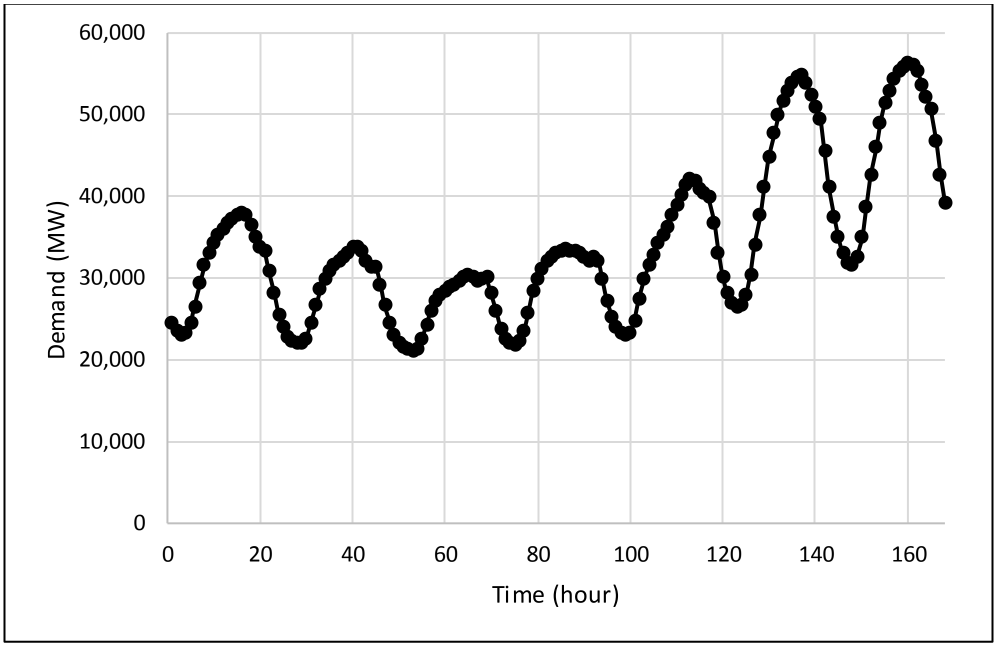

Figure 4: Hourly Demand in Classic PJM - One-Week Sample

Generators in the grid cannot instantaneously serve any demand load because transmission constraints are present that restrict the maximum electric power load that can flow from each generator to each point of use [51]. This study ignored transmission constraints for two reasons: transmission constraints add an enormously complex extra layer to the unit commitment model that would need extensive computing power to solve, and electric vehicles are reasonably expected to appear at the same rates across the PJM region (in other words, no geographic variances in EV market penetration will arise that would shift demand to different areas than the present day). While reasonable to assume that additional transmission lines are needed to meet increased demand, the expected increase in renewable generating technologies in the coming years will force regulators to identify the parties responsible for building these transmission lines regardless of whether increased EV usage increases electricity demand or not. The Obama Administration's adoption of the Paris Climate Agreement may spur increased adoption of renewable generating technologies [52]. However, the upcoming Trump Administration's energy platform [53], [54] may shift the United States back towards coal thus avoiding potential transmission line upgrades needed for a bigger renewable portfolio [55]. Thus, the topic of potential transmission constraints is complicated, and will likely pan out in one of several outcomes as federal policy evolves, and is best subject to future studies as outlined in Chapter 6.

Electric Vehicle Integration

A significantly increased market penetration of electric vehicles will add additional electric demand onto the regional electric grid. As described earlier, the level of market penetration by electric vehicles by 2030 is significantly difficult to predict, as price fluctuation in the price of oil, regulatory legislation, and increased affordability of electric vehicle technology are variable and uncertain. However, this study first assumes a market penetration of 20%. This figure seems optimistic considering the United States' current EV market share of 0.7% [8], but predictions in the industry and other research on this topic have used figures similar to this [10], [33], [56]. This study also ran the analysis using a 50% market penetration and a 100% market penetration. These market penetration represent a market of 12,723,142 cars in the Classic PJM region [57], broken down by state/territory in Table 1. This figure includes both private and commercial automobiles, including taxicabs, but does not include buses and trucks.

Table 1: Passenger Cars in Classic PJM

State	*Automobiles*
PA	5,637,973
NJ	3,926,249
MD	2,576,329
DE	426,890
DC	155,701
Total	**12,723,142**
➢ *MP = 0.2*	*2,544,628*
➢ *MP = 0.5*	*6,361,571*
➢ *MP = 1.0*	*12,723,142*

The number of electric vehicles in the study is calculated by multiplying the market penetration of electric vehicles by the total number of vehicles, shown in Equation (2), where N_{EV} is the number of electric vehicles, N_V is the number of passenger vehicles, and MP_{EV} is the predicted market penetration of electric vehicles.

$$N_{EV} = N_V \cdot MP_{EV} \tag{2}$$

In addition to market penetration, user driving trends for a typical week were taken into consideration. Table 2 shows the average number of miles driven per day by drivers in the United States in 2013-2014 [7].

Table 2: Weekly Driving Trends in the United States

Day	*Miles Driven per Day*
Monday	30.1
Tuesday	30.2
Wednesday	32.0
Thursday	32.9
Friday	28.2
Saturday	25.8
Sunday	25.0

The properties of typical long-range electric vehicles on the market today were used. Some electric cars on the road today are limited-range, but this study assumes that by 2030, the long ranges seen in today's high-end electric vehicles will be the standard. The typical electric vehicle uses 0.32 kWh per mile [24]. This study assumes that electric vehicle owners will charge their vehicles at home, without spending money on extremely fast charging stations but instead using a standard 230V outlet or a custom auto manufacturer-supplied charging outlet that supplies power around the rate of 3.3 kW [10]. Faster charging stations are expensive for consumers to install so they typically appear in public where charging rates above 50 kW and 100 kW are not uncommon [13]. However, this study assumes that most charging will be done at home, in part because of the increasing battery capacities and driving ranges of electric vehicles that allow drivers to go a full day, and even multiple days, without recharging [2], [58]. These higher-capacity electric vehicles, currently on the market with Tesla [5], will become more prevalent with other manufacturers in the next decade [59].

This study uses two extremes of the possible range of scenarios, and an intermediate scenario, that would result from a sizable portion of vehicle owners plugging in their electric vehicles at night. The charge needed would only need to be enough to replenish energy used that day in driving, not a full 0% to 100% charge. Both extremes assume a plug-in time of 8:00 pm and an unplug time of 9:00 am the following morning, based on user trends used in [10]. The first extreme, Scenario 1, has all users plug-in at 8:00 pm and begin charging at the maximum charging rate (3.3 kW) until charging is completed. This scenario, that assumes absolutely no control of charging either from a centralized or decentralized algorithm, results in a large spike of demand from 8:00 pm until charging finishes for all vehicles, a few hours later. The second extreme, Scenario 2, assumes that all users plug-in at 8:00 pm and the charging rate is lowered by a control algorithm so that charging finishes as the charging window closes at 9:00 am the next day. Scenario 2 effectively spreads the demand from EV charging across the 13-hour charging window. In reality, the effect of millions of drivers plugging in their electric vehicles at night would need a control algorithm described above in the second extreme scenario, but this control algorithm would not attain a perfectly flat demand load due to variances in individual users' charging windows [22]. Plug-in and unplug time would be distributed around a time in the evening and a time in the morning, respectively [60]. Scenario 3 models this more accurate EV demand profile, where demand increases and then decreases across the charging window.

All of these factors were used to calculate hourly demand loads for the market penetration of electric vehicles in the Classic PJM region. Equation (3) calculates the demand in a given hour, where D_h is the hourly demand in kWh, P_{charge} is the charge rate in kW, and N_{EV} is the number of electric vehicles in the Classic PJM region.

$$D_h = P_{charge} \cdot N_{EV} \tag{3}$$

The hourly demand from electric vehicles, for all three scenarios, was then added to the rest of the demand in the electric grid. The market penetration at which electric vehicle charging begins to have a sizable effect on regional grid demand can then be determined for each scenario.

Chapter 3

Method

A unit commitment model representing the Classic PJM grid region was constructed using the General Algebraic Modeling System (GAMS) Version 24.3.3 [47]. The mixed integer linear program was based off that used in [61]. The model includes the parameters described in the previous section for each of the 1,172 generators in the Classic PJM region: minimum output, ramp rate, startup fixed cost, minimum startup time, minimum shutdown time, nameplate capacity, fuel cost, variable cost, heat rate, fuel used on startup, and capacity factors for wind, solar, and hydro. Also included was the region's demand taken from the 2012 data [50], as well as the demand from electric vehicle charging, as described in Chapter 2. The Classic PJM regional demand for a 168-hour week used in this analysis is shown in Figure 4 on page 10. During the nighttime, demand falls as less electricity is used, and demand peaks during the day.

A MATLAB model was created to model the hourly demand created by electric vehicles in Classic PJM in the future after a certain market penetration is reached. The energy used per EV per day was calculated using Eqaution (4), where E_{EV} is the energy used each day by each EV, η is the efficiency (i.e. consumption rate) of each EV in kWh/mile, and d_{day} is the daily driving distance that varies by day of the week.

$$E_{EV} = \eta \cdot d_{day} \tag{4}$$

The number of electric vehicles in the region, calculated in Equation (2), is the factor by which the individual vehicle's energy demand for each night is multiplied by to obtain total regional energy usage for electric vehicles. The deviation from the average daily driving distance depending on the day of the week, using values from Table 2, is also written into the model.

The MATLAB program takes the energy of each day and recharges the electric vehicle completely, beginning at the plug-in time. Scenario 1 has the vehicles charged at their maximum charging rate of 3.3 kW, resulting in the vehicles completing their recharging before unplug time. This results in a spike of demand each night that lasts approximately three hours, and is shown in Figure 5. Scenario 2 lowers the charging rate so that the vehicles take the full 13 hours each night from 8:00 pm to 9:00 am to recharge. This results in a much lower hourly energy demand, spread out across the charging window, and is shown in Figure 6. Scenario 3 represents a realistic EV demand load curve, and has demand rising and falling across the charging window. Scenario 3 is shown in Figure 7.

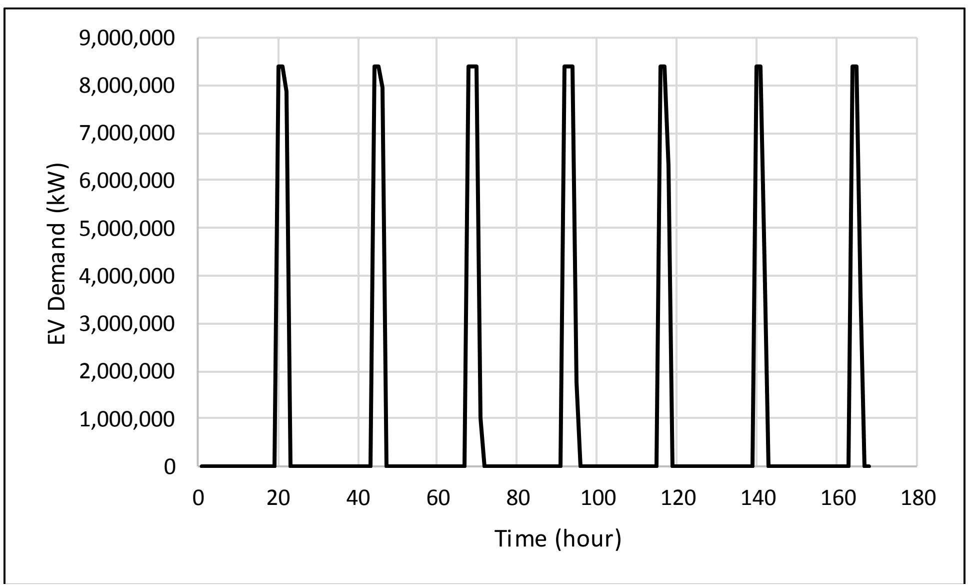

Figure 5: EV Charging Demand in Scenario 1

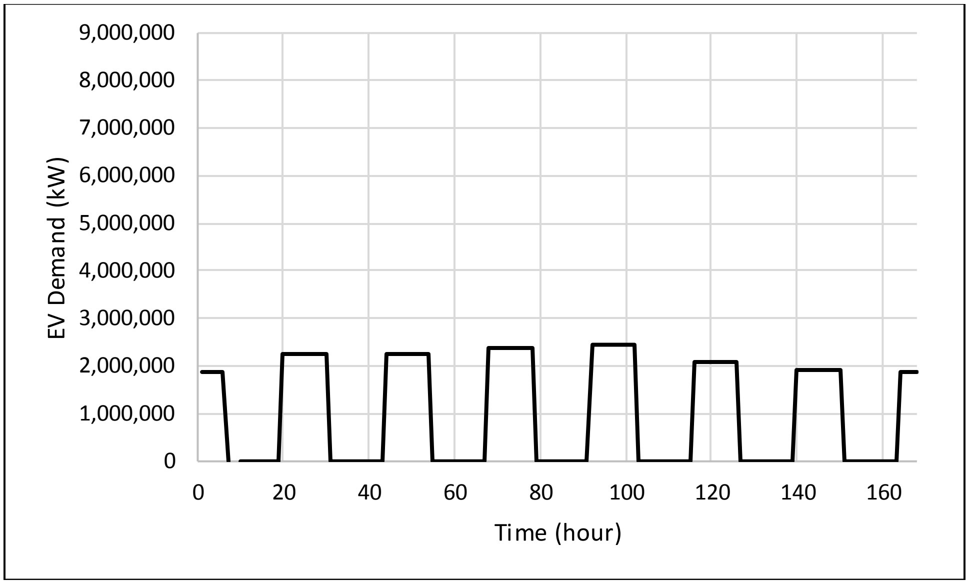

Figure 6: EV Charging Demand in Scenario 2

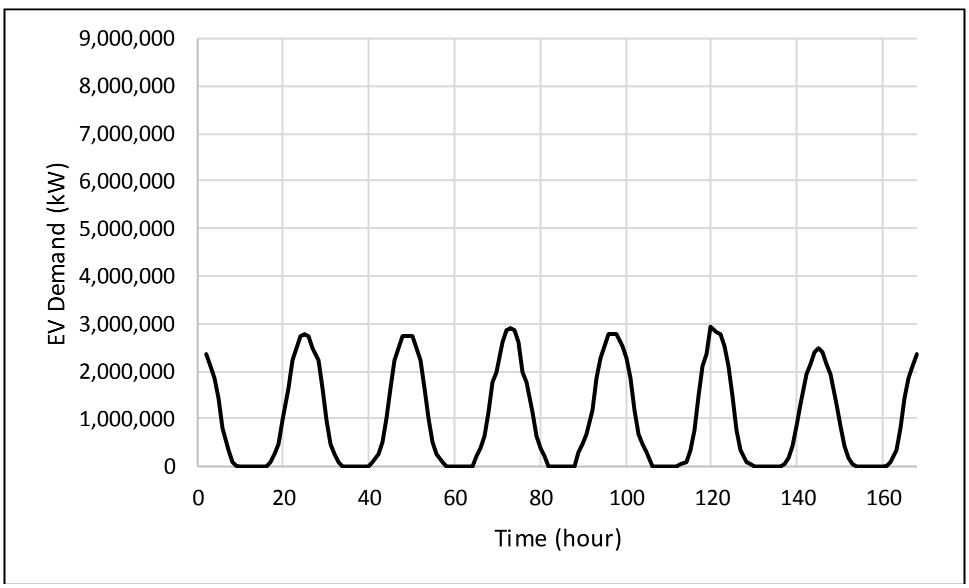

Figure 7: EV Charging Demand in Scenario 3

As stated above, this hourly EV demand was added onto the existing electricity demand in the grid. All three scenarios were analyzed independently, along with a control scenario in which no EV demand is added (Scenario 0). The GAMS unit commitment model takes the total demand (sum of the regional grid demand and the additional EV demand) and the parameters for the 1,172 generators and models the hourly dispatch profile using a set of equations. These equations ensure that the constraints, including the ramping constraint, the minimum startup and shutdown times, and the capacity factors, are satisfied. The individual hydro, wind, and solar generators were lumped as one generator in their respective categories to save computing resources. This was possible because the parameters for all hydro, wind, and solar, respectively, were the same. After aggregating hydro, wind, and solar generators, and removing inactive generators, the number of generators in the unit commitment model was reduced to 590. The equation for total cost is the equation that GAMS is programmed to minimize, and is shown in Equation (5) where TC is the total cost, $P_{g,h}$ is the power generated by each generator g in each hour h, $OC_{g,h}$ is the operating cost of each generator g in each hour h, SF_g is the startup fuel cost of each generator, $vGen_{g,h}$ is a binary variable that indicates whether a generator g is turned on in hour h, SFC_g is the startup fixed cost of each generator, $cNse$ is the cost of non-served energy, and $vNse_h$ is the non-served energy in each hour h.

$$TC = \sum_{g,h} \left[P_{g,h} \cdot OC_{g,h} + SF_g \cdot vGen_{g,h} + SFC_g \cdot vGen_{g,h}\right] + \sum_{g,h} [cNse \cdot vNse_h] \tag{5}$$

GAMS minimized this total cost function subject to all of the other constraints, after which a set of results was outputted. The hourly generation of each generator was reported, as was the total cost of the system (shown in Equation (5)), the hourly operating costs of each generator, the hourly variable cost, and the hourly marginal cost of generator dispatching.

