Electrical Distribution System Tolerance to Electrical Vehicle Proliferation

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Abstract

Driven by the increasing price of crude oil, incentives and an improving economy, the electric vehicle market is forecasted to proliferate in the near to mid-term. In addition to this trend, the consumer energy demand will also increase in parallel with the electric vehicle proliferation. The positive growth of both markets denotes the impending inadequacy of the current grid technology. There will be a point that the current grid feeder will be unable to meet the growing demand of the residential customers and electric vehicles. In fact the demand will exceed the maximum allowable thermal level that a feeder can withstand; thus, the feeder will overheat and fail.

There is a pressing need for a solution to be implemented that can rectify the inevitable failure of the current technology. By establishing an accurate model of a typical New England feeder that supplies power to residential customers and electric vehicles various situations can be tested. The results of these tests can be leveraged to prove the need of a solution as well as determine the best possible solution.

Executive Summary

The price of crude oil is increasing driving consumers to be conscious of their fuel consumption [9]. Additionally, it is increasing the demand for more compact and fuel efficient vehicles. Also, there are incentives in place promoting fuel efficient vehicles. Both of these factors, as well as an improving economy are driving the electric vehicle market to proliferate in the near to mid-term. In addition to this trend, the consumer energy demand will also increase over time [5]. With both of these markets forecasted to increase over time there is an impending issue. The positive growth of both consumer demand and the number of electric vehicles denotes the inevitable inadequacy of the current grid technology. There will be a tipping point when the current grid feeders will be unable to meet the demand of the residential customers and electric vehicles. In fact the demand will exceed the maximum allowable amount that a feeder can withstand; thus, the feeder will overheat and fail [11].

It is necessary to establish a solution to supplement the current grid feeders in order to avoid the possibility of failure. The most costly option is to build and install new transmission lines and feeders. This is not ideal given time constraints and the high capital investment needed [10]. A more alluring concept is grouping. This is a technique the utilities can use to monitor the demand on the feeder by controlling when electric vehicles charge. This solution is viable, but it can only work to a point. When there are too many electric vehicles demanding power, there will not be enough time or power from the feeder to deviate the charge times for all the electric vehicles that are trying to charge. The third option is to supplement the feeder with an energy storage device. This allows power to be pulled from this additional source at peak demand times. Additionally, the energy storage device can be charge via alternative

resources, such as photovoltaic, making it independent of the grid. This is an optimal long term solution.

In order to prove the necessity of a solution as well as the feasibility of each, a base model needs to be established. This base model is based on a typical New England feeder that supplies power to residential customers and electric vehicles via a transmission line. Once this model's functionality is verified it can be leveraged to simulate various situations. For each simulation the value of focus is the feeders' allowable maximum current and power. For a typical feeder the maximum current it can handle is 400 A and the maximum power it can withstand is 10 MW [11]. For each case tested these values are determined to indicate how the feeder is being affected. If the feeders current or the power demanded reach the maximum values, it indicates that the feeder is inadequate for the given load because it is at its thermal limit.

The first situation of interest is an increasing residential demand over time. For this three cases of growth are examined: 1%, 2% and 3% increase per year. The effect of this increasing demand is forecasted over a span of 10 years. For each case and each year a simulation in PSpice, an analog and digital logic simulation program, was created to determine the feeder current at that point. Once all the cases and values of the current were determined, a trend could be established. From the results it was apparent that as the residential customer demand increased with time, so did the feeder current. Thus, given enough time, there will be a point that the residential customer demand has increased enough to drive the feeder current to and past its maximum limit of 400 A.

The second condition that needed to be examined was the effect of electric vehicles on the feeder. For this, the residential customer demand was held constant to solely observe how the electric vehicles affected the feeder. Similar to the first situation, three cases of growth were used, 1%, 2% and 3% per year, as well as a span of 10 years. Additionally, for each case and each year a simulation was created and ran on PSpice to determine the value of the feeder current at that point. Once curves were established from the measured data, it was determined that as the number of electric vehicles increased over time so did the feeder current. Thus, with enough time to proliferate the electric vehicle market will eventually drive the feeder current past 400 A.

To model the most realistic situation, it was necessary to observe how the feeder would be affected when both the residential customer demand and the number of electric vehicles increased with time. Both demands increased at the three cases of growth: 1%, 2% and 3% per year. Also, a span of ten years was used. With both markets increasing the feeder current increased over time at an exponential rate which drove the current past the maximum 400A within the observed time. Even with the most conservative rate of growth at 1%, the current was determined to reach and exceed the maximum thermal level within the 10 year forecast. Thus, it is clear that it is imperative that a solution be implemented, so that the current feeders not reach this limit and fail.

Before testing the possible solutions, it is necessary to establish a characteristic curve of the daily power demand for residential customers and electric vehicles. Based on a typical Massachusetts feeder a daily residential customer demand curve was established. A typical charging period for electric vehicles was assumed. Typical consumers will charge their electric vehicles overnight. With this the demand of electric vehicles and residential customers could be established. These demand curves were leveraged to test the viability of the posed solutions. The demand was driven to the maximum feeder power limit of 10 MW, so that when the solutions were implemented it could be observed if the solution could drive the demand below the maximum limit. Thus, verifying its desired functionality.

The first solution that was tested was the technique of grouping. When applied to the established worst case scenario when the demand exceeds 10 MW, the grouping technique worked moderately well. After testing the grouping technique in various demand scenarios it was clear that grouping will only work to a point. When the residential customer and electric vehicle demand reaches a particular maximum level there will not be enough time nor power to charge all the electric vehicles demanding power.

The last solution tested was energy storage. For this a typical 1 MW community battery was used [3]. It was also modeled to be charged via photovoltaic. Given a typical photovoltaic charging cycle of a parabolic trend peaking at noon when the sun is at its highest point, the available power was determined. Once the amount of supplemental power was established, it was then distributed to the loads at peak times. Even at a worst case situation when the residential customer and electric vehicle demand exceeded 10 MW the energy storage proved viable. Additionally, it was not even necessary to use all of the batteries available to supplement the demand on the feeder. This alludes to the fact that energy storage is an ideal long term solution.

When all of the solutions were created and the necessary data was collected the optimal solutions were clear. Grouping is a feasible solution that should be implemented as a temporary solution. It can only work to a point and at this point energy storage can be applied as a long term solution.

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$$\omega = 2\pi f \quad (2)$$

$$L = \frac{X}{\omega} \quad (3)$$

$$S^2 = P^2 + Q^2 \quad (4)$$

$$PF = \frac{P}{S} \quad (5)$$

$$P = 3\left(\frac{V^2}{R}\right) \quad (6)$$

$$Q = 3\left(\frac{V^2}{X}\right) \quad (7)$$

Introduction

Driven by the increasing price of crude oil as well as incentives and an improving economy, the electric vehicle market is forecasted to proliferate over time [9]. In addition to this trend, consumer energy demand will also increase over time [5]. These trends will potentially culminate and create a significant challenge on the U.S. electrical grid. The positive growth of both portends the potential crash of the U.S. electrical grid when this trend reaches the tipping point. There will be a point that the current grid feeder will be unable to meet the demand of the residential customers and electric vehicles. In fact the demand will exceed the maximum allowable amount that a feeder can withstand; thus, the feeder will overheat and fail [11].