Chapter 4

Results and Discussion

Scenario 0 (Control Scenario)

The dispatch profile for the control scenario (Scenario 0), in which no EV demand was added to the grid demand, is shown in Figure 8. The baseload demand scenario illustrates that the nuclear and hydro plants always remained on at full capacity due to cost advantages. In addition, the next-least expensive generators, coal and gas, were only turned on when necessary and were kept on at their minimum generation level to avoid startup and shutdown costs. The renewables also played a small role, remaining on when possible, due to minimal or no startup and shutdown costs. The dispatch schedule never called on the expensive oil generators, because the demand never reached the level needed for oil.

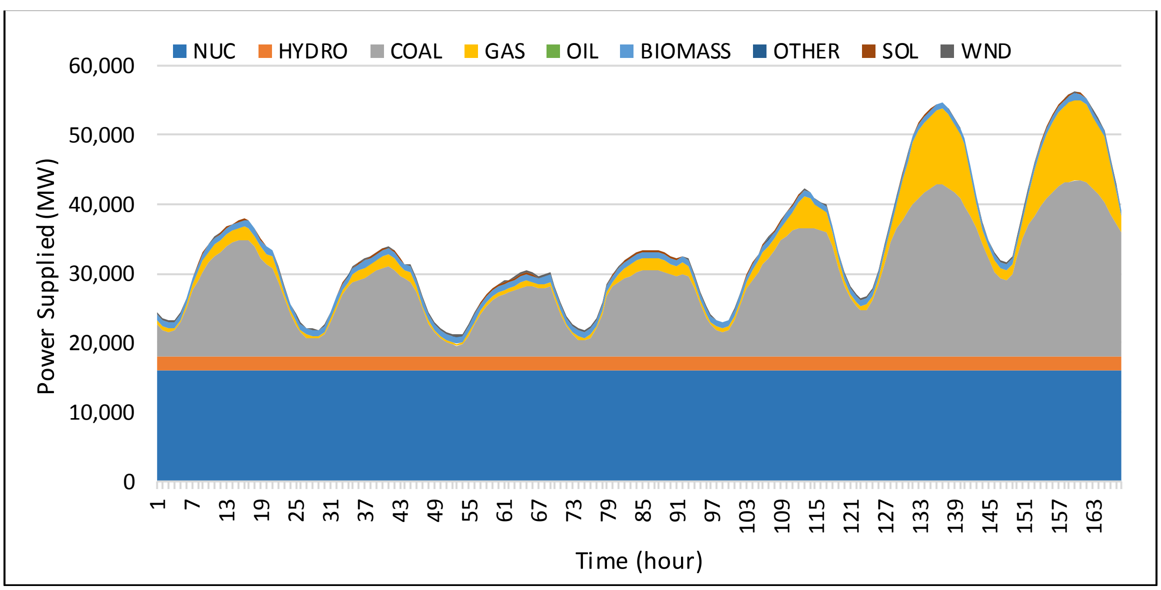

Figure 8: Scenario 0 Dispatch Schedule

Scenario 1

Figure 9, Figure 10, and Figure 11 show the dispatch profiles in which all EV drivers began charging their EVs at the maximum rate at the beginning of the charging window (8:00 pm), where market penetration was 0.2, 0.5, and 1.0 respectively. The large spikes in demand that forced the system to quickly call on generators are clearly visible. While the demand was met by the unit commitment model in all three scenarios, Scenario 1 resulted in the most impractical dispatch schedule due to the high demand spikes, quick ramping, and high-priced generators needed to meet demand. The impracticability of the uncontrolled charging scenario, with no control algorithm, manifests in the higher prices needed to meet demand, as discussed later in Table 3 on page 27. By the time EV market penetration reached 100%, the expensive oil generators were used considerably to meet demand spikes, resulting in an unreasonable and impractical cost for the week.

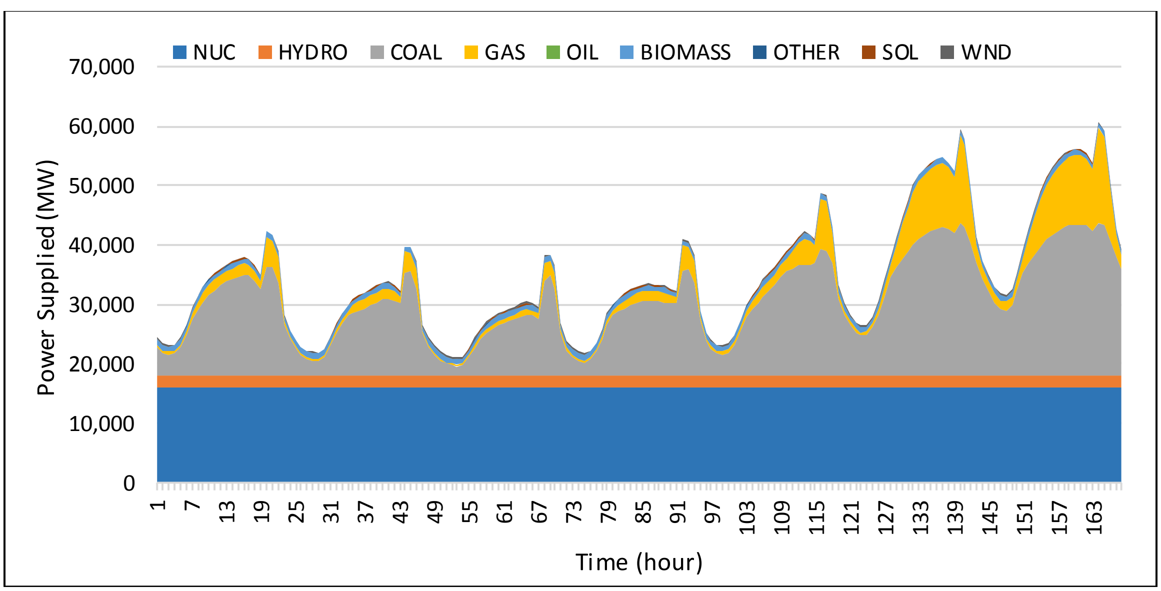

Figure 9: Scenario 1 Dispatch Schedule, MP = 0.2

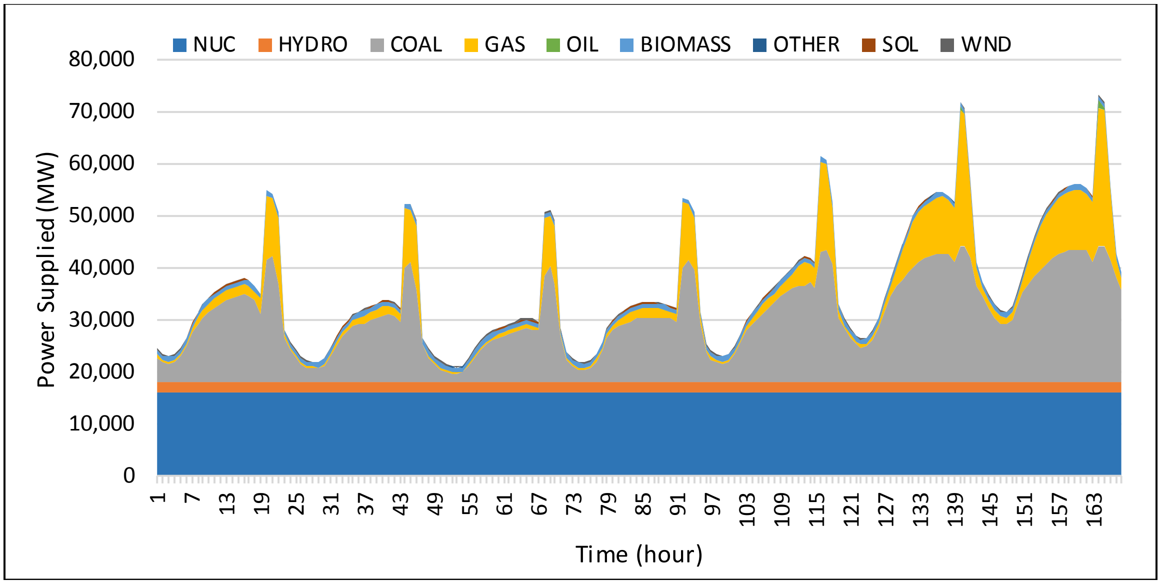

Figure 10: Scenario 1 Dispatch Schedule, MP = 0.5

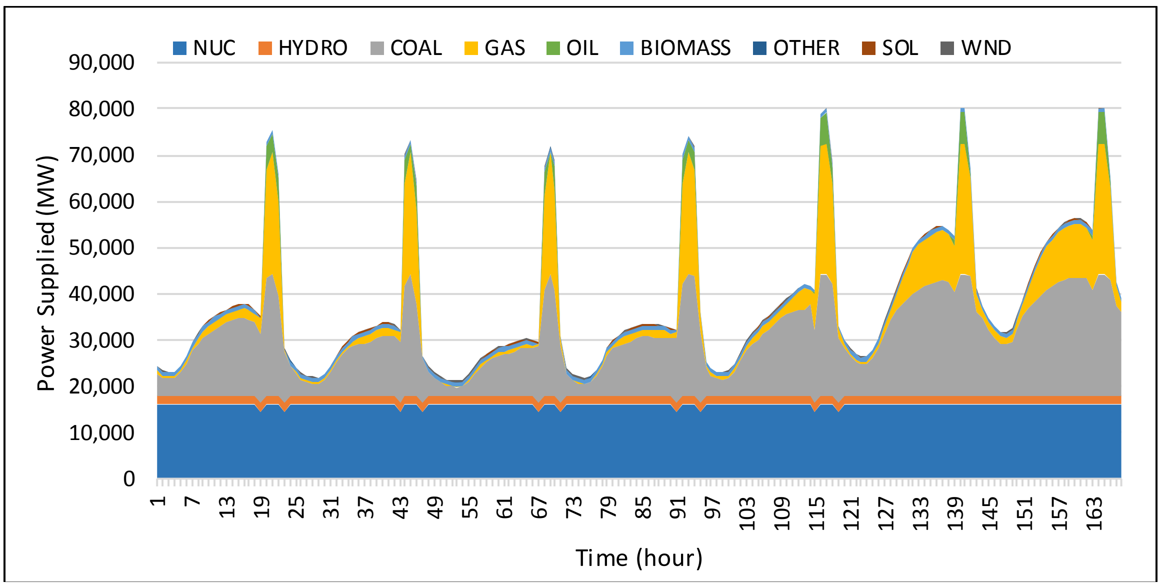

Figure 11: Scenario 1 Dispatch Schedule, MP = 1.0

Scenario 2

Shown in Figure 12, Figure 13, and Figure 14 are the dispatch profiles in which EV demand from all customers was spread out over the 13-hour charging window, for EV market penetrations of 0.2, 0.5, and 1.0 respectively. All three market penetrations avoided the high cost of using oil generators by eliminating the large demand spike, and by spreading out demand over the charging window. However, for the market penetrations of 0.5 and 1.0, the quick ramping needed to supply the sudden increase in demand is clearly visible. At the beginning of the 13-hour charging window, the EV charging demand rapidly increased while the grid still experienced relatively high demand at 8:00 pm. This lead to 8:00 pm becoming the hour with the highest demand – thus, some of the more expensive generators needed to be dispatched.

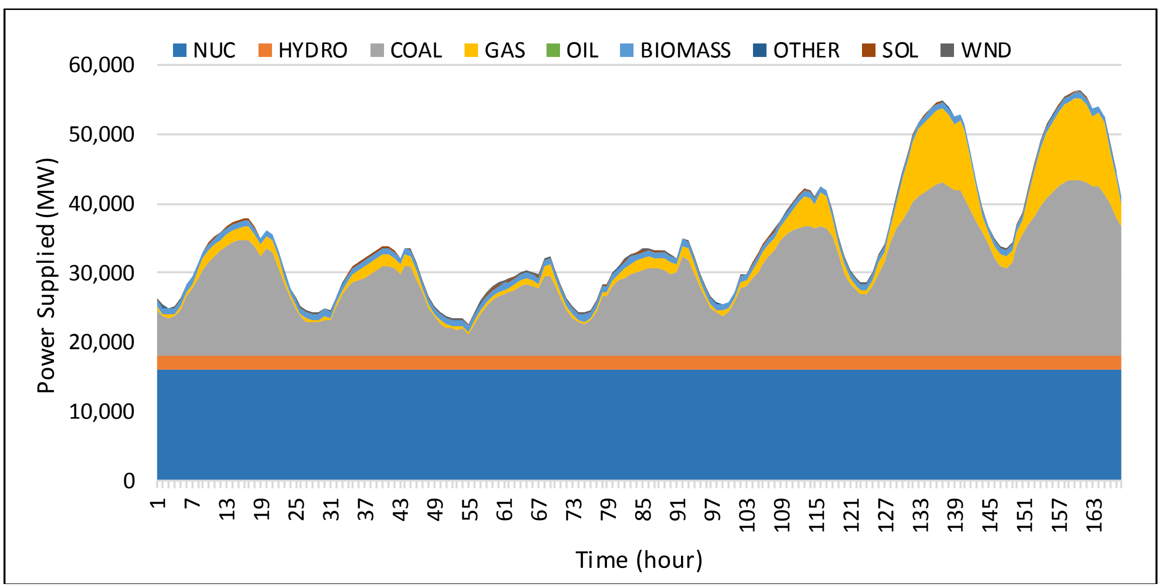

Figure 12: Scenario 2 Dispatch Schedule, MP = 0.2

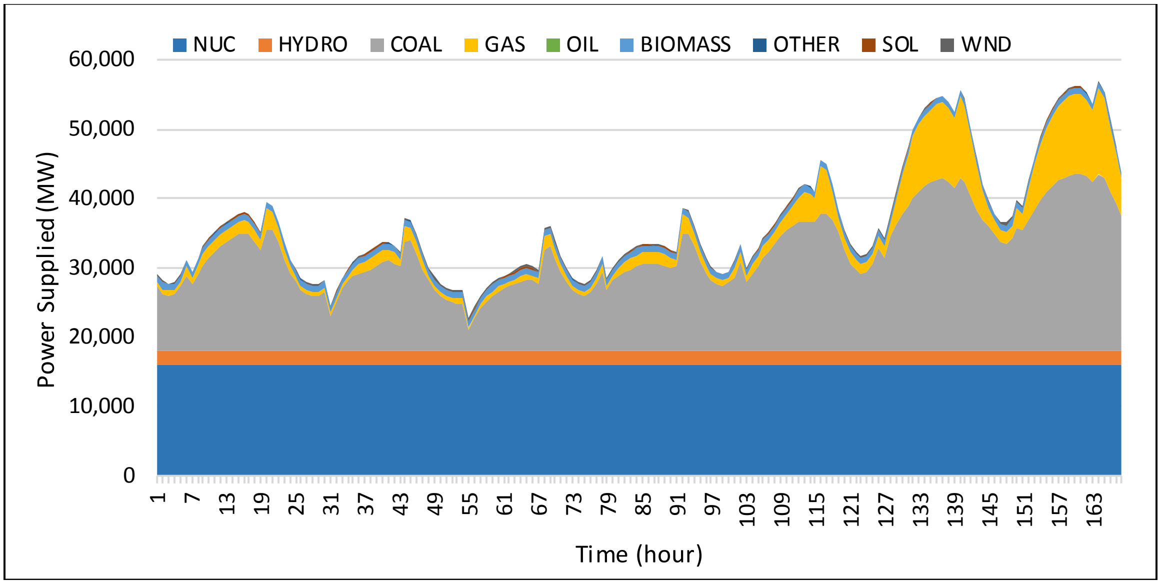

Figure 13: Scenario 2 Dispatch Schedule, MP = 0.5

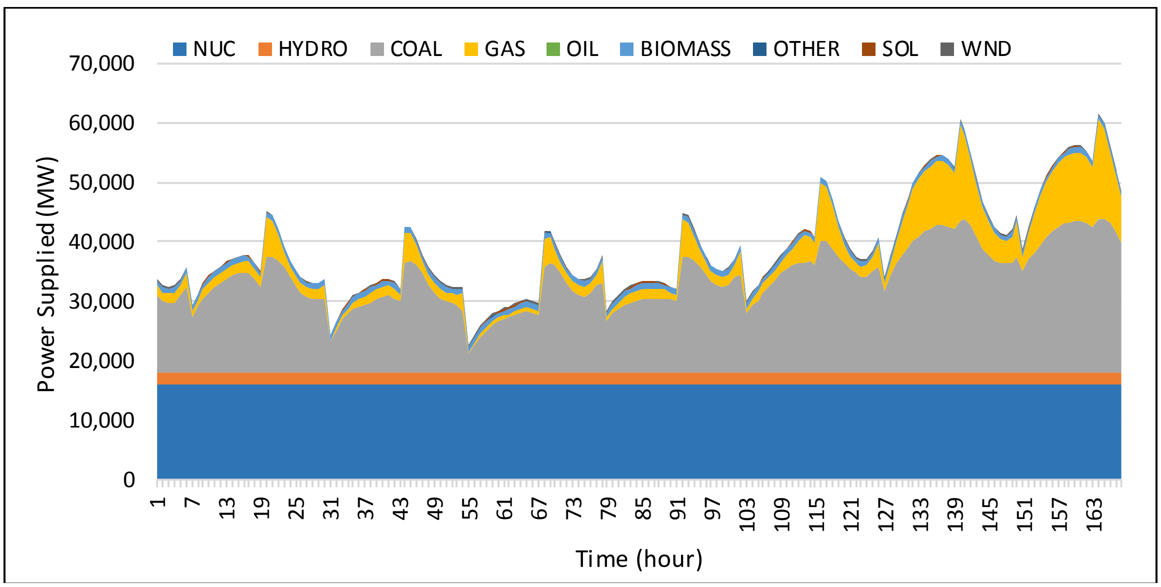

Figure 14: Scenario 2 Dispatch Schedule, MP = 1.0

Scenario 3

Scenario 3, in which EV demand was ramped up and down across the charging window, is shown in Figure 15, Figure 16, and Figure 17. Again, the market penetration used were 0.2, 0.5, and 1.0 respectively. Scenario 3 resulted in a much more practical dispatch schedule because the quick changes in demand level were avoided. Thus, the unit commitment model found an optimal solution which avoided dispatching the more expensive plants much more easily than Scenario 1 or 2. The extra demand from the EVs were better shifted into the valleys in the grid demand curve. Even with a market penetration of 1.0, the unit commitment model avoided using the expensive oil plants altogether.

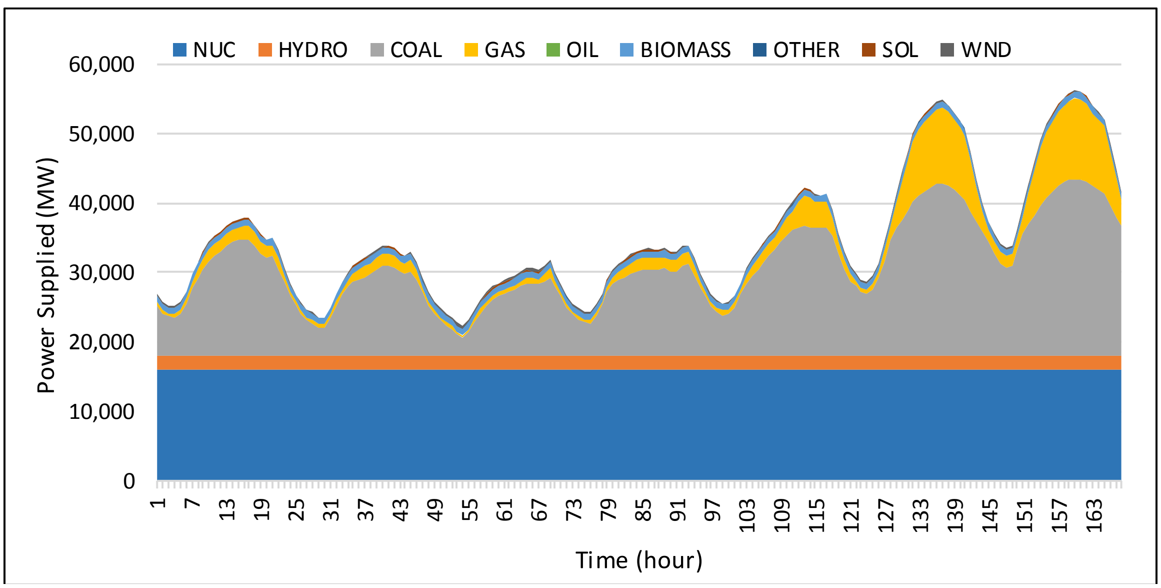

Figure 15: Scenario 3 Dispatch Schedule, MP = 0.2

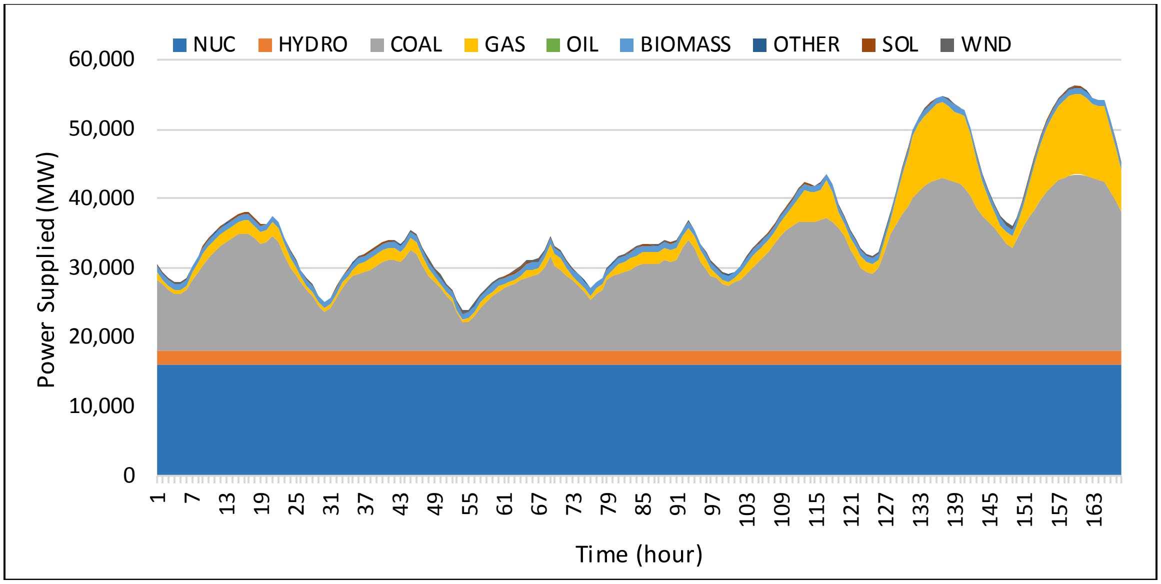

Figure 16: Scenario 3 Dispatch Schedule, MP = 0.5

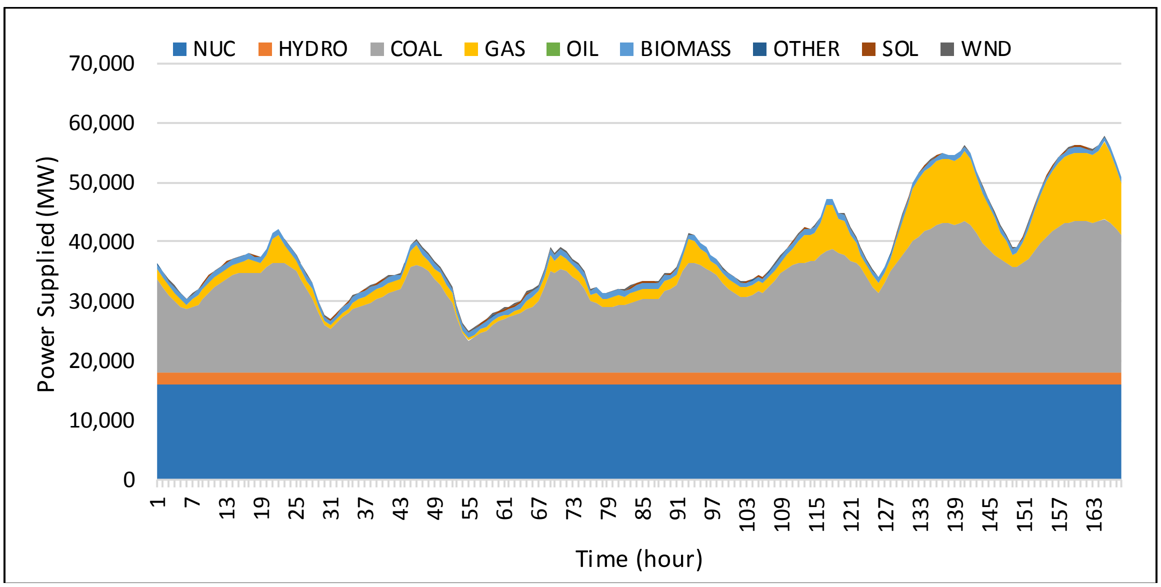

Figure 17: Scenario 3 Dispatch Schedule, MP = 1.0

Costs

Table 3: Weekly Total Cost of Dispatch

Scenario	*Total Cost ($)*	*% Increase from Scenario 0*	*% Decrease from Scenario 1*
	MP = 0.0		
Scenario 0	$66,611,768.61	–	–
	MP = 0.2		
Scenario 1	$71,497,598.38	7.33%	–
Scenario 2	$70,979,856.66	6.56%	0.72%
Scenario 3	$70,961,736.02	6.53%	0.75%
	MP = 0.5		
Scenario 1	$80,957,244.84	21.54%	–
Scenario 2	$77,655,997.66	16.58%	4.08%
Scenario 3	$77,580,935.95	16.47%	4.17%
	MP = 1.0		
Scenario 1	$207,480,139.90	211.48%	–
Scenario 2	$89,193,492.56	33.90%	57.01%
Scenario 3	$88,936,866.21	33.52%	57.13%

Table 3 shows a complete breakdown of the costs incurred by running the unit commitment model for a week of demand. The *Total Cost ($)* column shows that with increasing market penetrations of electric vehicles, the cost rose. This was expected because more power was needed in the grid as more EVs demanded electricity. The *% Increase from Scenario 0* column shows how much more each market penetration costed, over the baseload scenario with no EV demand. This column is also broken down by scenario – the most expensive scenario was Scenario 1, followed by Scenario 2, and finally by Scenario 3. Spreading out demand via a control algorithm effectively reduced price substantially. Not only that, but this price reduction got larger with increasing market penetrations. The cost savings are further explored in the *% Decrease from Scenario 1*. Scenario 3 did a slightly better job than Scenario 2 in reducing costs, and the overall savings when demand is spread increased when market penetration increased.

The data in Table 3 is shown visually in Figure 18. Again, the savings in cost are evident when using an effective control algorithm to spread EV demand throughout the night, especially for high market penetrations.

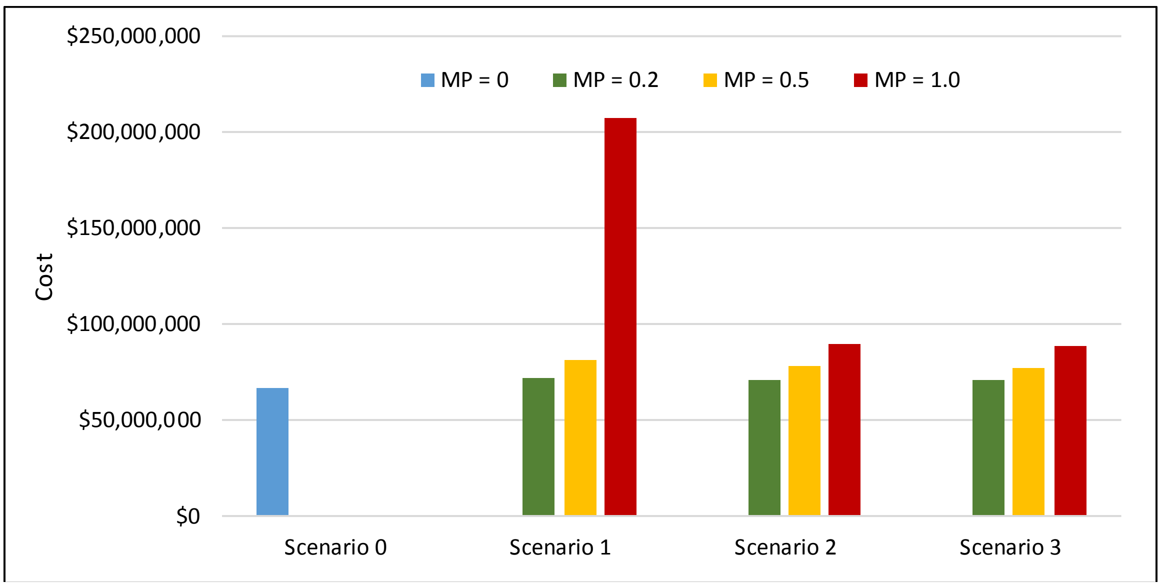

Figure 18: Summary of Costs of All Scenarios and MPs

Chapter 5

Conclusions

The unit commitment model for the Classic PJM region confirmed that as the market penetration of electric vehicles rises, the demand for electricity increases, thus increasing the cost of generation. Market penetrations of 0.2, 0.5, and 1.0 resulted in increased costs ranging from 6.53% to 7.33%, 16.47% to 21.54%, and 33.52% to 211.48%, respectively, depending on the hourly EV demand profile. The model also showed that a control algorithm that spreads out the hourly charging demand of the electric vehicles throughout the charging window can reduce the extra costs associated with widespread electric vehicle charging. Specifically, the scenario in which all charging started at the beginning of the charging window and took place at the maximum charging rate (Scenario 1) resulted in the highest costs, because the more expensive generators needed to be dispatched to meet the quick demand spikes. This was especially prevalent when electric vehicle market penetration was 100% and costs were 211.48% higher than the baseload with no EV charging. The scenario in which demand was evenly spread out across the 13-hour charging window (Scenario 2) was the second most cost effective scenario, but resulted in quick, yet not as pronounced, spikes in demand at the beginning of the charging window. Scenario 2 reduced costs from Scenario 1 by 0.72%, 4.08%, and 57.01% for market penetrations of 0.2, 0.5, and 1.0, respectively. Lastly, the scenario in which charging demand steadily increased and decreased across the charging window (Scenario 3) was the most cost-effective solution. Scenario 3 reduced costs from Scenario 1 by 0.75%, 4.17%, and 57.13% for market penetrations of 0.2, 0.5, and 1.0, respectively. Fortunately, the real-world EV charging demand using a control algorithm will likely resemble this scenario. This study reiterates the need for control algorithms to spread demand as electric vehicle market penetration rises. Doing so can significantly reduce cost by forgoing the need to dispatch the most expensive generators.

This study, and similar studies like it, are necessary to predict future issues with increased electric vehicle usage in the coming decades. Successful identification of regional grid infrastructure improvements needed to support this increased electricity demand will ensure a smooth transition from fossil-fueled powered vehicles to electric vehicles, with minimum interruption from the grid. Although usage remains under one percent in 2016, the United States will lead the electric vehicle trend in the coming decades because we currently lead in the research and development of electric vehicles. Adequate grid infrastructure and an EV charging control algorithm to ensure appropriate economic dispatch in a significantly altered daily demand load is necessary to support a sizeable increase in electric vehicle market penetration while minimizing cost increases.

Chapter 6

Future Areas of Research

A more accurate representation of the Classic PJM grid is attainable with the addition of the known transmission constraints present in the grid. The Department of Energy has identified an easing of transmission congestion in the United States due to several trends: the economic recession of 2008-2009, implementation of energy efficiency measures, and transmission infrastructure improvement [62]. However, before 2030, this trend may reverse with further economic recovery, increased use of electric vehicles, and a changing national energy policy post-Obama Administration [53], [54]. The increased use of renewables may also affect transmission congestion, as it is currently unclear in some areas who pays for new transmission interconnections for renewable energy projects [62]. As stated in an earlier chapter, including transmission constraints into the unit commitment model would add another layer of complexity to the algebraic modelling system, and would require more computing power and time. Thus, while an interesting and important next step, it would be best to continue this research in a later study. More time will also serve to better predict the direction that the United States will take in its energy policy, thus allowing for a more accurate representation of future generating trends.