There is a need for an optimal solution to be implemented that can rectify the inevitable failure of the current technology. The most promising solutions are to supplement the feeders with energy storage devices that can provide power during peak times, lessoning the strain on the feeder. Additionally, the technique of grouping is a viable solution. Grouping allows the utility to control when the electric vehicles are charging, thus monitoring the demand. The third solution is to build new transmission lines and feeders; this is however the most costly option and not ideal.

In order to propose an optimal solution, it is necessary to create a test environment that can accurately model a typical New England feeder that supplies power to residential customers and electric vehicles [11]. The basis of this model can be found in Figure 1. The full model circuit has many more residential customer cells because a typical feeder has upwards of

2000 customers. Once this model is tested and its functionality is verified it can be used to test various situations.

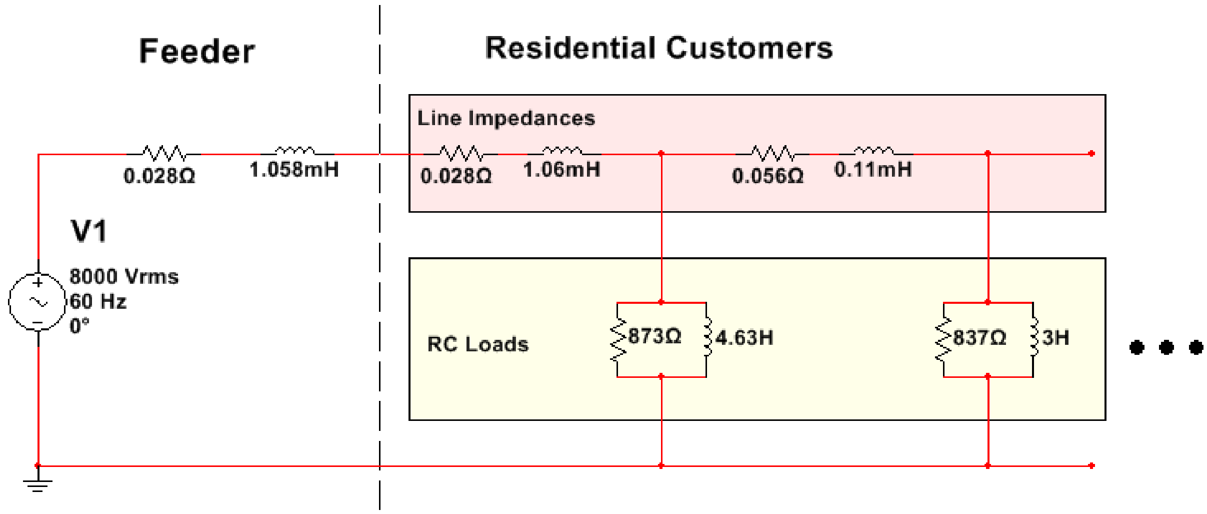

Figure 1: Base Model Circuit

It is necessary to examine the effect of an increasing residential demand as well as an increasing number of electric vehicles have on the feeder. Also, given a worst case scenario, the possible solutions need to be tested to verify or disprove their viability. Once the necessary information is gathered an optimal solution can be determined.

Background

It is necessary to observe the driving variables for the electric power market as well as the electric vehicle market. Additionally, it is important to observe the trends and forecast for both markets.

Electric Power Demand

In the technological age that has emerged in the last 10 to 20 years, an ever increasing demand for electrical power has been at the forefront of commodity usage. Usage demands span across the household and personal sectors, as well as the corporate world; the United States simply could not function without the existence of the power grid providing electricity into the many facets of American livelihood [5]. However, it must be said that the power grid cannot produce an infinite amount of energy, and is limited in its output. As the capacity of the grid is neared, it is necessary to look to alternative methods to reduce electric usage and to enhance the method of electricity delivery to minimize inefficiencies.

Current State of Power Consumption

In an increasingly technological and electricity-centric age, coupled with a growing population, it is expected that the electricity consumption of the United States would be positively related to these trends. In the past twenty years, the trending consumption proved this assumption, averaging a 1.59% increase in kWh's consumed per annum. These trends can be observed in Table 1 that was established from data gathered from IBISWorld's Business Environment Profiles [5].

Table 1: US Percent Change in Kilowatt Hours per Annum

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
% Change	3.58	2.66	2.69	2.84	1.47	3.72	1.72	3.09	-1	2.1
Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
% Change	0.82	1.47	2.55	0.15	1.91	-0.7	-3.7	4.35	-0.8	2.82

Energy Consumption Trend Outliers

It should be noted that in the twenty year time frame illustrated in Table 1, the United States posted four years in which consumption dropped. When a trend should appear to be so positively related to population and technological innovation, it's important to analyze the outliers to understand why consumption dipped, as this consumption trend could have an even more powerfully related relationship with some other factor. In looking at the years in which consumption dropped from the year before (2001, 2008, 2009 and 2011) there is one factor that seems to link these, and explain why energy consumption followed suit; the country's economic status.

Financial analysts speculated several causes to a drop in the US economy in 2001, ending ten years of growth [7]. It was ascertained that the driving factor in the drop in gross domestic product (GDP) was in fact the Y2K bug. In 1999 and 2000, the fear of technological crashes led to a surge in sales of upgraded computers and software. Computers, with a determined 2 year useful life, saw a huge drop in sales in mid-2000 through the third quarter of 2001, due to the hyper-procurement in 1999 and 2000. As investors realized the computer industry was slowing down for the time being, they sold out their stocks and the dot com era experienced its first downturn, leading to a decline in the economy and people started making spending constraints, including paying closer attention to energy consumption.

The US experienced another recession in 2008 and 2009 which has been determined to be caused primarily by major issues in subprime mortgages [1]. Years of inflation drove mortgage interest rates down, making them very appealing to people with poor credit. However, these people were not able to pay them back, resulting in the massive surge in housing sales. With a high supply of homes on the market, prices plummeted, making foreclosures almost certain. This resulted in a screeching stop in the construction of both commercial and residential, rippling from this sector across the entire economy. Another major issue driving the US to recession were skyrocketing oil prices. Prices were driven upwards by the exponential oil demand growth from China, coupled with the fear of war in the Middle East. Higher costs in oil resulted in higher production cost, lowering profit margins unless prices rose; prices rising resulted in a decrease in consumption across the entire economy.

Lastly, in 2011, just as the US was battling its way to recovery from the 2008-2009 economic crisis, the Eurozone economic crisis was emerging, threatening to drag the US back into the hole it had just dug itself out of [8]. Greece, Spain, Portugal and Ireland all experienced an economic crisis created by overwhelming gross external debt exceeding their respective countries' GDP by up to 35%. This caused hyperinflation of debt in each of these countries, resulting in the debt being written down by as much as fifty cents to the dollar. This scare induced panic across the entire European Union and its central bank. This drove US exports to Europe down, as well as scared US investors away from foreign investment in US markets, threatening a "double-dip recession." Double dip recession refers to the fact that the US was emerging from its own housing bubble burst where financial institutions were feeling the full brunt of their mistakes in handing out subprime mortgages to poor credit owners. With a scare like this, investors are much more likely to pull out of the markets once again, as they would fear the effects of the European issues would strike the US economy, rendering the current reform useless. With the drop in exports to Europe, the US economy already stressed and even more tension from the European economy struggling, the U.S. power demand once again dipped below the previous year's level.