Appendix A

GAMS Code for Unit Commitment Model

The unit commitment model used for this study was adapted from the model created by Michael Craig in [61], and is included in this section.

```
$TITLE UNIT COMMITMENT FOR PJM, NOV 8 2013, MICHAEL CRAIG

*NO ZONAL CONSTRAINTS, TREAT ALL OF PJM AS ONE ZNE. BUT BECAUSE
*ALSO RUN ERCOT MODEL WHICH HAS ZNES, MAINTAIN ZNE NOMENCLATURE FOR
*SIMPLIFCATION OF CONVERTING MATLAB CODE TO HANDLE PJM. HERE, JUST
*ASSUME THERE IS ONE ZNE AND NO TRANSMISSION CONSTRAINTS, SO SYNONYMOUS TO
*ASSUMING NO ZNES.




*Turn off output in .lst file
*$offlisting
*$offsymxref offsymlist
option threads=4;

*Set tolerance level
option optcr = 1E-4;
option reslim = 999999;

Sets
         egu                        "electric generating units - labelled ordinally" /1*590/
         h                          "hour of day" /1*168/
         zones                      "just 1 demand zone" /1/
                 ;

alias(h,hh);

*Set this to ERCOT price cap in 2005 of $1,000/MWh
*ERCOT price cap in 2012: $4,500/MWh
Scalar
         scCnse                      "cost of non-served energy (thousands$/GWh), set to PJM price
cap (see below)"
         scNumplants                 "number of plants. Valued later by looping through egu."    /0/
                 ;
$ontext
Parameters
*UNIT COMMITMENT PARAMETERS
         pMinload(egu)               "minimum load of EGU (GW)"

         pRamprate(egu)              "ramprate of each EGU, assumed to be the same up & down
(GW/hr)"
         pStartupfixedcost(egu)      "start up cost for EGU (thousands$/GW)"
         pMindowntime(egu)           "minimum down time for a power plant (hours)"
         pMinuptime(egu)             "minimum up time for a power plant (hours)"
```

```
*Next parameters are entered as (h,egu) because that's how they are input from Matlab, with hour
in 1st col & EGU in 2nd.
         pCapac(egu)            "capacity of egu (GW)"
         pOpcost(egu)           "plant operating cost (thousands$/GWh)"
         pTurnonfuelcost(egu)   "cost of fuel to heat up boiler (thousands$)"
*ZONAL PARAMETERS
         pEguzones(egu)           "zone EGU is in, entered as array with egu in col 1 and egu's
zone in col 2"
         pDemand(h)         "demand for each zone"
                 ;
$offtext

Parameter pGenresults(egu,h)       Generation output in MW;

Parameter pCostresults(egu,h)      Total cost in $;

Parameter pMarginalcost (h)       Marginal cost of the last unit;

Parameter pVariablecost (egu)       Marginal cost of the last unit scheduled in hour D in $ per
MW;


*pEguzones(egu) = 1;

$include pMinload.gms
$include pRamprate.gms
$include pStartupfixedcost.gms
$include pMindowntime.gms
$include pMinuptime.gms
$include pCapac.gms
$include pOpcost.gms
$include pTurnonfuelcost.gms
$include UnitCommitmentDemand.gms
$include pEVdemand.gms
$include pEVdemandSpread.gms
$include pEVdemandRamp.gms
$include pMustRun.gms
*$include pMustOff.gms
*$include pHydro.gms
*$include pSolar.gms
*$include pWind.gms
$include pSolarGen.gms
$include pWindGen.gms
$include pThermal.gms

Parameter      pSpinreserves(h)         "required hourly spinning reserves (GW)" ;
pSpinreserves(h)=sum(zones,pDemand(h))*0.01;

*Day-ahead offer cap in PJM in 2005 & 2012 was $1,000/MWh (see 2005 and 2012
*PJM State of Market reports). Below numbers account for inflation, adjusting
*both values to 2007 dollars.
*CPI2012: 229.594. CPI2007: 207.342. CPI2005: 195.3.
*First loop through egu set to determine number plants. Then set scCnse
*based on number of generators, which we use as an indicator for the year we are in.
*2012: 953 generator. 2005: 779 genreators.
loop(egu, scNumplants=scNumplants+1);
scCnse$(scNumplants<850)=1061;
scCnse$(scNumplants>850)=903;

Variables
         vTotalcost                "total cost of power generation (thousands $)"
                 ;

Positive Variables
         vGen(egu,h)               "power generation at plant egu at end of hour h (GW)"
         vGenaboveminload(egu,h)   "power generation above minimum stable load (GW)"
         vNse(h)                   "nonserved energy (GW)"
*vTurnoffdecision is a binary variable, as it's forced to be binary by vTurnondecision and
vOnoroff. Tested speed with
```

```
*vTurnoffdecision as a positive vs. binary variable on 3/12/13, and found it to be 18 seconds
faster when it's a positive variable.
         vTurnoffdecision(egu,h)  "indicates whether plant decides to turn off (1) or not (0) in
hour h"
                ;

Binary Variables
         vTurnondecision(egu,h)   "indicates whether plant decides to turn on (1) or not (0) in
hour h"
         vOnoroff(egu,h)          "indicates whether plant is up (1) or down (0) in hour h)"
                ;

Equations
*Unit commitment equations
         costfunc                             "define objective function to be minimized"
         relationbwnGenAndGenabovemin(egu,h)  "establish relationship between Gen (total gen)
and Genaboveminload (gen just above min stable load)"
         demand(h)                            "must meet electric demand"
         rampconstraintup(egu,h)              "ramping up constraint of units"
         rampconstraintdown(egu,h)            "ramping down constraint of units"
         statusofplant(egu,h)                 "balance whether thermal plant is on or off with
whether shutting down or starting up"
         determineloadabovemin(egu,h)         "determine what each thermal unit's generation
is above its minimum load. Constraints Genaboveminload to be between max and min capacity"
         meetreserves(h)                      "meet hourly spinning reserve requirements"
         enforcemindowntime(egu,h)            "make sure plant, once it turns off, doesn't
turn back on before mindowntime passes"
         enforceminuptime(egu,h)              "make sure plant, once turns on, doesn't turn
back off before minuptime passes"
                 ;

*Objective function: minimize total cost - includes operation & costs to turn on
costfunc .. vTotalcost =e= sum((h),scCnse*vNse(h)) + sum((egu,h),
                vGen(egu,h)*pOpcost(egu)
                +pTurnonfuelcost(egu)*vTurnondecision(egu,h)
                +pStartupfixedcost(egu)*vTurnondecision(egu,h));


*Limit plant to not shut down until it reaches its min up time - see discussion below for
*discussion of the constraints and formulation.
enforceminuptime(egu,h) .. vOnoroff(egu,h) =g= sum(hh$[ORD(hh)<=ORD(h) and ORD(hh)>(ORD(h)-
pMinuptime(egu))],vTurnondecision(egu,hh));
*At hour h, onoroff if on =1. Then must be greater than sum of turnons during prior hours through
minuptime. So can't turn on twice during that time.
*Alternatively, if unit is off at t=h, then unit could not have turned on during prior period.
Because if it did, then would have had
*to turn off in that same period, thereby violating its minuptime.

*Limit plant to not start up until it reaches its min down time
enforcemindowntime(egu,h) .. 1-vOnoroff(egu,h) =g= sum(hh$[ORD(hh)<=ORD(h) and ORD(hh)>(ORD(h)-
pMindowntime(egu))],vTurnoffdecision(egu,hh));
*Variables: 1 - onoroff > turnoffdecision. Onoroff=1 when on. So unit can be on, onoroff=1, and
greater than or equal to turnoffdecision
*over hh when the plant has not turned off over the last hh hours (b/c turnoffdecision = 1 when
unit turns off).
*Basically, when it turns off, for next mindowntime-1 hours, turnoffdecision summed across hh
will equal 1,
*which means onoroff will always have to be 0, meaning plant will have to stay off.

*Constrains status of plant per whether it's on/off, turning on, or shutting down
statusofplant(egu,h) .. vOnoroff(egu,h) =e= vOnoroff(egu,h-1)$[ORD(h)>1]+vTurnondecision(egu,h)-
vTurnoffdecision(egu,h);
*statusofplant(egu,h) .. vOnoroff(egu,h) =e= pOnoroffinitial(egu)$[ORD(h)=1]+vOnoroff(egu,h-
1)$[ORD(h)>1]+vTurnondecision(egu,h)-vTurnoffdecision(egu,h);

*Constrain plants to generate below their max capacity (set at 85% of nameplate capacity for
thermal units in Matlab input)
relationbwnGenAndGenabovemin(egu,h).. vGen(egu,h) =e=
vOnoroff(egu,h)*pMinload(egu)+vGenaboveminload(egu,h);
```

```
*Establish relationship between gen above min load, gen output, and min load
determineloadabovemin(egu,h)$(pThermal(egu) ) .. vGenaboveminload(egu,h) =l= (pCapac(egu)-
pMinload(egu))*vOnoroff(egu,h);

*Ensure plants are limited to their ramping speed
rampconstraintup(egu,h)$((ORD(h)>1)$(pThermal(egu))) .. vGenaboveminload(egu,h)-
vGenaboveminload(egu,h-1) =l= pRamprate(egu) * pCapac(egu);
rampconstraintdown(egu,h)$((ORD(h)>1)$(pThermal(egu))) .. vGenaboveminload(egu,h-1)-
vGenaboveminload(egu,h) =l= pRamprate(egu) * pCapac(egu);

*Spinning reserve requirement: need enough spare capacity in units to meet reserve requirement
meetreserves(h)  .. pSpinreserves(h) =l= sum(egu,vOnoroff(egu,h)*pCapac(egu)-vGen(egu,h));

*Supply = demand each hour system-wide and in each zone. When line is coming from a zone, it
subtracts from that zone's
*power generation. When line is arriving at a zone (i.e., when the zone is a line's sink), the
line adds to that zone's generation.
*Non-served energy is zonal here.
demand(h).. sum(egu, vGen(egu,h)) + (vNse(h)) =e= (pDemand(h)+(0.001*pEVdemand (h)));

**VARIABLE LIMITS**
*Limit gen variable to max values (min taken care of through onoroff variable carried through
minload & genaboveminload)
vGen.up(egu,h)=pCapac(egu);

* Set status for non-dispatchable units
vOnoroff.fx(egu,h)$pMustRun(egu) = 1;
*vOnoroff.fx(egu,h)$pMustOff(egu) = 0;
*vGen.fx(egu,h)$pMustOff(egu) = 0;

* Set generation levels for renewable sources
vGen.fx('422',h) = pCapac('422')*0.6;
vGen.fx('590',h) = pCapac('590')*pWindGen(h);
vGen.fx('589',h) = pCapac('589')*pSolarGen(h);

model unitcommitmentPJM /all/;
solve unitcommitmentPJM using mip minimizing vTotalcost;

pGenresults(egu,h) = vGen.l(egu,h);
pCostresults(egu,h) = vGen.l(egu,h)*pOpcost(egu);
pVariablecost(egu) = pOpcost(egu);
pMarginalcost(h) = demand.m(h);

display pDemand, vGen.l, demand.m, vOnoroff.l, vTotalcost.l, rampconstraintup.m,
rampconstraintdown.m;


FILE OUTFILE / 'ucGEN.put' /;

PUT OUTFILE;

OUTFILE.PW =2000;

OUTFILE.PC = 6;


* write column headers


put 'Generation table' /;put '    ';

loop (egu, put egu.TL );

put /;
```

```
* write body of generation table
loop (egu,
    put egu.TL loop (h, put pGenresults(egu,h))  put /;
);
put /;

putclose OUTFILE;

FILE OUTFILE2 / 'ucCOST.put' /;
PUT OUTFILE2;
OUTFILE2.PW =2000;
OUTFILE2.PC = 6;


put 'Total Cost ' vTotalcost.l /;
put /;

loop (egu,
    put egu.TL loop (h, put pCostresults(egu,h))  put /;
);
put /;

putclose OUTFILE2;

* write variable cost vector

FILE OUTFILE3 / 'ucVC.put' /;
PUT OUTFILE3;
OUTFILE3.PW =2000;
OUTFILE3.PC = 6;

loop (egu,
    put egu.TL pVariablecost(egu) put /;
);
put /;

putclose OUTFILE3;

* write marginal cost vector

FILE OUTFILE4 / 'ucMC.put' /;
```

```
PUT OUTFILE4;
OUTFILE4.PW =2000;
OUTFILE4.PC = 6;

loop (h,
    put h.TL pMarginalcost(h) put /;
);


putclose OUTFILE4;
```

Appendix B

Table of Generators

Table 4: Generator Properties

OrisID	Gen Fuel	GenName Capac	GenHeat Rate	MinDown Time	MinUp Time	Ramp Rate	StartUp FixedCost	StartUp Fuel	PlantMin Output	GenFuel CostOnly	Gen VarOM
10746	BIO	90	19.68	12	16	1	33	16.7	0.5	0	5
50657	BIO	67.8	19.05	12	16	1	33	16.7	0.5	0	5
10629	BIO	60.2	16.28	12	16	1	33	16.7	0.5	0	5
54638	BIO	54	6.70	12	16	1	33	16.7	0.5	0	5
54746	BIO	53.3	16.23	12	16	1	33	16.7	0.5	0	5
50960	BIO	45	9.47	12	16	1	33	16.7	0.5	0	5
50397	BIO	39.1	5.55	12	16	1	33	16.7	0.5	0	5
50215	BIO	36.5	19.82	12	16	1	33	16.7	0.5	0	5
50859	BIO	35.7	20.17	12	16	1	33	16.7	0.5	0	5
10643	BIO	34.9	10.47	12	16	1	33	16.7	0.5	0	5
10643	BIO	34.9	10.47	12	16	1	33	16.7	0.5	0	5
58023	BIO	33	10.77	12	16	1	33	16.7	0.5	0	5
54625	BIO	32.1	19.32	12	16	1	33	16.7	0.5	0	5
7701	BIO	30	14.29	12	16	1	33	16.7	0.5	0	5
7701	BIO	30	14.29	12	16	1	33	16.7	0.5	0	5
10118	BIO	24.1	5.84	12	16	1	33	16.7	0.5	0	5
50279	BIO	23.2	16.58	12	16	1	33	16.7	0.5	0	5
10435	BIO	17.5	8.53	12	16	1	33	16.7	0.5	0	5
10435	BIO	17.5	8.53	12	16	1	33	16.7	0.5	0	5
50885	BIO	14	21.58	12	16	1	33	16.7	0.5	0	5
10012	BIO	13.5	18.07	12	16	1	33	16.7	0.5	0	5
10731	BIO	12.5	15.35	12	16	1	33	16.7	0.5	0	5
58208	BIO	9.6	11.78	1	1	1	33	0	0.95	0	3
58476	BIO	5.6	11.78	1	1	1	33	0	0.95	0	7
58476	BIO	5.6	11.78	1	1	1	33	0	0.95	0	7
56572	BIO	5.5	16.49	1	1	1	33	0	0.95	0	7
56911	BIO	5.5	20.24	1	1	1	33	0	0.95	0	7
56911	BIO	5.5	20.24	1	1	1	33	0	0.95	0	7
55618	BIO	4.9	15.91	1	1	1	33	0	0.95	0	7
55618	BIO	4.9	15.91	1	1	1	33	0	0.95	0	7
50279	BIO	4.6	16.58	1	1	1	33	0	0.95	0	7
50279	BIO	4.6	16.58	1	1	1	33	0	0.95	0	7
10629	BIO	4.3	16.28	12	16	1	33	16.7	0.5	0	5
55765	BIO	3.3	22.25	1	1	1	33	0	0.95	0	7
55765	BIO	3.3	22.25	1	1	1	33	0	0.95	0	7
55765	BIO	3.3	22.25	1	1	1	33	0	0.95	0	7
7690	BIO	3	2.88	1	1	1	33	0	0.95	0	7
7690	BIO	3	2.88	1	1	1	33	0	0.95	0	7
50578	BIO	3	17.18	1	1	1	33	0	0.95	0	7
55074	BIO	3	11.34	1	1	1	33	0	0.95	0	3
55074	BIO	3	11.34	1	1	1	33	0	0.95	0	3
55142	BIO	3	10.87	1	1	1	33	0	0.95	0	3
55142	BIO	3	10.87	1	1	1	33	0	0.95	0	3
55142	BIO	3	10.87	1	1	1	33	0	0.95	0	3
57848	BIO	2	11.78	1	1	1	33	0	0.95	0	3
3118	COAL	936	9.15	12	16	0.6	33	16.7	0.25	2.4	3
3118	COAL	936	9.37	12	16	0.6	33	16.7	0.25	2.4	3
3136	COAL	936	9.41	12	16	0.6	33	16.7	0.25	2.4	3
3136	COAL	936	9.51	12	16	0.6	33	16.7	0.25	2.4	3
6094	COAL	913.7	9.31	12	16	0.6	33	16.7	0.25	2.4	3
6094	COAL	913.7	8.73	12	16	0.6	33	16.7	0.25	2.4	3
6094	COAL	913.7	9.27	12	16	0.6	33	16.7	0.25	2.4	3
3149	COAL	819	9.27	12	16	0.6	33	16.7	0.25	2.4	3