In each of these instances, the US economy was suffering, GDP was dropping and both the residential and commercial sectors were looking for a way to lower costs and save money. One of the first ways they looked to do this was through energy conservation. Once the economy picked back up, as the economy recovered, the energy consumption jumped as manufacturers and industrial producers once again were able to produce and sell.

Driving Factors of Energy Demand

As demonstrated, energy demand is relational to the health of the economy [13]. In an economic recession, the demand shrinks due to lack of interest in purchasing goods. The creation of these goods, from a manufacturing standpoint is heavily reliant on energy to run the production sites. Should productivity demands drop, so do the needs for energy. Worldwide, it is apparent that developing countries have a much higher rate of growth in energy demand to support major infrastructure overhaul and development, versus an already affluent country that is already developed (like the US), where there is no need for such an overhaul. This results in a lower rate of growth, but high energy consumption per capita.

Forecast of Energy Demand

Energy demand is expected to continue to rise, as the economy continues to recover from the 2008-2009 economic crises, and demand for production will continue to increase [5]. These trends can be found in Table 2, which was adapted from data from the IBISWorld database. However, it should be noted that the rate of growth in energy demand is expected to slow down starting after 2014. Though it cannot be guaranteed, there are speculations as to what would cause the decrease in energy use growth.

Table 2: US Percent Change in Kilowatt Hours per Annum

Year	2013	2014	2015	2016	2017	2018
% Change	1.79	2.79	2.53	2.11	1.28	-1.07

The first speculation is the increased interest in outsourcing manufacturing and production. As the price of energy, labor, and raw materials increase, it becomes easier for companies to consider outsourcing to other countries to meet their manufacturing needs at a fraction of the cost. With that, US companies save big on their production overhead, and lower their demand for energy consumption [5].

Another speculation is government regulation to promote energy efficiencies from energy generation, transmission, and usage. From a governmental perspective, these regulations are geared towards cutting down on emissions resulting from energy generation and usage [13]. Efficiencies are also being sought after by commercial and residential a like as a means of lowering energy costs. Newer devices and appliances that are labeled as energy efficient are sought after for both annual savings and tax incentives for the year of the purchase. Devices have also been created and scaled to a household level as a means of monitoring energy consumption and allow for individuals and families to cut back on unnecessary energy usage [5].

Electric Vehicle Demand

It is imperative to examine the electric vehicle market, to deduce the overall outlook for electric vehicles.

State of the Electric Vehicle Industry

The main drivers of the electric vehicle market are the price of crude oil, incentives and the state of the economy [9]. The projection of the world price of crude oil can be found in Figure 2. There has been a general trend of an increasing price of gasoline, which has led consumers to be more conscious of their fuel consumption. With the addition of lower disposable incomes, which came with a struggling economy, consumers have also been demanding smaller more fuel efficient vehicles. With this it can be concluded that as the cost of gasoline increases over time, this represents an opportunity for the electric vehicle market to proliferate.

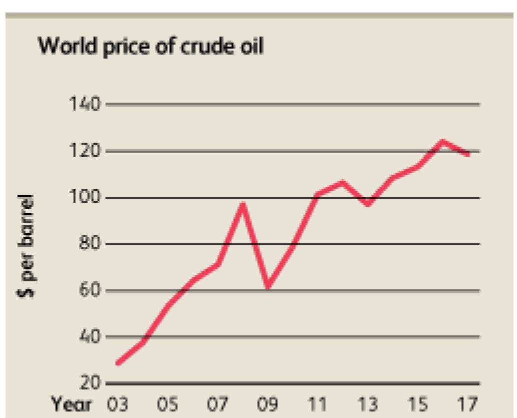

Figure 2: World Price of Cure Oil Per Year [9]

Unfortunately during the recession consumers have a lower disposable income, so they are less willing to make large purchases, such as automobiles [9]. In addition to this, car dealers have lower funds to stock their showrooms and have made cuts in purchasing electric vehicles. Without accessible electric vehicles consumer sentiment has dropped. As the economy improves the demand for electric vehicles will also increase.

Another driver for the electric vehicle market are tax credits and incentives for energy efficiency [2]. For the past five years consumers have received tax credits for purchasing electric vehicles. If these incentives are maintained or improved they will drive the growth of the electric vehicle market.

All of the discussed drivers contribute to the current state of the electric vehicle market. The industry has suffered with the difficult economic times; however it is forecast to grow significantly as the economy improves. The outlook of the industry revenue can be found in Figure 3. The revenue peaked when electric vehicles were introduced and became commercially available in the automobile industry. The revenue has plateaued mainly due to the state of the economy. However, as the price of crude oil continues to increase and the economy continues to improve, the electric vehicle market has a great opportunity to proliferate.

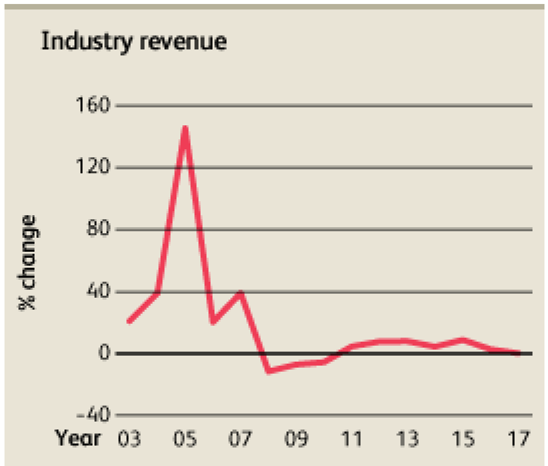

Figure 3: Electric Vehicle Industry Revenue per Year

Forecast of Electric Vehicle Market

Considering all the drivers for the electric vehicle market Frost and Sullivan constructed a reasonable forecast of the market [4]. The forecast can be found in Figure 4.Three cases of growth are illustrated, conservative to optimistic. It is clear that in time the electric vehicle market will grow.

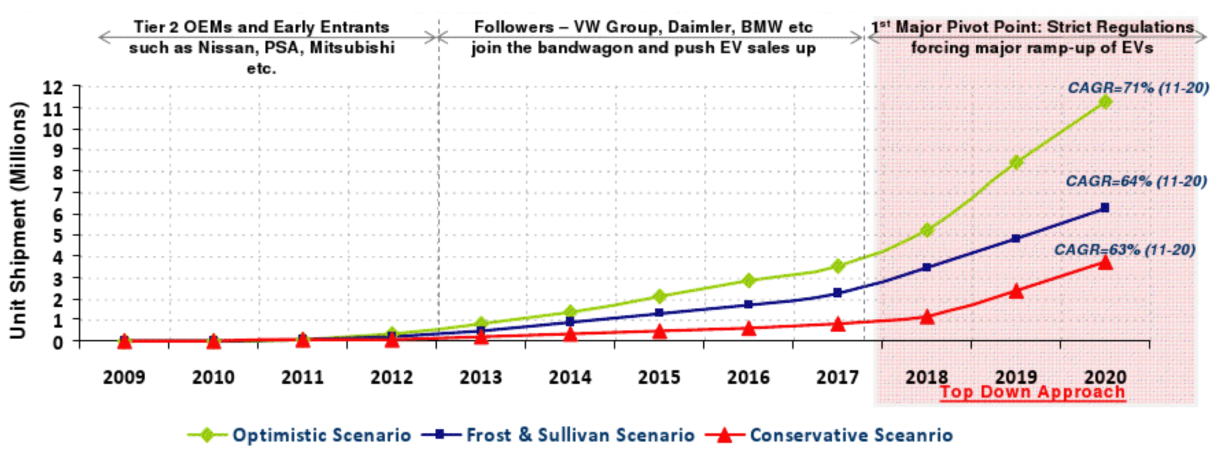

Figure 4: Forecast of Electric Vehicle Market [4]

Methodology

In order to propose an optimal solution to rectify the inadequacy of the current grid technology that is driven by energy demand and the number of EVs increasing over time, it is necessary to create a test environment based in real data. The goal of the system is to simulate a typical grid feeder that supplies power to residential customers (RCs) via a transmission line. Once a general case is established that accurately simulates the test case, which is based on average data, then this environment can be used to test varying situations and cases. For this study it is necessary to examine how the increase in energy demand over time affects the grid feeder, as well as the situation of the increase of EVs over time. Furthermore, it is vital to examine the culmination of the increase of energy demand and the number of EVs over time and the effect that they have on the feeder. Additionally, possible solutions can be tested to validate their feasibility.

Feeder and Transmission Line

The feeder characteristics were chosen based on the U.S. Department of Energy's catalog of grid feeder types. From this catalog the most typical feeder was determined and used to define the following parameters for the simulation [11]:

Line-to-Ground Voltage: $V_{LN} = 8000V$

Short-Circuit Current: $I_{sc} = 20000 < -86°A$

Frequency: $f = 60Hz$

Allowable Feeder Current Maximum: $I = 400A$

Allowable Maximum Power: P= 10 MW

With these defined parameters the feeder's impedance can be determined via (1), (2) and (3):

$$R + jX = \frac{V}{I} \quad (1)$$

$$\omega = 2\pi f \quad (2)$$

$$L = \frac{X}{\omega} \quad (3)$$

Therefore, the feeder impedance can be defined by the following values:

$$R = 0.028\ \Omega$$

$$L = 0.001058\ H$$

The transmission line that theoretically connects the residential customers to the grid feeder is relevant to the simulation since any transmission line will have minor impedance. Based on the chosen typical feeder and an assumed end of line current of $2000 < 82°\ A$. This end of line current was determined by assuming a desired feeder current of 200 A, which is average for the chosen feeder. The overall impedance of the line can be determined via (1), (2) and (3).

$$R_T = 1.76\ \Omega$$

$$L_T = 0.001353\ H$$

The total line impedance is distributed amongst each load on the transmission line; thus, each load has a percentage of the total line impedance. The manner of distribution is irrelevant; it is only the total line impedance that affects the overall result. Additionally, the transmission line impedance is much smaller than the impedances of the loads; therefore, the line impedance has a minimal influence on the results of the simulation. The line impedance can be distributed amongst the loads any number of ways and the overall simulation would produce the same result. For the test environment, the total line impedance was distributed as follows:

Table 3: Transmission Line Impedance Distribution

Load	R (Ω)	L (H)
1	0.028	0.00106
2	0.056	0.00011
3	0.086	0.000053
4	0.07	0.00013
5	0.07	2.1E-10
6	0.11	2.4E-10
7	0.15	3.7E-10
8	0.23	6.4E-10
9	0.48	1.25E-09
10	0.48	1.25E-09

Loads

For this study the test environment for a typical feeder, it is assumed that the loads are average residential customers. For a typical feeder there are approximately 2000 residential customers or otherwise homes. After reviewing data from the U.S. Energy Information Administration (U.S. EIA), it was clear that RCs can be grouped because typically a home will only demand an amount of energy from the grid that falls into a small range [12]. A typical RC requires 1 to 3kW. The 2000 RCs of the typical feeder can be grouped by aggregating all RCs with like amounts of energy demands together. The following table illustrates the groups of RCs, where each group is one equivalent load connected to the feeder, for the test situation.

Table 4: Energy Demanded by Each Load

Load	Power Demand per Residential Unit(kW)	Number of Residential Units	Total Power Demanded per Load (MW)
1	1.1	200	0.22
2	1.3	200	0.26
3	1.5	200	0.3
4	1.6	200	0.32
5	2	200	0.4
6	2.2	200	0.44
7	2.3	200	0.46
8	2.5	200	0.5
9	2.9	200	0.58
10	3	200	0.6

It is relevant to discuss that there are three type of power: true, reactive and apparent. True power, P, is measured in watts, reactive power, Q, is measured in volt-amperes-reactive and apparent power, S, and is measured in volt-amps. Power factor (PF) is also a relevant coefficient. It represents the cosine of the phase-angle between the line current and the line-to-ground voltage. The relationship between these three powers can be defined by the following equations:

$$S^2 = P^2 + Q^2 \quad (4)$$

$$PF = \frac{P}{S} \quad (5)$$

The power factor (PF) of each load was determined by using average values proven relevant by data from U.S. EIA. It was determined that for an average RC the PF ranges from 0.80 to 0.89; therefore the following power factors were assumed for the test loads:

Table 5: Power Factors of Loads

Load	Power Factor
1	0.85
2	0.85
3	0.85
4	0.85
5	0.84
6	0.84
7	0.83
8	0.83
9	0.8
10	0.89

With known true power, as found in table 2, and power factors, found in table 3, the reactive and apparent power of each load can be determined by applying equations (4) and (5). The following table illustrates the results:

Table 6: Power Values for Each Load

Load	Power Factor	P(MW)	Q(var)	S(VA)
1	0.85	0.22	0.11	0.25
2	0.85	0.26	0.17	0.31
3	0.85	0.3	0.18	0.35
4	0.85	0.32	0.19	0.37
5	0.84	0.4	0.25	0.47
6	0.84	0.44	0.27	0.52
7	0.83	0.46	0.3	0.55
8	0.83	0.5	0.31	0.6
9	0.8	0.58	0.43	0.72
10	0.89	0.6	0.3	0.67

A residential load can be represented by equivalent impedance. The impedance value is determined and driven by the power demanded by the customer. The following equations illustrate the relationship between power and impedance:

$$P = 3\left(\frac{V^2}{R}\right) \quad (6)$$

$$Q = 3\left(\frac{V^2}{X}\right) \quad (7)$$

With the known voltage $V_{LN} = 8000V$ and the known values of Q and P for each load, as seen in Table 4, the impedance of each load can be found by applying equation 6, 7 and 3. The results are as follows:

Table 7: Impedance of Each Load

Load	R (Ω)	X (Ω)	L (H)
1	873	1746	4.63
2	837	1128	3
3	639	1068	2.83
4	600	1011	2.68
5	480	768	2.04
6	435	711	1.89
7	417	639	1.7
8	384	618	1.64
9	330	447	1.19
10	321	639	1.7

In order to simulate the increase in energy demand over time the power of each load is increased, which in affect alters the impedance of each load in a manner that mirrors the earlier discussed process. For each year, or data point, the test environment can be altered and simulated to obtain the desired result. For every simulation the value of focus is the feeder current because if the current exceeds the maximum allowable value this is an indication that the grid technology has faltered and will be damaged. Thus, for every simulation the feeder current will be measured and recorded.