OrisID	Gen Fuel	GenName Capac	GenHeat Rate	MinDown Time	MinUp Time	Ramp Rate	StartUp FixedCost	StartUp Fuel	PlantMin Output	GenFuel CostOnly	Gen VarOM
3149	COAL	805.5	8.95	12	16	0.6	33	16.7	0.25	2.4	3
3140	COAL	790.4	9.22	12	16	0.6	33	16.7	0.25	2.4	3
3122	COAL	692	8.99	12	16	0.6	33	16.7	0.25	2.4	3
602	COAL	685	10.74	12	16	0.6	33	16.7	0.25	2.4	3
602	COAL	685	9.62	12	16	0.6	33	16.7	0.25	2.4	3
3122	COAL	660	9.39	12	16	0.6	33	16.7	0.25	2.4	3
3122	COAL	660	9.61	12	16	0.6	33	16.7	0.25	2.4	3
2403	COAL	659.7	11.76	12	16	0.6	33	16.7	0.25	2.4	3
8226	COAL	637	9.77	12	16	0.6	33	16.7	0.25	2.4	3
1573	COAL	626	9.03	12	16	0.6	33	16.7	0.25	2.4	3
1573	COAL	626	9.29	12	16	0.6	33	16.7	0.25	2.4	3
3130	COAL	585	11.16	12	16	0.6	33	16.7	0.25	2.4	3
3179	COAL	576	9.36	12	16	0.6	33	16.7	0.25	2.4	3
3179	COAL	576	9.36	12	16	0.6	33	16.7	0.25	2.4	3
3179	COAL	576	9.46	12	16	0.6	33	16.7	0.25	2.4	3
594	COAL	445.5	9.37	12	16	0.6	33	16.7	0.25	2.4	3
3140	COAL	405	9.11	12	16	0.6	33	16.7	0.25	2.4	3
1571	COAL	364	10.95	12	16	0.6	33	16.7	0.25	2.4	3
1571	COAL	364	10.51	12	16	0.6	33	16.7	0.25	2.4	3
3140	COAL	363.3	8.82	12	16	0.6	33	16.7	0.25	2.4	3
1554	COAL	359	9.53	12	16	0.6	33	16.7	0.25	2.4	3
2408	COAL	326.4	13.29	12	16	0.6	33	16.7	0.25	2.4	3
2408	COAL	326.4	14.17	12	16	0.6	33	16.7	0.25	2.4	3
3181	COAL	299.2	12.53	12	16	0.6	33	16.7	0.25	2.4	3
10566	COAL	285	8.55	12	16	0.6	33	16.7	0.25	2.4	3
3113	COAL	255	10.31	12	16	0.6	33	16.7	0.25	2.4	3
10043	COAL	242.3	9.37	12	16	0.6	33	16.7	0.25	2.4	3
10678	COAL	229	11.57	12	16	0.6	33	16.7	0.25	2.4	3
1552	COAL	209.4	13.51	12	16	0.6	33	16.7	0.25	2.4	3
1572	COAL	196	9.77	12	16	0.6	33	16.7	0.25	2.4	3
1572	COAL	196	9.44	12	16	0.6	33	16.7	0.25	2.4	3
1572	COAL	196	9.47	12	16	0.6	33	16.7	0.25	2.4	3
1552	COAL	190.4	13.14	12	16	0.6	33	16.7	0.25	2.4	3
3131	COAL	188	12.61	12	16	0.6	33	16.7	0.25	2.4	3
3131	COAL	188	10.28	12	16	0.6	33	16.7	0.25	2.4	3
594	COAL	176.8	10.44	12	16	0.6	33	16.7	0.25	2.4	3
3113	COAL	172	9.87	12	16	0.6	33	16.7	0.25	2.4	3
2378	COAL	163.2	10.62	12	16	0.6	33	16.7	0.25	2.4	3
3152	COAL	156.2	13.17	12	16	0.6	33	16.7	0.25	2.4	3
1554	COAL	136	15.90	12	16	0.6	33	16.7	0.25	2.4	3
2378	COAL	136	12.09	12	16	0.6	33	16.7	0.25	2.4	3
3138	COAL	136	11.55	12	16	0.6	33	16.7	0.25	2.4	3
3131	COAL	125	11.59	12	16	0.6	33	16.7	0.25	2.4	3
3131	COAL	125	11.26	12	16	0.6	33	16.7	0.25	2.4	3
10143	COAL	118	10.58	12	16	0.6	33	16.7	0.25	2.4	3
50888	COAL	114.1	10.39	12	16	0.6	33	16.7	0.25	2.4	3
3138	COAL	114	10.34	12	16	0.6	33	16.7	0.25	2.4	3
10676	COAL	114	8.85	12	16	0.6	33	16.7	0.25	2.4	3
3152	COAL	103.5	13.17	12	16	0.6	33	16.7	0.25	2.4	3
54634	COAL	99.2	13.81	12	16	0.6	33	16.7	0.25	2.4	3
3138	COAL	98	10.51	12	16	0.6	33	16.7	0.25	2.4	3
10641	COAL	98	11.90	12	16	0.6	33	16.7	0.25	2.4	3
50974	COAL	94.7	11.06	12	16	0.6	33	16.7	0.25	2.4	3
50776	COAL	94	10.18	12	16	0.6	33	16.7	0.25	2.4	3
3152	COAL	89.1	13.17	12	16	0.6	33	16.7	0.25	2.4	3
3152	COAL	89.1	13.17	12	16	0.6	33	16.7	0.25	2.4	3
10113	COAL	88.4	5.74	12	16	0.6	33	16.7	0.25	2.4	3
3115	COAL	75	12.19	12	16	0.6	33	16.7	0.25	2.4	3
3115	COAL	75	12.26	12	16	0.6	33	16.7	0.25	2.4	3
3115	COAL	75	12.38	12	16	0.6	33	16.7	0.25	2.4	3
50039	COAL	59	13.37	12	16	0.6	33	16.7	0.25	2.4	3
10603	COAL	57.6	13.09	12	16	0.6	33	16.7	0.25	2.4	3

OrisID	Gen Fuel	GenName Capac	GenHeat Rate	MinDown Time	MinUp Time	Ramp Rate	StartUp FixedCost	StartUp Fuel	PlantMin Output	GenFuel CostOnly	Gen VarOM
50879	COAL	48	13.75	12	16	0.6	33	16.7	0.25	2.4	3
10343	COAL	47.3	16.19	12	16	0.6	33	16.7	0.25	2.4	3
50397	COAL	45.9	5.55	12	16	0.6	33	16.7	0.25	2.4	3
54144	COAL	36.2	12.06	12	16	0.6	33	16.7	0.25	2.4	3
50611	COAL	36	13.80	12	16	0.6	33	16.7	0.25	2.4	3
10676	COAL	35	8.85	12	16	0.6	33	16.7	0.25	2.4	3
10030	COAL	18	13.97	12	16	0.6	33	16.7	0.25	2.4	3
3149	COAL	17.2	9.39	12	16	0.6	33	16.7	0.25	2.4	3
50397	COAL	7.5	5.55	12	16	0.6	33	16.7	0.25	2.4	3
57944	COAL	6.2	11.22	12	16	0.6	33	16.7	0.25	2.4	3
57944	COAL	6.2	11.22	12	16	0.6	33	16.7	0.25	2.4	3
50397	COAL	6	5.55	12	16	0.6	33	16.7	0.25	2.4	3
50397	COAL	5.1	5.55	12	16	0.6	33	16.7	0.25	2.4	3
58194	COAL	3.5	11.22	12	16	0.6	33	16.7	0.25	2.4	3
58194	COAL	2.5	11.22	12	16	0.6	33	16.7	0.25	2.4	3
3148	GAS	850.5	62.40	12	16	1	33	16.7	0.3	3.4	3
3148	GAS	850.5	109.97	12	16	1	33	16.7	0.3	3.4	3
593	GAS	446	12.24	12	16	1	33	16.7	0.3	3.4	3
55976	GAS	361	7.34	8	12	1	12.5	2.5	0.5	3.4	2.5
55239	GAS	330	7.36	8	12	1	12.5	2.5	0.5	3.4	2.5
2398	GAS	325.2	7.82	8	12	1	12.5	2.5	0.5	3.4	2.5
55516	GAS	317.1	7.76	8	12	1	12.5	2.5	0.5	3.4	2.5
2406	GAS	315	7.43	8	12	1	12.5	2.5	0.5	3.4	2.5
2406	GAS	315	7.43	8	12	1	12.5	2.5	0.5	3.4	2.5
55801	GAS	271.5	9.13	8	12	1	12.5	2.5	0.5	3.4	2.5
55298	GAS	271.2	7.18	8	12	1	12.5	2.5	0.5	3.4	2.5
55298	GAS	271.2	7.18	8	12	1	12.5	2.5	0.5	3.4	2.5
55337	GAS	259.2	11.35	8	12	1	12.5	2.5	0.5	3.4	2.5
55337	GAS	259.2	11.46	8	12	1	12.5	2.5	0.5	3.4	2.5
55337	GAS	259.2	7.66	8	12	1	12.5	2.5	0.5	3.4	2.5
2398	GAS	258.4	7.82	8	12	1	12.5	2.5	0.5	3.4	2.5
55193	GAS	250	6.81	8	12	1	12.5	2.5	0.5	3.4	2.5
55193	GAS	250	6.78	8	12	1	12.5	2.5	0.5	3.4	2.5
55231	GAS	242	7.33	8	12	1	12.5	2.5	0.5	3.4	2.5
55690	GAS	230	8.33	8	12	1	12.5	2.5	0.5	3.4	2.5
55690	GAS	230	8.33	8	12	1	12.5	2.5	0.5	3.4	2.5
55667	GAS	228.6	7.38	8	12	1	12.5	2.5	0.5	3.4	2.5
55193	GAS	228	7.19	8	12	1	12.5	2.5	0.5	3.4	2.5
50006	GAS	212.5	6.58	8	12	1	12.5	2.5	0.5	3.4	2.5
55239	GAS	212	10.74	8	12	1	12.5	2.5	0.5	3.4	2.5
55239	GAS	212	10.79	8	12	1	12.5	2.5	0.5	3.4	2.5
55239	GAS	212	10.92	8	12	1	12.5	2.5	0.5	3.4	2.5
55667	GAS	211.5	7.58	8	12	1	12.5	2.5	0.5	3.4	2.5
55667	GAS	211.5	7.16	8	12	1	12.5	2.5	0.5	3.4	2.5
7153	GAS	200	8.36	8	12	1	12.5	2.5	0.5	3.4	2.5
55524	GAS	200	12.58	8	12	1	12.5	2.5	0.5	3.4	2.5
7835	GAS	198.9	9.41	1	1	1	12.5	0	0	3.4	7
7835	GAS	198.9	9.37	1	1	1	12.5	0	0	3.4	7
7835	GAS	198.9	9.49	1	1	1	12.5	0	0	3.4	7
55298	GAS	198.9	6.99	8	12	1	12.5	2.5	0.5	3.4	2.5
55298	GAS	198.9	6.83	8	12	1	12.5	2.5	0.5	3.4	2.5
55298	GAS	198.9	6.92	8	12	1	12.5	2.5	0.5	3.4	2.5
55298	GAS	198.9	7.04	8	12	1	12.5	2.5	0.5	3.4	2.5
7153	GAS	195	8.36	8	12	1	12.5	2.5	0.5	3.4	2.5
1556	GAS	192	11.12	1	1	1	12.5	0	0	3.4	7
55938	GAS	191.5	9.69	1	1	1	12.5	0	0	3.4	7
55938	GAS	191.5	9.67	1	1	1	12.5	0	0	3.4	7
55801	GAS	188.2	11.02	8	12	1	12.5	2.5	0.5	3.4	2.5
55801	GAS	188.2	11.16	8	12	1	12.5	2.5	0.5	3.4	2.5
55801	GAS	188.2	10.60	8	12	1	12.5	2.5	0.5	3.4	2.5
55710	GAS	188	7.41	8	12	1	12.5	2.5	0.5	3.4	2.5
55231	GAS	186	10.43	8	12	1	12.5	2.5	0.5	3.4	2.5

OrisID	Gen Fuel	GenName Capac	GenHeat Rate	MinDown Time	MinUp Time	Ramp Rate	StartUp FixedCost	StartUp Fuel	PlantMin Output	GenFuel CostOnly	Gen VarOM
55231	GAS	186	10.34	8	12	1	12.5	2.5	0.5	3.4	2.5
55710	GAS	184	10.66	8	12	1	12.5	2.5	0.5	3.4	2.5
55710	GAS	184	10.38	8	12	1	12.5	2.5	0.5	3.4	2.5
2398	GAS	183.6	11.89	8	12	1	12.5	2.5	0.5	3.4	2.5
2398	GAS	183.6	11.24	8	12	1	12.5	2.5	0.5	3.4	2.5
2406	GAS	181.4	11.13	8	12	1	12.5	2.5	0.5	3.4	2.5
2406	GAS	181.4	11.13	8	12	1	12.5	2.5	0.5	3.4	2.5
2406	GAS	181.4	10.81	8	12	1	12.5	2.5	0.5	3.4	2.5
2406	GAS	181.4	11.11	8	12	1	12.5	2.5	0.5	3.4	2.5
55976	GAS	179	10.82	8	12	1	12.5	2.5	0.5	3.4	2.5
55976	GAS	179	10.81	8	12	1	12.5	2.5	0.5	3.4	2.5
55976	GAS	179	10.80	8	12	1	12.5	2.5	0.5	3.4	2.5
7835	GAS	175.9	9.35	1	1	1	12.5	0	0	3.4	7
55347	GAS	172	9.75	1	1	1	12.5	0	0	3.4	7
55347	GAS	172	9.69	1	1	1	12.5	0	0	3.4	7
55347	GAS	172	9.94	1	1	1	12.5	0	0	3.4	7
55347	GAS	172	10.02	1	1	1	12.5	0	0	3.4	7
55516	GAS	163.5	7.14	8	12	1	12.5	2.5	0.5	3.4	2.5
55516	GAS	163.5	7.19	8	12	1	12.5	2.5	0.5	3.4	2.5
1572	GAS	163	9.64	1	1	1	12.5	0	0	3.4	7
1572	GAS	163	8.29	1	1	1	12.5	0	0	3.4	7
2393	GAS	161	10.34	1	1	1	12.5	0	0	3.4	7
3096	GAS	144	31.19	8	12	1	12.5	2.5	0.5	3.4	2.5
7153	GAS	144	11.57	8	12	1	12.5	2.5	0.5	3.4	2.5
7153	GAS	144	11.56	8	12	1	12.5	2.5	0.5	3.4	2.5
7153	GAS	144	11.59	8	12	1	12.5	2.5	0.5	3.4	2.5
10308	GAS	143.4	8.16	8	12	1	12.5	2.5	0.5	3.4	2.5
10308	GAS	143.4	8.22	8	12	1	12.5	2.5	0.5	3.4	2.5
10308	GAS	143.4	8.52	8	12	1	12.5	2.5	0.5	3.4	2.5
55690	GAS	140	7.57	8	12	1	12.5	2.5	0.5	3.4	2.5
55690	GAS	140	7.68	8	12	1	12.5	2.5	0.5	3.4	2.5
55690	GAS	140	7.72	8	12	1	12.5	2.5	0.5	3.4	2.5
55690	GAS	140	7.76	8	12	1	12.5	2.5	0.5	3.4	2.5
55690	GAS	140	7.96	8	12	1	12.5	2.5	0.5	3.4	2.5
55690	GAS	140	7.92	8	12	1	12.5	2.5	0.5	3.4	2.5
1559	GAS	135	15.50	1	1	1	12.5	0	0	3.4	7
2393	GAS	135	34.20	8	12	1	12.5	2.5	0.5	3.4	2.5
54785	GAS	135	12.27	8	12	1	12.5	2.5	0.5	3.4	2.5
1554	GAS	132.8	17.55	12	16	1	33	16.7	0.3	3.4	4
5083	GAS	131.8	12.55	1	1	1	12.5	0	0	3.4	7
2411	GAS	126.5	17.56	12	16	1	33	16.7	0.3	3.4	4
7153	GAS	122	12.31	8	12	1	12.5	2.5	0.5	3.4	2.5
7153	GAS	122	12.02	8	12	1	12.5	2.5	0.5	3.4	2.5
7153	GAS	122	11.96	8	12	1	12.5	2.5	0.5	3.4	2.5
1560	GAS	121.5	14.83	1	1	1	12.5	0	0	3.4	7
55524	GAS	120	12.58	8	12	1	12.5	2.5	0.5	3.4	2.5
55524	GAS	120	12.58	8	12	1	12.5	2.5	0.5	3.4	2.5
55524	GAS	120	12.58	8	12	1	12.5	2.5	0.5	3.4	2.5
599	GAS	113.6	11.93	12	16	1	33	16.7	0.3	3.4	4
7288	GAS	112.8	11.74	1	1	1	12.5	0	0	3.4	7
2398	GAS	112.5	11.17	8	12	1	12.5	2.5	0.5	3.4	2.5
2398	GAS	112.5	11.01	8	12	1	12.5	2.5	0.5	3.4	2.5
2398	GAS	112.5	12.24	8	12	1	12.5	2.5	0.5	3.4	2.5
2398	GAS	112.5	12.01	8	12	1	12.5	2.5	0.5	3.4	2.5
2411	GAS	110.7	13.54	12	16	1	33	16.7	0.3	3.4	4
2411	GAS	107.5	14.56	12	16	1	33	16.7	0.3	3.4	4
2411	GAS	107.5	17.84	12	16	1	33	16.7	0.3	3.4	4
1553	GAS	103.5	13.52	12	16	1	33	16.7	0.3	3.4	4
5083	GAS	99.4	6.52	1	1	1	12.5	0	0	3.4	7
2406	GAS	96.1	11.42	1	1	1	12.5	0	0	3.4	7
2406	GAS	96.1	12.14	1	1	1	12.5	0	0	3.4	7
2406	GAS	96.1	10.40	1	1	1	12.5	0	0	3.4	7

OrisID	Gen Fuel	GenName Capac	GenHeat Rate	MinDown Time	MinUp Time	Ramp Rate	StartUp FixedCost	StartUp Fuel	PlantMin Output	GenFuel CostOnly	Gen VarOM
2406	GAS	96.1	10.24	1	1	1	12.5	0	0	3.4	7
10751	GAS	95.2	8.35	8	12	1	12.5	2.5	0.5	3.4	2.5
50006	GAS	95.2	6.91	8	12	1	12.5	2.5	0.5	3.4	2.5
50006	GAS	95.2	6.87	8	12	1	12.5	2.5	0.5	3.4	2.5
50006	GAS	95.2	6.85	8	12	1	12.5	2.5	0.5	3.4	2.5
50006	GAS	95.2	6.87	8	12	1	12.5	2.5	0.5	3.4	2.5
50006	GAS	95.2	6.82	8	12	1	12.5	2.5	0.5	3.4	2.5
50006	GAS	95.2	6.35	8	12	1	12.5	2.5	0.5	3.4	2.5
50006	GAS	95.2	6.35	8	12	1	12.5	2.5	0.5	3.4	2.5
50006	GAS	95.2	6.35	8	12	1	12.5	2.5	0.5	3.4	2.5
2401	GAS	93.6	8.61	1	1	1	12.5	0	0	3.4	7
10099	GAS	92.1	8.20	8	12	1	12.5	2.5	0.5	3.4	2.5
52193	GAS	92	21.12	1	1	1	12.5	0	0	3.4	7
52193	GAS	92	21.12	1	1	1	12.5	0	0	3.4	7
50561	GAS	90	9.84	8	12	1	12.5	2.5	0.5	3.4	2.5
50561	GAS	90	9.69	8	12	1	12.5	2.5	0.5	3.4	2.5
2384	GAS	81.6	11.46	12	16	1	33	16.7	0.3	3.4	5
52193	GAS	75	21.12	12	16	1	33	16.7	0.3	3.4	5
2384	GAS	73.5	10.67	12	16	1	33	16.7	0.3	3.4	5
1559	GAS	72.2	13.97	12	16	1	33	16.7	0.3	3.4	5
2434	GAS	68.2	8.35	1	1	1	12.5	0	0	3.4	7
3096	GAS	65.3	28.36	8	12	1	12.5	2.5	0.5	3.4	2.5
3096	GAS	65.3	23.35	8	12	1	12.5	2.5	0.5	3.4	2.5
3096	GAS	65.3	18.82	8	12	1	12.5	2.5	0.5	3.4	2.5
10751	GAS	61.8	8.66	8	12	1	12.5	2.5	0.5	3.4	2.5
50497	GAS	61.4	4.46	8	12	1	12.5	2.5	0.5	3.4	2.5
2399	GAS	60.5	8.15	1	1	1	12.5	0	0	3.4	7
2399	GAS	60.5	8.29	1	1	1	12.5	0	0	3.4	7
2399	GAS	60.5	8.48	1	1	1	12.5	0	0	3.4	7
2399	GAS	60.5	10.03	1	1	1	12.5	0	0	3.4	7
2404	GAS	60.5	7.88	1	1	1	12.5	0	0	3.4	7
2404	GAS	60.5	8.23	1	1	1	12.5	0	0	3.4	7
2404	GAS	60.5	8.09	1	1	1	12.5	0	0	3.4	7
2404	GAS	60.5	8.24	1	1	1	12.5	0	0	3.4	7
2404	GAS	60.5	8.30	1	1	1	12.5	0	0	3.4	7
2404	GAS	60.5	8.20	1	1	1	12.5	0	0	3.4	7
2404	GAS	60.5	8.30	1	1	1	12.5	0	0	3.4	7
2404	GAS	60.5	10.00	1	1	1	12.5	0	0	3.4	7
2404	GAS	60.5	8.63	1	1	1	12.5	0	0	3.4	7
2404	GAS	60.5	8.86	1	1	1	12.5	0	0	3.4	7
50279	GAS	60.5	8.75	1	1	1	12.5	0	0	3.4	7
50852	GAS	59	9.65	8	12	1	12.5	2.5	0.5	3.4	2.5
55233	GAS	58.9	10.27	1	1	1	12.5	0	0	3.4	7
55233	GAS	58.9	10.27	1	1	1	12.5	0	0	3.4	7
55233	GAS	58.9	10.27	1	1	1	12.5	0	0	3.4	7
55233	GAS	58.9	10.27	1	1	1	12.5	0	0	3.4	7
55233	GAS	58.9	10.27	1	1	1	12.5	0	0	3.4	7
50385	GAS	58	8.54	8	12	1	12.5	2.5	0.5	3.4	2.5
50385	GAS	58	8.86	8	12	1	12.5	2.5	0.5	3.4	2.5
54785	GAS	57.6	5.71	8	12	1	12.5	2.5	0.5	3.4	2.5
2393	GAS	54	13.61	8	12	1	12.5	2.5	0.5	3.4	2.5
2393	GAS	54	13.48	8	12	1	12.5	2.5	0.5	3.4	2.5
2393	GAS	54	13.98	8	12	1	12.5	2.5	0.5	3.4	2.5
2393	GAS	54	13.32	8	12	1	12.5	2.5	0.5	3.4	2.5
2390	GAS	53	16.13	1	1	1	12.5	0	0	3.4	7
2390	GAS	53	21.90	1	1	1	12.5	0	0	3.4	7
2390	GAS	53	15.09	1	1	1	12.5	0	0	3.4	7
7962	GAS	51	10.08	1	1	1	12.5	0	0	3.4	7
10030	GAS	50	8.39	1	1	1	12.5	0	0	3.4	7
10030	GAS	50	8.02	1	1	1	12.5	0	0	3.4	7
3176	GAS	49.9	15.88	8	12	1	12.5	2.5	0.5	3.4	2.5
3176	GAS	48	7.74	8	12	1	12.5	2.5	0.5	3.4	2.5

OrisID	*Gen Fuel*	*GenName Capac*	*GenHeat Rate*	*MinDown Time*	*MinUp Time*	*Ramp Rate*	*StartUp FixedCost*	*StartUp Fuel*	*PlantMin Output*	*GenFuel CostOnly*	*Gen VarOM*
3176	GAS	48	7.70	8	12	1	12.5	2.5	0.5	3.4	2.5
50799	GAS	45.9	9.44	8	12	1	12.5	2.5	0.5	3.4	2.5
50799	GAS	45.9	8.11	8	12	1	12.5	2.5	0.5	3.4	2.5
7318	GAS	45.1	12.56	1	1	1	12.5	0	0	3.4	7
7962	GAS	45	7.84	1	1	1	12.5	0	0	3.4	7
50561	GAS	45	7.45	8	12	1	12.5	2.5	0.5	3.4	2.5
56397	GAS	44	10.94	1	1	1	12.5	0	0	3.4	7
55196	GAS	43.8	8.49	1	1	1	12.5	0	0	3.4	7
55196	GAS	43.8	8.60	1	1	1	12.5	0	0	3.4	7
55377	GAS	43.8	8.75	1	1	1	12.5	0	0	3.4	7
55377	GAS	43.8	8.68	1	1	1	12.5	0	0	3.4	7
55654	GAS	43.8	10.25	1	1	1	12.5	0	0	3.4	7
55654	GAS	43.8	10.25	1	1	1	12.5	0	0	3.4	7
50497	GAS	43.4	12.28	8	12	1	12.5	2.5	0.5	3.4	2.5
50497	GAS	43.4	12.13	8	12	1	12.5	2.5	0.5	3.4	2.5
50497	GAS	43.4	12.69	8	12	1	12.5	2.5	0.5	3.4	2.5
10099	GAS	42.4	7.90	8	12	1	12.5	2.5	0.5	3.4	2.5
2379	GAS	41.9	37.79	1	1	1	12.5	0	0	3.4	7
2379	GAS	41.9	51.40	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.22	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.19	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.24	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.25	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.22	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.27	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.22	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.29	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.21	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.28	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.29	1	1	1	12.5	0	0	3.4	7
2400	GAS	41.8	15.26	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	16.17	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	16.20	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	15.99	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	15.99	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	16.07	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	16.00	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	16.19	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	16.06	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	16.00	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	16.04	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	16.05	1	1	1	12.5	0	0	3.4	7
2401	GAS	41.8	16.11	1	1	1	12.5	0	0	3.4	7
50385	GAS	40	7.58	8	12	1	12.5	2.5	0.5	3.4	2.5
7138	GAS	38.4	16.70	1	1	1	12.5	0	0	3.4	7
7138	GAS	38.4	11.78	1	1	1	12.5	0	0	3.4	7
52193	GAS	27.5	21.12	12	16	1	33	16.7	0.3	3.4	5
52193	GAS	27.5	21.12	12	16	1	33	16.7	0.3	3.4	5
50732	GAS	25	9.81	12	16	1	33	16.7	0.3	3.4	5
50732	GAS	25	9.81	12	16	1	33	16.7	0.3	3.4	5
2393	GAS	24	34.20	1	1	1	12.5	0	0	3.4	7
2393	GAS	24	34.20	1	1	1	12.5	0	0	3.4	7
2393	GAS	24	34.20	1	1	1	12.5	0	0	3.4	7
2393	GAS	24	34.20	1	1	1	12.5	0	0	3.4	7
3120	GAS	24	21.59	1	1	1	12.5	0	0	3.4	7
50852	GAS	24	8.50	8	12	1	12.5	2.5	0.5	3.4	2.5
3148	GAS	22.3	11.88	1	1	1	12.5	0	0	3.4	7
3148	GAS	22.3	11.88	1	1	1	12.5	0	0	3.4	7
3148	GAS	22.3	11.88	1	1	1	12.5	0	0	3.4	7
3148	GAS	22.3	11.88	1	1	1	12.5	0	0	3.4	7
56668	GAS	22	11.98	1	1	1	12.5	0	0	3.4	7
50799	GAS	21.6	8.12	8	12	1	12.5	2.5	0.5	3.4	2.5

OrisID	*Gen Fuel*	*GenName Capac*	*GenHeat Rate*	*MinDown Time*	*MinUp Time*	*Ramp Rate*	*StartUp FixedCost*	*StartUp Fuel*	*PlantMin Output*	*GenFuel CostOnly*	*Gen VarOM*
50799	GAS	21.6	8.12	8	12	1	12.5	2.5	0.5	3.4	2.5
8227	GAS	20	24.23	1	1	1	12.5	0	0	3.4	7
8227	GAS	20	24.23	1	1	1	12.5	0	0	3.4	7
8227	GAS	20	24.23	1	1	1	12.5	0	0	3.4	7
8227	GAS	20	24.23	1	1	1	12.5	0	0	3.4	7
8227	GAS	20	24.23	1	1	1	12.5	0	0	3.4	7
8227	GAS	20	24.23	1	1	1	12.5	0	0	3.4	7
8227	GAS	20	24.23	1	1	1	12.5	0	0	3.4	7
8227	GAS	19.6	24.23	1	1	1	12.5	0	0	3.4	7
599	GAS	18.8	11.91	12	16	1	33	16.7	0.3	3.4	5
599	GAS	18.8	11.91	12	16	1	33	16.7	0.3	3.4	5
2398	GAS	18.6	7.82	1	1	1	12.5	0	0	3.4	7
2404	GAS	18.5	10.05	1	1	1	12.5	0	0	3.4	7
1555	GAS	18	17.07	1	1	1	12.5	0	0	3.4	7
1555	GAS	18	17.07	1	1	1	12.5	0	0	3.4	7
1555	GAS	18	17.07	1	1	1	12.5	0	0	3.4	7
1555	GAS	18	17.07	1	1	1	12.5	0	0	3.4	7
1555	GAS	18	17.07	1	1	1	12.5	0	0	3.4	7
1555	GAS	18	17.07	1	1	1	12.5	0	0	3.4	7
1555	GAS	18	17.07	1	1	1	12.5	0	0	3.4	7
1555	GAS	18	17.07	1	1	1	12.5	0	0	3.4	7
50729	GAS	10	7.28	12	16	1	33	16.7	0.3	3.4	5
52193	GAS	10	21.12	12	16	1	33	16.7	0.3	3.4	5
54693	GAS	9.5	10.97	8	12	1	12.5	2.5	0.5	3.4	2.5
54693	GAS	9.5	10.97	8	12	1	12.5	2.5	0.5	3.4	2.5
54693	GAS	8.3	10.97	8	12	1	12.5	2.5	0.5	3.4	2.5
54693	GAS	8.3	10.97	8	12	1	12.5	2.5	0.5	3.4	2.5
54693	GAS	8.3	10.97	8	12	1	12.5	2.5	0.5	3.4	2.5
54693	GAS	8.3	10.97	8	12	1	12.5	2.5	0.5	3.4	2.5
58442	GAS	7.8	12.58	1	1	1	12.5	0	0	3.4	7
58195	GAS	7	12.58	1	1	1	12.5	0	0	3.4	7
58165	GAS	6.2	12.58	1	1	1	12.5	0	0.95	3.4	3
10129	GAS	6.1	9.59	1	1	1	12.5	0	0.95	3.4	3
10129	GAS	6.1	9.59	1	1	1	12.5	0	0.95	3.4	3
10129	GAS	6.1	9.59	1	1	1	12.5	0	0.95	3.4	3
10129	GAS	6.1	9.59	1	1	1	12.5	0	0.95	3.4	3
50094	GAS	6	5.70	1	1	1	12.5	0	0.95	3.4	3
55997	GAS	6	8.87	1	1	1	12.5	0	0.95	3.4	3
55997	GAS	6	8.87	1	1	1	12.5	0	0.95	3.4	3
55997	GAS	6	8.87	1	1	1	12.5	0	0.95	3.4	3
55997	GAS	6	8.87	1	1	1	12.5	0	0.95	3.4	3
58433	GAS	5.8	12.58	1	1	1	12.5	0	0	3.4	0
58207	GAS	5.7	12.58	1	1	1	12.5	0	0.95	3.4	3
57788	GAS	5.4	12.58	1	1	1	12.5	0	0	3.4	7
57788	GAS	5.4	12.58	1	1	1	12.5	0	0	3.4	7
58207	GAS	4.3	12.58	1	1	1	12.5	0	0	3.4	7
58207	GAS	4.3	12.58	1	1	1	12.5	0	0	3.4	7
58207	GAS	4.3	12.58	1	1	1	12.5	0	0	3.4	7
58207	GAS	4.3	12.58	1	1	1	12.5	0	0	3.4	7
54707	GAS	4.1	5.82	1	1	1	12.5	0	0	3.4	7
7397	GAS	3.2	10.05	1	1	1	12.5	0	0.95	3.4	3
58110	GAS	3.1	12.58	1	1	1	12.5	0	0	3.4	0
7397	GAS	2	10.05	1	1	1	12.5	0	0.95	3.4	3
7397	GAS	2	10.05	1	1	1	12.5	0	0.95	3.4	3
56701	GAS	2	9.94	1	1	1	12.5	0	0.95	3.4	3
56701	GAS	2	9.94	1	1	1	12.5	0	0.95	3.4	3
56701	GAS	2	9.94	1	1	1	12.5	0	0.95	3.4	3
56701	GAS	2	9.94	1	1	1	12.5	0	0.95	3.4	3
HYDRO AGG	HYD-RO	3339.5	0.00	1	1	1	0	0	0	0	0
6103	NUC	1298	0.00	24	24	0.1	74	7.4	0.95	0	0
6103	NUC	1298	0.00	24	24	0.1	74	7.4	0.95	0	0