Electric Vehicles

Based on information from EcoTansportation LLC it was determined that the typical residential EV charger has the following parameters [2]:

$$V = 240V$$

$$P = 2kW$$

Additionally, it will take about 9 to 10 hours to charge an EV if the battery is fully depleted. Knowing that an EV charger pulls 2kW of power an EV can be incorporated into the test environment. The addition of an EV is equivalent to increasing the demanded power of a load by the amount an EV charger demands, 2kW. By increasing the demand true power, the impedance of that load will also change in accordance to the calculations discussed previously. In order to simulate the proliferation of EVs over time incorporate EVs into varying loads to achieve optimal results. More specifically, for realistic results, the EVs are distributed evenly amongst 5 of the 10 loads, each with a different power factor; for this case EVs are added to loads 1, 5, 7, 9, and 10. For every simulation the feeder current will be measured in order to determine the relationship between increasing number of EVs and the current. Additionally, it will be to note if the current exceeds the maximum value.

Average Daily Energy Demand

It is also necessary to examine the daily energy stress that a feeder undergoes. A standard energy demand pattern for RCs was developed from raw hourly market data from ISO New England [6]. From the hour at which the peak demand occurs was determine to be at hour

20. From the raw data, a relationship between the percent of the maximum demand and hour was determined to establish an overall hourly demand curve. Table 6 outlines this relationship.

Table 8: Hourly Description of Demand in Terms of Maximum Demand Value

Hour	**Fraction of Maximum Demand**
1	0.723019961
2	0.68818416
3	0.668126207
4	0.667160335
5	0.681326465
6	0.738731487
7	0.848132646
8	0.921152608
9	0.952994205
10	0.96242756
11	0.969381842
12	0.968770122
13	0.966677399
14	0.96567933
15	0.952768835
16	0.94871217
17	0.959336768
18	0.974146813
19	0.984674823
20	1
21	0.976497102
22	0.918158403
23	0.839278815
24	0.764101739

With this information and a set peak demand value the hourly demand curve for RCs can be established.

Solutions

With the ever increasing energy demand and the proliferation of EVs there will come a point that the power required will not be achieved with the current technology. There are three main solutions that could be implemented to rectify this issue: 1) new additional transmission lines, 2) grouping EVs, and 3) supplemental energy. Adding additional transmission lines is very costly and therefore not an ideal solution. On average it costs $2.0 to 6.6 million dollars per mile depending on the voltage and length of the line [10]. The remaining two possible solutions are worth further examining. By simulating a test case for each solution a better understanding and more thorough conclusion can be formed about which solution is optimal.

For these solutions it is most relevant to examine the hourly energy demand stresses on the feeder than over a yearly basis. The energy demand information as described above is leveraged to create a baseline curve for the demand from RCs alone. This curve is determined by setting the peak demand to 10 MW, which is the maximum power that a typical feeder and transmission line can handle. The maximum limit is chosen to model the worst case scenario, specifically when new solutions must be applied. This value of 10 MW represents the total demand from RCs on the typical feeder. The curve established with this given peak and the fractions outlined in Table 6 the hourly demand of RCs for these test cases is as follows:

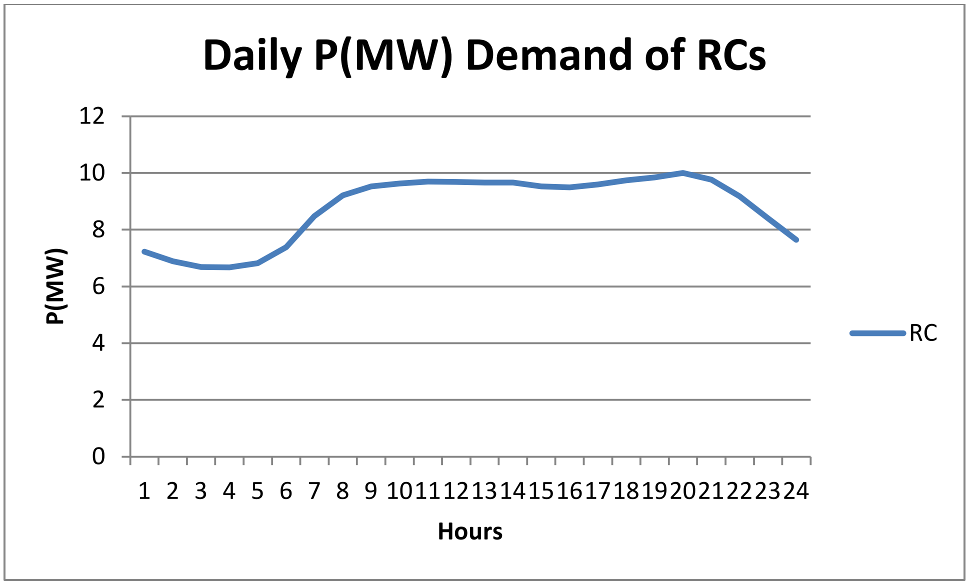

Figure 5: Hourly Demand from RCs

It is also vital to establish a daily demand curve for the demand from residential customers with the addition of electric vehicles. An assumption that typical consumer will charge their EV overnight can be made based on typical behavior [2]. With this, a demand curve for the charging electric vehicles, given a worst case scenario, can be established. Figure 2 illustrates the demand of residential customers and electric vehicles. Also, the demand solely from electric vehicles is shown.

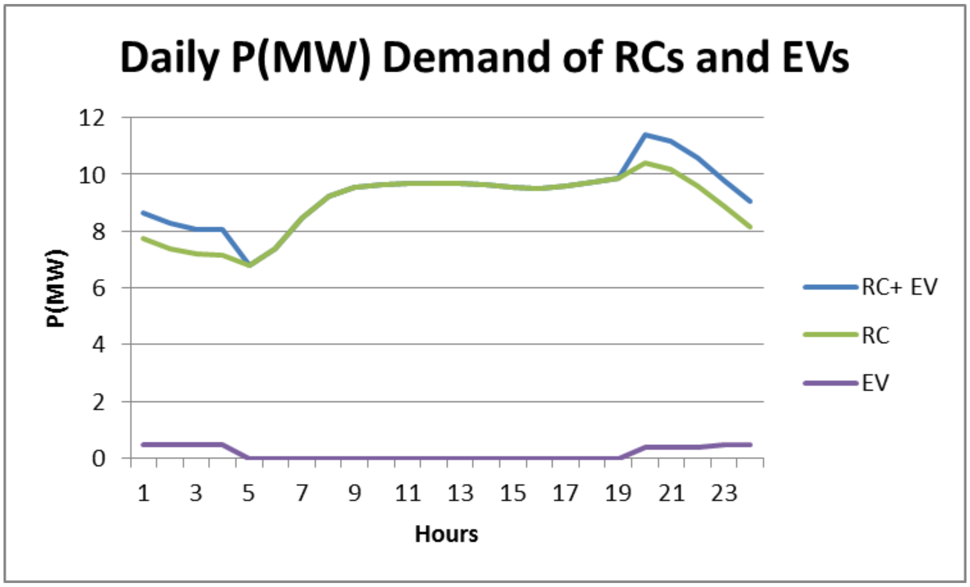

Figure 6: Daily P(MW) Demand of Residential Customers and Electric Vehicles

The purpose of the solution simulations is to observe how affective that solution is in supporting the grid to decrease the power demanded of the feeder, so that this demand is below the allowable maximum of 10 MW.