OrisID	Gen Fuel	GenName Capac	GenHeat Rate	MinDown Time	MinUp Time	Ramp Rate	StartUp FixedCost	StartUp Fuel	PlantMin Output	GenFuel CostOnly	Gen VarOM
6118	NUC	1290.7	0.00	24	24	0.1	74	7.4	0.95	0	0
2410	NUC	1170	60.10	24	24	0.1	74	7.4	0.95	0	0
2410	NUC	1170	60.10	24	24	0.1	74	7.4	0.95	0	0
3166	NUC	1159.7	0.00	24	24	0.1	74	7.4	0.95	0	0
3166	NUC	1159.7	0.00	24	24	0.1	74	7.4	0.95	0	0
6105	NUC	1138.5	0.00	24	24	0.1	74	7.4	0.95	0	0
6105	NUC	1138.5	0.00	24	24	0.1	74	7.4	0.95	0	0
8011	NUC	975.6	0.00	24	24	0.1	74	7.4	0.95	0	0
6040	NUC	923.4	0.00	24	24	0.1	74	7.4	0.95	0	0
6040	NUC	923.4	0.00	24	24	0.1	74	7.4	0.95	0	0
6011	NUC	918	0.00	24	24	0.1	74	7.4	0.95	0	0
6011	NUC	910.7	0.00	24	24	0.1	74	7.4	0.95	0	0
2388	NUC	550	0.00	24	24	0.1	74	7.4	0.95	0	0
1571	OIL	659	17.22	12	16	0.3	33	16.7	0.25	12.6	3
1571	OIL	659	16.27	12	16	0.3	33	16.7	0.25	12.6	3
1554	OIL	414.7	56.18	12	16	0.3	33	16.7	0.25	12.6	3
3161	OIL	391	98.49	12	16	0.3	33	16.7	0.25	12.6	3
3161	OIL	391	78.09	12	16	0.3	33	16.7	0.25	12.6	3
2378	OIL	176.4	12.88	12	16	0.3	33	16.7	0.25	12.6	4
1564	OIL	162	13.10	12	16	0.3	33	16.7	0.25	12.6	4
3113	OIL	156	10.19	1	1	1	12.5	0	0	12.6	7
1571	OIL	125	11.22	1	1	1	12.5	0	0	12.6	7
1571	OIL	125	11.74	1	1	1	12.5	0	0	12.6	7
2408	OIL	115.2	19.66	1	1	1	12.5	0	0	12.6	7
2411	OIL	115.2	22.71	1	1	1	12.5	0	0	12.6	7
1571	OIL	103	11.98	1	1	1	12.5	0	0	12.6	7
1571	OIL	103	12.63	1	1	1	12.5	0	0	12.6	7
1571	OIL	94	10.82	1	1	1	12.5	0	0	12.6	7
3181	OIL	74.7	10.98	12	16	0.3	33	16.7	0.25	12.6	5
8012	OIL	68.3	11.24	1	1	1	12.5	0	0	12.6	7
8012	OIL	68.3	10.64	1	1	1	12.5	0	0	12.6	7
8012	OIL	68.3	9.67	1	1	1	12.5	0	0	12.6	7
8012	OIL	68.3	10.13	1	1	1	12.5	0	0	12.6	7
8012	OIL	68.3	13.24	1	1	1	12.5	0	0	12.6	7
8012	OIL	68.3	9.83	1	1	1	12.5	0	0	12.6	7
8012	OIL	68.3	9.08	1	1	1	12.5	0	0	12.6	7
8012	OIL	68.3	9.71	1	1	1	12.5	0	0	12.6	7
3168	OIL	65.8	9.05	1	1	1	12.5	0	0	12.6	7
3168	OIL	65.8	9.23	1	1	1	12.5	0	0	12.6	7
1573	OIL	65	12.76	1	1	1	12.5	0	0	12.6	7
1573	OIL	65	12.87	1	1	1	12.5	0	0	12.6	7
1573	OIL	65	9.49	1	1	1	12.5	0	0	12.6	7
1573	OIL	65	10.90	1	1	1	12.5	0	0	12.6	7
1556	OIL	53.1	12.84	1	1	1	12.5	0	0	12.6	7
1556	OIL	53.1	16.67	1	1	1	12.5	0	0	12.6	7
1556	OIL	53.1	14.18	1	1	1	12.5	0	0	12.6	7
1556	OIL	53.1	16.63	1	1	1	12.5	0	0	12.6	7
3132	OIL	53.1	17.25	1	1	1	12.5	0	0	12.6	7
2385	OIL	53	17.41	1	1	1	12.5	0	0	12.6	7
2385	OIL	53	15.37	1	1	1	12.5	0	0	12.6	7
2385	OIL	53	16.23	1	1	1	12.5	0	0	12.6	7
2385	OIL	53	17.33	1	1	1	12.5	0	0	12.6	7
2390	OIL	53	18.57	1	1	1	12.5	0	0	12.6	7
2399	OIL	41.8	16.92	1	1	1	12.5	0	0	12.6	7
2399	OIL	41.8	16.95	1	1	1	12.5	0	0	12.6	7
2399	OIL	41.8	16.41	1	1	1	12.5	0	0	12.6	7
2399	OIL	41.8	16.96	1	1	1	12.5	0	0	12.6	7
2399	OIL	41.8	16.95	1	1	1	12.5	0	0	12.6	7
2399	OIL	41.8	16.92	1	1	1	12.5	0	0	12.6	7
2399	OIL	41.8	16.96	1	1	1	12.5	0	0	12.6	7
2399	OIL	41.8	16.79	1	1	1	12.5	0	0	12.6	7
2410	OIL	41.8	21.36	1	1	1	12.5	0	0	12.6	7

OrisID	Gen Fuel	GenName Capac	GenHeat Rate	MinDown Time	MinUp Time	Ramp Rate	StartUp FixedCost	StartUp Fuel	PlantMin Output	GenFuel CostOnly	Gen VarOM
1571	OIL	35	7.36	1	1	1	12.5	0	0	12.6	7
3111	OIL	27	14.60	1	1	1	12.5	0	0	12.6	7
3111	OIL	27	15.06	1	1	1	12.5	0	0	12.6	7
3112	OIL	27	20.96	1	1	1	12.5	0	0	12.6	7
6776	OIL	27	13.69	1	1	1	12.5	0	0	12.6	7
3096	OIL	25.5	31.19	1	1	1	12.5	0	0	12.6	7
1559	OIL	25	8.67	1	1	1	12.5	0	0	12.6	7
1559	OIL	25	8.67	1	1	1	12.5	0	0	12.6	7
3160	OIL	21.2	14.98	1	1	1	12.5	0	0	12.6	7
3161	OIL	21.2	13.65	1	1	1	12.5	0	0	12.6	7
3161	OIL	21.2	13.65	1	1	1	12.5	0	0	12.6	7
3162	OIL	21.2	229.43	1	1	1	12.5	0	0	12.6	7
3162	OIL	21.2	229.43	1	1	1	12.5	0	0	12.6	7
3162	OIL	21.2	229.43	1	1	1	12.5	0	0	12.6	7
3163	OIL	21.2	13.94	1	1	1	12.5	0	0	12.6	7
3163	OIL	21.2	13.94	1	1	1	12.5	0	0	12.6	7
3163	OIL	21.2	13.94	1	1	1	12.5	0	0	12.6	7
3169	OIL	21.2	15.41	1	1	1	12.5	0	0	12.6	7
1557	OIL	20.7	16.41	1	1	1	12.5	0	0	12.6	7
1557	OIL	20.7	16.41	1	1	1	12.5	0	0	12.6	7
1557	OIL	20.7	16.41	1	1	1	12.5	0	0	12.6	7
1557	OIL	20.7	16.41	1	1	1	12.5	0	0	12.6	7
3110	OIL	20	32.09	1	1	1	12.5	0	0	12.6	7
3110	OIL	20	32.09	1	1	1	12.5	0	0	12.6	7
3110	OIL	20	32.09	1	1	1	12.5	0	0	12.6	7
3113	OIL	20	9.93	1	1	1	12.5	0	0	12.6	7
3114	OIL	20	36.08	1	1	1	12.5	0	0	12.6	7
3109	OIL	19.6	38.13	1	1	1	12.5	0	0	12.6	7
594	OIL	18.6	9.75	1	1	1	12.5	0	0	12.6	7
1564	OIL	18.6	16.72	1	1	1	12.5	0	0	12.6	7
3157	OIL	18.6	15.59	1	1	1	12.5	0	0	12.6	7
3157	OIL	18.6	15.59	1	1	1	12.5	0	0	12.6	7
3157	OIL	18.6	15.59	1	1	1	12.5	0	0	12.6	7
3160	OIL	18.6	14.98	1	1	1	12.5	0	0	12.6	7
3160	OIL	18.6	14.98	1	1	1	12.5	0	0	12.6	7
3160	OIL	18.6	14.98	1	1	1	12.5	0	0	12.6	7
3161	OIL	18.6	13.65	1	1	1	12.5	0	0	12.6	7
3161	OIL	18.6	13.65	1	1	1	12.5	0	0	12.6	7
3169	OIL	18.6	29.49	1	1	1	12.5	0	0	12.6	7
3170	OIL	18.6	13.53	1	1	1	12.5	0	0	12.6	7
3170	OIL	18.6	13.53	1	1	1	12.5	0	0	12.6	7
3170	OIL	18.6	13.53	1	1	1	12.5	0	0	12.6	7
3170	OIL	18.6	13.53	1	1	1	12.5	0	0	12.6	7
2399	OIL	18.5	9.51	1	1	1	12.5	0	0	12.6	7
2409	OIL	18.5	31.19	1	1	1	12.5	0	0	12.6	7
3142	OIL	18.5	14.24	1	1	1	12.5	0	0	12.6	7
3142	OIL	18.5	14.24	1	1	1	12.5	0	0	12.6	7
3147	OIL	18.5	14.44	1	1	1	12.5	0	0	12.6	7
3154	OIL	18.5	14.06	1	1	1	12.5	0	0	12.6	7
3154	OIL	18.5	14.06	1	1	1	12.5	0	0	12.6	7
1573	OIL	18	9.24	1	1	1	12.5	0	0	12.6	7
1573	OIL	18	9.24	1	1	1	12.5	0	0	12.6	7
3113	OIL	18	9.93	1	1	1	12.5	0	0	12.6	7
3115	OIL	18	10.11	1	1	1	12.5	0	0	12.6	7
3115	OIL	18	10.11	1	1	1	12.5	0	0	12.6	7
50628	OIL	18	16.88	1	1	1	33	16.7	0.95	12.6	0
1552	OIL	16	10.96	1	1	1	12.5	0	0	12.6	7
1554	OIL	16	10.07	1	1	1	12.5	0	0	12.6	7
1571	OIL	16	10.82	1	1	1	12.5	0	0	12.6	7
1572	OIL	16	9.73	1	1	1	12.5	0	0	12.6	7
3139	OIL	16	16.10	1	1	1	12.5	0	0	12.6	7
3139	OIL	16	16.10	1	1	1	12.5	0	0	12.6	7

OrisID	Gen Fuel	GenName Capac	GenHeat Rate	MinDown Time	MinUp Time	Ramp Rate	StartUp FixedCost	StartUp Fuel	PlantMin Output	GenFuel CostOnly	Gen VarOM
3139	OIL	16	16.10	1	1	1	12.5	0	0	12.6	7
3139	OIL	16	16.10	1	1	1	12.5	0	0	12.6	7
3143	OIL	16	16.60	1	1	1	12.5	0	0	12.6	7
3143	OIL	16	16.60	1	1	1	12.5	0	0	12.6	7
3143	OIL	16	16.60	1	1	1	12.5	0	0	12.6	7
3143	OIL	16	16.60	1	1	1	12.5	0	0	12.6	7
3144	OIL	16	16.41	1	1	1	12.5	0	0	12.6	7
3144	OIL	16	16.41	1	1	1	12.5	0	0	12.6	7
3146	OIL	16	16.03	1	1	1	12.5	0	0	12.6	7
3146	OIL	16	16.03	1	1	1	12.5	0	0	12.6	7
3155	OIL	16	17.13	1	1	1	12.5	0	0	12.6	7
3155	OIL	16	17.13	1	1	1	12.5	0	0	12.6	7
4257	OIL	6.3	44.41	1	1	1	33	0	0.95	12.6	3
4257	OIL	6.3	44.41	1	1	1	33	0	0.95	12.6	3
4257	OIL	6.2	44.41	1	1	1	33	0	0.95	12.6	3
4257	OIL	6.2	44.41	1	1	1	33	0	0.95	12.6	3
1580	OIL	5.6	23.21	1	1	1	33	0	0.95	12.6	3
1580	OIL	5.6	23.21	1	1	1	33	0	0.95	12.6	3
4257	OIL	5.4	44.41	1	1	1	12.5	0	0	12.6	7
4257	OIL	5.4	44.41	1	1	1	12.5	0	0	12.6	7
1580	OIL	4.1	23.21	1	1	1	33	0	0.95	12.6	3
1580	OIL	3.8	23.21	1	1	1	33	0	0.95	12.6	3
1580	OIL	3.5	23.21	1	1	1	33	0	0.95	12.6	3
3138	OIL	3.2	11.33	1	1	1	33	0	0.95	12.6	3
1580	OIL	3	23.21	1	1	1	33	0	0.95	12.6	3
3136	OIL	3	9.48	1	1	1	33	0	0.95	12.6	3
3136	OIL	3	9.48	1	1	1	33	0	0.95	12.6	3
3136	OIL	3	9.48	1	1	1	33	0	0.95	12.6	3
3136	OIL	3	9.48	1	1	1	33	0	0.95	12.6	3
1580	OIL	2.5	23.21	1	1	1	33	0	0.95	12.6	3
1580	OIL	2.5	23.21	1	1	1	33	0	0.95	12.6	3
6565	OIL	2.5	13.64	1	1	1	33	0	0.95	12.6	3
2378	OIL	2	10.82	1	1	1	33	0	0.95	12.6	3
2378	OIL	2	10.82	1	1	1	33	0	0.95	12.6	3
2378	OIL	2	10.82	1	1	1	33	0	0.95	12.6	3
2378	OIL	2	10.82	1	1	1	33	0	0.95	12.6	3
58172	OIL	2	19.37	1	1	1	33	0	0.95	12.6	3
58172	OIL	2	19.37	1	1	1	33	0	0.95	12.6	3
58172	OIL	2	19.37	1	1	1	33	0	0.95	12.6	3
56294	OTHER	11.2	9.76	1	1	1	33	16.7	0.95	0	0
SOLAGG	SOL	325.9	0.00	1	1	1	0	0	0	0	0
WIND AGG	WND	1473.6	0.00	1	1	1	0	0	0	0	0