Grouping

Grouping is a means to monitor and control when an EV is actually charged. The concept is that if the load of EVs trying to charge is too much for the feeder, then the utility can select only a number of EVs to charge at a time. For example, if there are 100 EVs trying to charge over night the utility could group the EVs, so that half of the EVs charge for the first half of the night and the other half of EVs for the latter part of the night. This technique lessens the strain on the feeder; however, it can only work to a point. The limit to this method is due to the fact that a user will only have their EV charging for a set amount of time and if the EV numbers grow extensively there will be a point that there will not be enough time for the necessary groups of

EVs to charge. This technique can be simulated for a worst case scenario to determine its feasibility.

For this test case there are 700 EVs and three groups. The EVs will be charged from hour 20 to hour 4 because it can be assumed that the typical consumer will charge their EV overnight [2]. From EcoTransportation LLC it was determined that for the chosen typical charger that was discussed previously, it takes 9 to 10 hours for the EV to charge from full depletion to full capacity. For this test case it is assumed that the EVs will begin charge with 30% of the total capacity because typically a user will not begin charge at 0%. With this it can be stated that it will take each EV about 3 hours to charge to capacity. With this information charging times for each of the three groups can be set. The following table outlines the number of EVs in each group and the hours they will charge.

Table 10: Groups and Charge Times

Group	Number of Evs	P(MW)	Charge Hours
1	200	0.4	20, 21, 22
2	250	0.5	23, 24, 1
3	250	0.5	2,3,4

Community Battery

The final solution is to supplement the grid with an energy storage system, so that with the demand is too great power can be drawn from the additional source. This concept can be described with a community battery of an average 1MW size that is charged with photovoltaic (PV). The community battery was chosen from information from EOS [7]. A 1MW energy storage system is an average size for a community. The battery is charged with PV instead of wind power because currently less controversy surrounds PVs than wind. In order to simulate this situation the nature of PV must be examined. It can be assumed that the daily PV charge life is parabolic and only occurs when the sun is out. With this information a general curve can be determined given the 1MW desired peak. This curve is as follows:

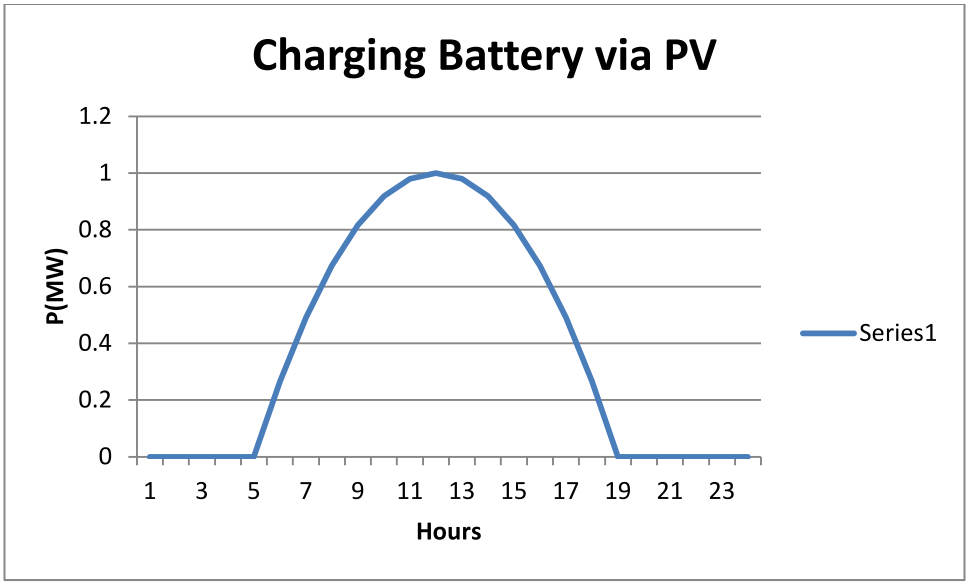

Figure 7: Charge Life of PV for 1MW Battery

This curve establishes the amount of supplemental power available for use at the given hours in a day. By examining the hourly RC demand the additional power can be distributed at peak demand times. The power stored in the battery will be used when the demand of RC and EVs exceeds the limit.

Results

In order accordance to the method discussed previously a base model for a typical New England feeder in a residential area was created in PSpice. This model was then manipulated to simulate the varying cases of discussion, such as the proliferation of EVs over time. Additionally, this base model was used to examine the possible solutions to rectify the excessive energy demand.

Base Model

The base model is derived from the typical data of the feeder and transmission line as discussed in the methodology. The model was designed using sub circuit for each load, encapsulating the line and load impedance. These sub circuits were then added to the feeder and its corresponding impedance. The PSpice code can be found in Appendix A. This model is the basis for all following theoretical models.

For every model the value of focus is the feeder current. This current cannot exceed 400 A because based on the chosen feeder, this is the maximum possible current. Therefore, for every simulation it is vital to determine the current value. Additionally, the point at which the current exceeds 400A is the point of focus because this represents the point in time that the current grid technology cannot handle the load of RCs and EVs.

Increasing Energy Demand of Residential Customers Model

In order to simulate the RCs increasing energy demand over time the base model was used. For the most accurate portrayal three cases were examined. These cases were when the RC energy demand increases at a rate of 1%, 2% and 3%, to model best to worst case scenarios. Additionally, for each case the years 2011 to 2021 were examined. The increasing demand from

RCs affects the load impedances. Thus, for each case and for each year the base case load impedance values are adjusted to reflect the new variables.

The year 2011 acts as a constant for all cases. The load impedances for each year were found by first adjusting the true power demanded by each load by the rate of increase for the respective case. Thus, the power demanded by each load was determined by the following expression:

$$P_N = [P_{N-1} * (rate\ of\ increase)] + P_{N-1}$$

This expression states that the power of a particular load for a given year is equal to the product of the power of that load of the previous year and the rate of increase summed with the power of the particular load for the previous year.

Once the new true power value is determined the reactive and apparent power values can be adjusted via equations (4) and (5). With these values established the new impedance for each load can be found by using equations (6) and (7). The values found and used for each year and case can be found in Appendix B. For each year for each case, the base model load impedances were altered according to this data. Please note that the feeder voltage and impedance as well as the line impedances were note altered because only the RC loads are affected.

Once all of the load impedance data is determined, a simulation can be run for each year of each case to obtain the feeder current. This is to observe the relationship between the feeder current and the increase in RC energy demand over time. The current values determined from running the simulations can be found in Table 8.

Table 11: Feeder Current Values for Each Year and Case of Increasing RC Energy Demand

	1% Increase	2% Increase	3% Increase
Year	**I(A)**	**I(A)**	**I(A)**
2011	194.5	194.5	194.5
2012	199.6	201.5	203.4
2013	201.5	205.5	209.5
2014	203.5	209.5	215
2015	205.5	213.6	221.9
2016	207.5	217.1	228.3
2017	209.5	222	235.1
2018	211.6	225.9	241.9
2019	213.7	230.8	249
2020	215.7	235.2	256.3
2021	217.9	239.8	263.7

From this measured data, a curve for each case was established. These curves can be found in Figure 3.

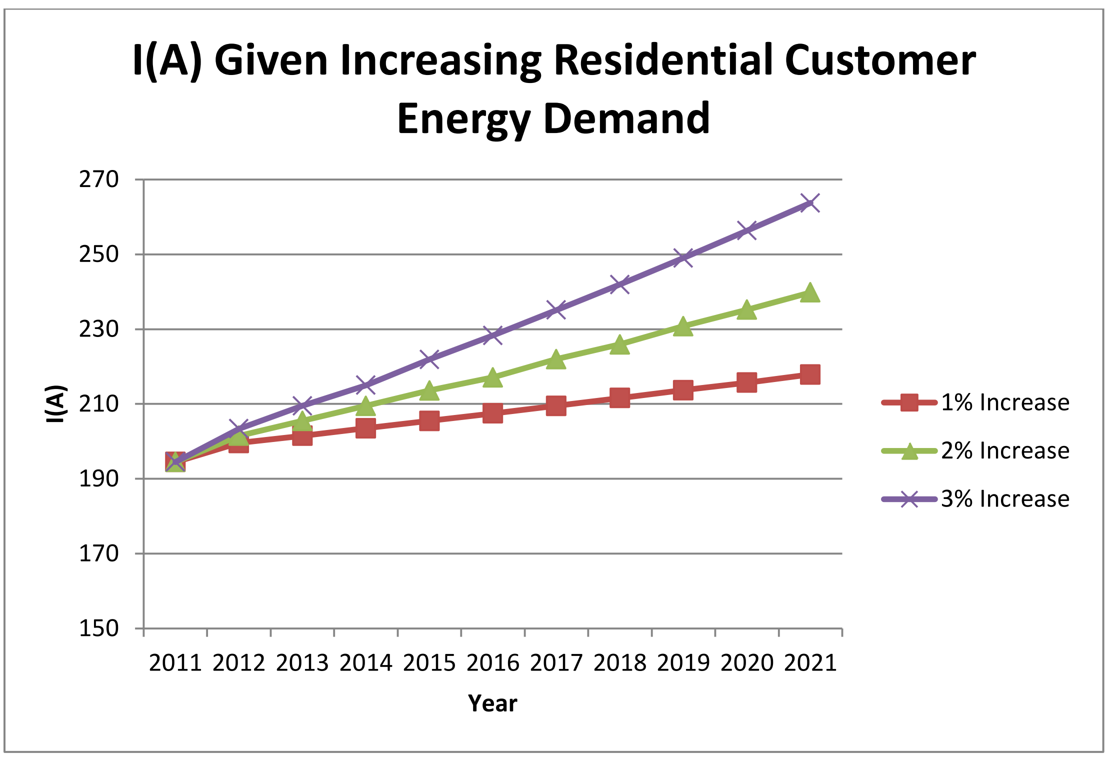

Figure 8: I(A) Given Increasing Residential Customer Energy Demand

From the simulation data it can be concluded that as the RC energy demand increases, so does the feeder current. This proportional relationship alludes to future issues. An increasing demand from RCs alone will eventually drive the feeder current above its limit.

Proliferation of Electric Vehicles Model

The simulation of the proliferation of EVs was handled in a similar manner to the increase of the energy demand of RCs. For this simulation the RC load is held constant for all years and cases. It is known, as discussed in the methodology, that an EV charger demands 2kW of true power. Thus, this amount of true power for every EV is added to the corresponding load's true power. The following equation describes how to find the new value of true power, where P_o represents the original value of true power:

$$P = P_o + 2kW(Number\ of\ EVs)$$

Once the new value of true power is determined, the values of the reactive and apparent power can be found via (4) and (5). Once these are calculated, the new load impedance values can be found with equations (6) and (7). As discussed in the methodology, EVs are added to loads 1, 5, 7, 9 and 10, so that every varied PF is represented. This means that the loads without EVs do not falter from the base model.

The rate of proliferation is represented by three cases: 1) 1% increase, 2) 2% increase, and 3) 3% increase. The rate of increase determines the number of EVs per year. The EV proliferation is illustrated in Table 9.

Table 12: Proliferation of Electric Vehicles for Three Cases

	Number of Evs		
Year	**1% Increase**	**2% Increase**	**3% Increase**
2011	0	0	0
2012	20	40	60
2013	40	80	120
2014	60	120	180
2015	80	160	240
2016	100	200	300
2017	120	240	360
2018	140	280	420
2019	160	320	480
2020	180	360	540
2021	200	400	600

Given the number of EVs per year the new impedances for the particular loads can be determined. The data calculated and used for the simulation can be found in Appendix C. This data was used to simulate each year for each case to determine the feeder current. Table 10 illustrates the resulting currents.

Table 13: Feeder Current Given Three Cases of Electric Vehicle Proliferation

Year	**I(A)**		
	1% Increase	**2%increase**	**3% increase**
2011	194.5	194.5	194.5
2012	197.6	199.5	201.4
2013	199.5	203.3	207.1
2014	201.4	207.1	212.8
2015	203.3	210.9	218.5
2016	205.1	214.6	223.3
2017	207.1	218.5	229.7
2018	208.9	222.2	235.4
2019	210.9	225.9	241
2020	212.8	229.7	246.6
2021	214.6	233.5	252.2

These results were used to develop curves for each case, which can be found in Figure 4. These curves are used to establish the relationship between the increasing number of EVs and the feeder current.