Appendix C

MATLAB Code for EV Demand

The MATLAB code used to generate an EV demand profile is included in this section. The code included was used to generate Scenario 1, with a market penetration of 0.2. The code was modified to generate the EV demand for Scenario 2 and 3, and for market penetrations of 0.5 and 1.0.

```
clear, close all

cars=12723142;
MP=0.2;
ev=MP*cars;      %number of EVs

plugin = 20;    %plug in time (8:00 pm)
unplug = 9;     %unplug time  (9:00 am)

charge_rate = 3.3;    %[kW]


%%%%%%%%%%%%Adjustments for Day and Season%%%%%%%%%%%%%%%%
dAvgDay    = 29.17143;
dMonday    = dAvgDay*(30.1/dAvgDay);   %[miles/day]
dTuesday   = dAvgDay*(30.2/dAvgDay);   %[miles/day]
dWednesday = dAvgDay*(32.0/dAvgDay);   %[miles/day]
dThursday  = dAvgDay*(32.9/dAvgDay);   %[miles/day]
dFriday    = dAvgDay*(28.2/dAvgDay);   %[miles/day]
dSaturday  = dAvgDay*(25.8/dAvgDay);   %[miles/day]
dSunday    = dAvgDay*(25.0/dAvgDay);   %[miles/day]

dAvgQ  = 29.075;
dQ1    = dAvgQ*(25.7/dAvgQ);  %[miles/day] Jan - March
dQ2    = dAvgQ*(29.9/dAvgQ);  %[miles/day] April - June
dQ3    = dAvgQ*(30.6/dAvgQ);  %[miles/day] July - Sept
dQ4    = dAvgQ*(30.1/dAvgQ);  %[miles/day] Oct - Dec
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%Electricity Used in a Day%%%%%%%%%%%%%
c_rate = 0.2*(1/0.621371);    %[kWh/mile] Consumption Rate

AvgDay    = dAvgDay*c_rate;
Monday    = dMonday*c_rate;  %[kWh/day]
Tuesday   = dTuesday*c_rate;  %[kWh/day]
Wednesday = dWednesday*c_rate;   %[kWh/day]
Thursday  = dThursday*c_rate;   %[kWh/day]
Friday    = dFriday*c_rate;  %[kWh/day]
Saturday  = dSaturday*c_rate;   %[kWh/day]
Sunday    = dSunday*c_rate;  %[kWh/day]

AvgQ  = dAvgQ*c_rate;
Q1    = dQ1*c_rate;  %[kWh/day] Jan - March
```

```
Q2    = dQ2*c_rate;  %[KWh/day] April - June
Q3    = dQ3*c_rate;  %[kWh/day] July - Sept
Q4    = dQ4*c_rate;  %[kWh/day] Oct - Dec
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

demand = zeros(1,168);

for i = 1:1:168
    hour(i) = i;
    if i <= unplug
        demand(i) = charge_rate*ev;
    else if i >= plugin && i <= (unplug+24)
        if Monday >= charge_rate
            demand(i) = charge_rate*ev;
        else if Monday > 0 && Monday < charge_rate
            demand(i) = Monday*ev;
        else
            demand(i) = 0;
            end
        end
        Monday = Monday - charge_rate;
    else if i >= (plugin+24) && i <= (unplug+48)
        if Tuesday >= charge_rate
            demand(i) = charge_rate*ev;
        else if Tuesday > 0 && Tuesday < charge_rate
            demand(i) = Tuesday*ev;
        else
            demand(i) = 0;
            end
        end
        Tuesday = Tuesday - charge_rate;
    else if i >= (plugin+48) && i <= (unplug+72)
        if Wednesday >= charge_rate
            demand(i) = charge_rate*ev;
        else if Wednesday > 0 && Wednesday < charge_rate
            demand(i) = Wednesday*ev;
        else
            demand(i) = 0;
            end
        end
        Wednesday = Wednesday - charge_rate;
    else if i >= (plugin+72) && i <= (unplug+96)
        if Thursday >= charge_rate
            demand(i) = charge_rate*ev;
        else if Thursday > 0 && Thursday < charge_rate
            demand(i) = Thursday*ev;
        else
            demand(i) = 0;
            end
        end
        Thursday = Thursday - charge_rate;
    else if i >= (plugin+96) && i <= (unplug+120)
        if Friday >= charge_rate
            demand(i) = charge_rate*ev;
        else if Friday > 0 && Friday < charge_rate
            demand(i) = Friday*ev;
        else
            demand(i) = 0;
            end
        end
        Friday = Friday - charge_rate;
```

```
    else if i >= (plugin+120) && i <= (unplug+144)
        if Saturday >= charge_rate
            demand(i) = charge_rate*ev;
        else if Saturday > 0 && Saturday < charge_rate
            demand(i) = Saturday*ev;
        else
            demand(i) = 0;
            end
        end
        Saturday = Saturday - charge_rate;
    else if i >= (plugin+144)
        if Sunday >= charge_rate
            demand(i) = charge_rate*ev;
        else if Sunday > 0 && Sunday < charge_rate
            demand(i) = Sunday*ev;
        else
            demand(i) = 0;
            end
        end
        Sunday = Sunday - charge_rate;
    else
        demand(i) = 0;


        end
        end
        end
        end
        end
        end
        end
    end
end

for j = 1:1:unplug
    hour(j) = j;
    if j <= unplug
        if Sunday >= charge_rate
            demand(j) = charge_rate*ev;
        else if Sunday > 0 && Sunday < charge_rate
            demand(j) = Sunday*ev;
        else
            demand(j) = 0;
            end
        end
        Sunday = Sunday - charge_rate;
    end
end

h1 = figure(1);
set(h1,'Name','LatVel')
p1=plot(hour,demand);
axis([0 168 (-1*10^6) (9*10^6)])
xlabel('Time (hour)'); ylabel('EV Demand (kW)');
ax=gca;
ax.XTick = 0:24:168;
```

BIBLIOGRAPHY

[1] M. Nikowitz, *Fully Autonomous Vehicles: Visions of the future or still reality?* epubli, 2015.
[2] J. Cobb, “Chevy Bolt Production Confirmed For 2016,” *HybridCars.com*, 02-Oct-2015. .
[3] “2016 Focus Electric | View Focus Electric Highlights | Ford.com.” [Online]. Available: http://www.ford.com/cars/focus/trim/electric/. [Accessed: 13-Nov-2016].
[4] “Nissan LEAF® Electric Car: 100% Electric. 100% Fun.,” *Nissan USA*. [Online]. Available: http://www.nissanusa.com/electric-cars/leaf. [Accessed: 13-Nov-2016].
[5] “Tesla.” [Online]. Available: https://www.tesla.com/. [Accessed: 12-Nov-2016].
[6] B. Müller and G. Meyer, *Electric Vehicle Systems Architecture and Standardization Needs: Reports of the PPP European Green Vehicles Initiative*. Springer, 2015.
[7] T. Triplett, R. Santos, and S. Rosenbloom, “American Driving Survey: Methodology and Year One Results, May 2013 – May 2014,” AAA Foundation for Traffic Safety, Washington D.C., Apr. 2015.
[8] P. Cazzola and M. Gorner, “Global EV Outlook 2016,” International Energy Agency, Paris, 2016.
[9] R. Liu, L. Dow, and E. Liu, “A survey of PEV impacts on electric utilities,” in *Innovative Smart Grid Technologies (ISGT), 2011 IEEE PES*, 2011, pp. 1–8.
[10] L. Gan, U. Topcu, and S. H. Low, “Optimal decentralized protocol for electric vehicle charging,” *IEEE Trans. Power Syst.*, vol. 28, no. 2, pp. 940–951, May 2013.
[11] S. Srinivasaraghavan and A. Khaligh, “Time Management,” *IEEE Power Energy Mag.*, vol. 9, no. 4, pp. 46–53, Jul. 2011.
[12] H. Petroski, *The Road Taken: The History and Future of America’s Infrastructure*. Bloomsbury Publishing USA, 2016.
[13] J. Voelcker, “Tesla boosts Supercharger electric-car charging rate to 145 kw,” *Green Car Reports*. [Online]. Available: http://www.greencarreports.com/news/1105234_tesla-boosts-supercharger-electric-car-charging-rate-to-145-kw. [Accessed: 12-Nov-2016].
[14] U. S. D. O. Energy, *National Transmission Grid Study*. General Books, 2011.
[15] *Code of Federal Regulations, Title 18, Conservation of Power and Water Resources: Pt. 1-399, Revised As of April 1 2011*. Government Printing Office, 2011.
[16] “PJM - PJM History.” [Online]. Available: http://www.pjm.com/about-pjm/who-we-are/pjm-history.aspx. [Accessed: 12-Nov-2016].
[17] “PJM - Territory Served.” [Online]. Available: http://www.pjm.com/about-pjm/who-we-are/territory-served.aspx. [Accessed: 12-Nov-2016].
[18] Z. Liu, *Ultra-High Voltage AC/DC Grids*. Academic Press, 2014.
[19] F. P. Sioshansi, *Competitive Electricity Markets: Design, Implementation, Performance*. Elsevier, 2011.
[20] J. Zhu, *Optimization of Power System Operation*. John Wiley & Sons, 2014.
[21] A. A. Sallam and O. P. Malik, *Electric Distribution Systems*. Wiley, 2012.
[22] R.-C. Leou, C.-L. Su, and C.-N. Lu, “Stochastic Analyses of Electric Vehicle Charging Impacts on Distribution Network,” *IEEE Trans. Power Syst.*, vol. 29, no. 3, pp. 1055–1063, May 2014.
[23] J. de Hoog, T. Alpcan, M. Brazil, D. A. Thomas, and I. Mareels, “Optimal Charging of Electric Vehicles Taking Distribution Network Constraints Into Account,” *IEEE Trans. Power Syst.*, vol. 30, no. 1, pp. 365–375, Jan. 2015.
[24] D. Steen, L. A. Tuan, O. Carlson, and L. Bertling, “Assessment of Electric Vehicle Charging Scenarios Based on Demographical Data,” *IEEE Trans. Smart Grid*, vol. 3, no. 3, pp. 1457–1468, Sep. 2012.

[25] C. L. Su, R. C. Leou, K. Z. Chuang, and C. N. Lu, "Power quality measurement and analysis for electric vehicle charging," *Proc 33rd Symp Electr. Eng.*, 2012.
[26] S. Rahman and G. B. Shrestha, "An investigation into the impact of electric vehicle load on the electric utility distribution system," *IEEE Trans. Power Deliv.*, vol. 8, no. 2, pp. 591–597, Apr. 1993.
[27] C. Gerkensmeyer, M. Kintner-Meyer, and J. DeSteese, "Technical Challenges of Plug-In Hybrid Electric Vehicles and Impacts to the US Power System: Distribution System Analysis," *Pac. Northwest Natl. Lab.*, Jan. 2010.
[28] J. A. P. Lopes, F. J. Soares, and P. M. R. Almeida, "Integration of Electric Vehicles in the Electric Power System," *Proc. IEEE*, vol. 99, no. 1, pp. 168–183, Jan. 2011.
[29] M. A. S. Masoum, P. S. Moses, and S. Hajforoosh, "Distribution transformer stress in smart grid with coordinated charging of Plug-In Electric Vehicles," in *2012 IEEE PES Innovative Smart Grid Technologies (ISGT)*, 2012, pp. 1–8.
[30] J. de Hoog *et al.*, "Electric vehicle charging and grid constraints: Comparing distributed and centralized approaches," in *2013 IEEE Power Energy Society General Meeting*, 2013, pp. 1–5.
[31] L. Kelly, A. Rowe, and P. Wild, "Analyzing the impacts of plug-in electric vehicles on distribution networks in British Columbia," in *2009 IEEE Electrical Power Energy Conference (EPEC)*, 2009, pp. 1–6.
[32] C. Roe, E. Farantatos, J. Meisel, A. P. Meliopoulos, and T. Overbye, "Power System Level Impacts of PHEVs," in *42nd Hawaii International Conference on System Sciences, 2009. HICSS '09*, 2009, pp. 1–10.
[33] K. Clement, E. Haesen, and J. Driesen, "Coordinated charging of multiple plug-in hybrid electric vehicles in residential distribution grids," in *Power Systems Conference and Exposition, 2009. PSCE '09. IEEE/PES*, 2009, pp. 1–7.
[34] P. Denholm, *An evaluation of utility system impacts and benefits of optimally dispatched plug-in hybrid electric vehicles*, Revised. Golden, Colo. : National Renewable Energy Laboratory, 2006.
[35] A. Ipakchi and F. Albuyeh, "Grid of the future," *IEEE Power Energy Mag.*, vol. 7, no. 2, pp. 52–62, Mar. 2009.
[36] W. Kempton and J. Tomić, "Vehicle-to-grid power fundamentals: Calculating capacity and net revenue," *J. Power Sources*, vol. 144, no. 1, pp. 268–279, Jun. 2005.
[37] S. Bergman, "Plug-in Hybrider: Elhybridfordon för Framtiden," *Elforsk Tech Rep*.
[38] Z. Ma, D. S. Callaway, and I. A. Hiskens, "Decentralized Charging Control of Large Populations of Plug-in Electric Vehicles," *IEEE Trans. Control Syst. Technol.*, vol. 21, no. 1, pp. 67–78, Jan. 2013.
[39] D. M. Lemoine, D. M. Kammen, and A. E. Farrell, "An innovation and policy agenda for commercially competitive plug-in hybrid electric vehicles," *Environ. Res. Lett.*, vol. 3, no. 1, p. 14003, 2008.
[40] F. Koyanagi and Y. Uriu, "Modeling power consumption by electric vehicles and its impact on power demand," *Electr. Eng. Jpn.*, vol. 120, no. 4, pp. 40–47, Sep. 1997.
[41] N. P. Padhy, "Unit commitment-a bibliographical survey," *IEEE Trans. Power Syst.*, vol. 19, no. 2, pp. 1196–1205, May 2004.
[42] "FACT SHEET: Obama Administration Announces Federal and Private Sector Actions to Accelerate Electric Vehicle Adoption in the United States," *whitehouse.gov*, 21-Jul-2016. [Online]. Available: https://www.whitehouse.gov/the-press-office/2016/07/21/fact-sheet-obama-administration-announces-federal-and-private-sector. [Accessed: 13-Nov-2016].
[43] D. Beeton and G. Meyer, *Electric Vehicle Business Models: Global Perspectives*. Springer, 2014.
[44] R. F. Aguilera and M. Radetzki, *The Price of Oil*. Cambridge University Press, 2015.
[45] *Impact of Lower Oil Prices on Renewable Energy Technologies*. World Bank Publications.
[46] E. Allen and M. Ilic, *Price-Based Commitment Decisions in the Electricity Market*. Springer Science & Business Media, 2012.
[47] "GAMS Home Page." [Online]. Available: http://www.gams.com/. [Accessed: 13-Nov-2016].

[48] "EIA - Electricity Data." [Online]. Available: https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_6_07_b. [Accessed: 17-Nov-2016].
[49] "U.S. Energy Information Administration (EIA)." [Online]. Available: https://www.eia.gov/. [Accessed: 17-Nov-2016].
[50] "PJM - Estimated Hourly Load." [Online]. Available: http://www.pjm.com/markets-and-operations/energy/real-time/loadhryr.aspx. [Accessed: 17-Nov-2016].
[51] M. M. Begovic, *Electrical Transmission Systems and Smart Grids: Selected Entries from the Encyclopedia of Sustainability Science and Technology*. Springer Science & Business Media, 2012.
[52] "Paris Agreement - European Commission." [Online]. Available: https://ec.europa.eu/clima/policies/international/negotiations/paris/index_en.htm. [Accessed: 13-Nov-2016].
[53] "Energy," *Donald J. Trump for President, Inc.* [Online]. Available: https://www.donaldjtrump.com/policies/energy. [Accessed: 13-Nov-2016].
[54] "Energy Independence," *www.greatagain.gov*, 18-Oct-2016. [Online]. Available: https://www.greatagain.gov/policy/energy-independence.html. [Accessed: 18-Nov-2016].
[55] J. C. Stephens, E. J. Wilson, and T. R. Peterson, *Smart Grid (R)Evolution*. Cambridge University Press, 2015.
[56] Q. Wu, *Grid Integration of Electric Vehicles in Open Electricity Markets*. John Wiley & Sons, 2013.
[57] "Office of Highway Policy Information - State Motor-Vehicle Registrations - 2010," *U.S. Federal Highway Administration*, 2010. [Online]. Available: https://www.fhwa.dot.gov/policyinformation/statistics/2010/mv1.cfm. [Accessed: 14-Sep-2016].
[58] A. Pesaran, "Battery Requirements for Plug-In Hybrid Electric Vehicles – Analysis and Rationale," presented at the National Renewable Energy Laboratory, Golden, Colorado, 02-Dec-2007.
[59] G. Schuh, R. Neugebauer, and E. Uhlmann, *Future Trends in Production Engineering: Proceedings of the First Conference of the German Academic Society for Production Engineering (WGP), Berlin, Germany, 8th-9th June 2011*. Springer Science & Business Media, 2012.
[60] "Transportation Electrification - A Technology Overview, Final Report," EPRI, Jul. 2011.
[61] M. Craig, E. McDonald-Buller, and M. Webster, "Technology Adoption under Time Differentiated Market-Based Instruments for Pollution Control," *Energy Econ.*, vol. (in press), 2016.
[62] "National Electric Transmission Congestion Study," U.S. Department of Energy, Washington D.C., Sep. 2015.

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Education

The Pennsylvania State University
Majors: B.S. in Energy Engineering and B.S. in Energy Business and Finance
Honors: Energy Engineering

Thesis Title: Impact of Increased Market Penetration of Electric Vehicles on the PJM Regional Electric Grid
Thesis Supervisor: Dr. Mort Webster

Work Experience

Summer of 2016
Sustainability Intern
Analyzed market outlook and regional grid emissions factors for the primary production of steel and competing materials for U.S. market in the wake of Chinese overproduction. Evaluated EPDs and LCAs to address sustainability campaigns of competing materials.
American Iron and Steel Institute (Greentree, PA)
Supervisor: Mark Thimons

Summer of 2015
Energy Intern
Organized a comprehensive analysis and review of the NELC Home Energy Assessment program in between its funding phases, including interviewing homeowners and program leaders.
The Penn State Center Pittsburgh (Pittsburgh, PA)
Supervisor: Deno De Ciantis

Summers of 2013 and 2014
Summer Intern
Performed or assisted with operations such as traffic signal inspections and maintenance, stormwater outfall testing, GIS mapping, road paving and line striping, and PA One Call locating.
Monroeville Municipality – Building and Engineering Department (Monroeville, PA)
Supervisor: Paul Hugus

Professional Memberships: Society of Energy Engineers

Language Proficiency: English, Spanish