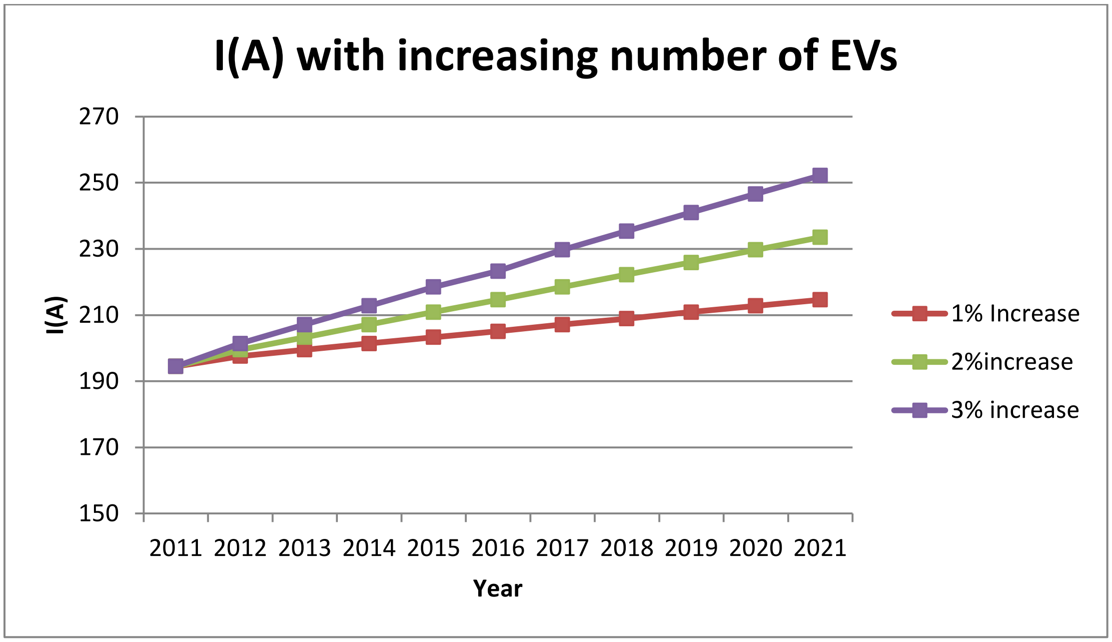

Figure 9: Feeder Current Given Three Cases of Electric Vehicle Proliferation

From these curves it is clear that the number of EVs and feeder current are proportional. Therefore, as the number of EVs increases over time the feeder current increases as well. Given enough time for the EV market to grow, eventually the load of charging EVs would be too great for the current grid feeders, even with a constant RC load over time.

Increasing Residential Customer Energy Demand and Number of Electric Vehicles

Both an increasing RC energy demand and an increasing number of EVs over time will increase the feeder current. Due to this behavior, it is vital to observe the combination of these trends and determine how it affects the feeder current. To combine these trends is to increase both the RC load and the number of EVs over time. In order to simulate this behavior, the models from just an increasing RC load were used as a base. In order to also incorporate an increasing number of EVs over time, loads loads 1, 5, 7, 9 and 10 of each year of each case were adjusted. The load values were changed in the same fashion as previously used when just the number of EVs was increasing and the RC load was constant. The data used for the simulations can be found in Appendix D.

When each simulation is run the feeder current is determined. The results for each simulation can be found in Table 11.

Table 14: Feeder Current Given Three Cases of Residential Customer Energy Demand and Number of Electric Vehicles Increasing over time

Year	1% Increase	2% Increase	3% Increase
	I(A)	I(A)	I(A)
2011	194.5	194.5	194.5
2012	208.9	220.4	231.8
2013	224.8	259.1	294.6
2014	260.3	323.1	385.2
2015	299.9	402.4	504.4
2016	349.1	499.6	649
2017	407.1	613.9	786.3
2018	473.8	744.2	1008
2019	549	889	1218
2020	632.2	1048	1438
2021	723	1218	1683

The measured data from the simulations can be used to create a curve for each case to illustrate the relationship between increasing RC loads and number of EVs to the feeder current. This relationship over time can be found in Figure 5. The red line at 400 A denotes the thermal current limit of the feeder.

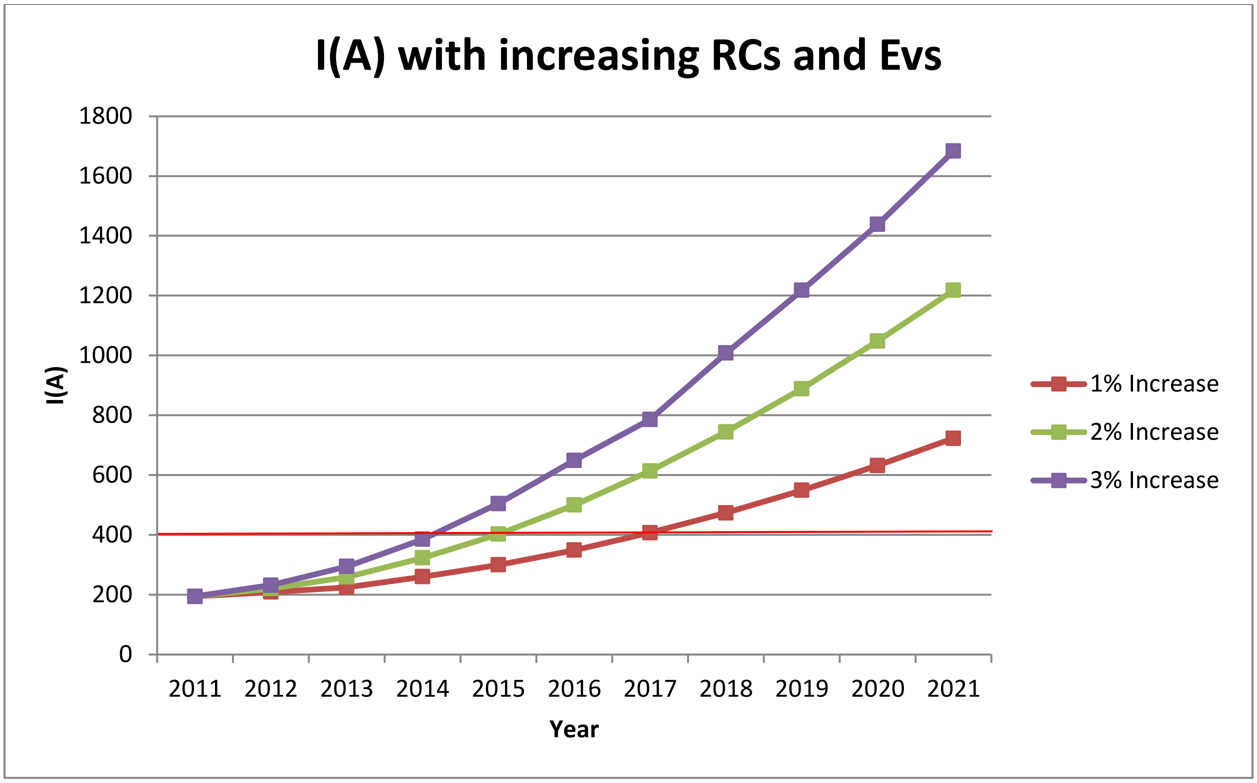

Figure 10: Feeder Current Given Three Cases of Residential Customer Energy Demand and Number of Electric Vehicles Increasing over Time

From the curves it is clear that the feeder current increases exponentially over time as the RC energy demand increases and the number of EVs increases as well. Also from the results, it can be concluded in time with the proliferation of EVs and consumers increasing energy demands, the current grid technology is not sufficient. In all cases within the span of time observed, the feeder current exceeds the allowable maximum of 400 A. It is obvious that a solution must be implemented to rectify this impending issue.

Solutions

From the specified typical feeder the maximum allowable power is 10MW. At this point the feeder current exceeds 400A. With this, a daily power demand curve can established. This curve will mirror the characteristics of the hourly demand curve discussed in the methodology.

The EVs charging cycle will be added to the daily demand curve. The charging cycle is that discussed in the methodology. These two curves can be found in Figure 6. The data used to create these curves via simulations can be found in Appendix E.

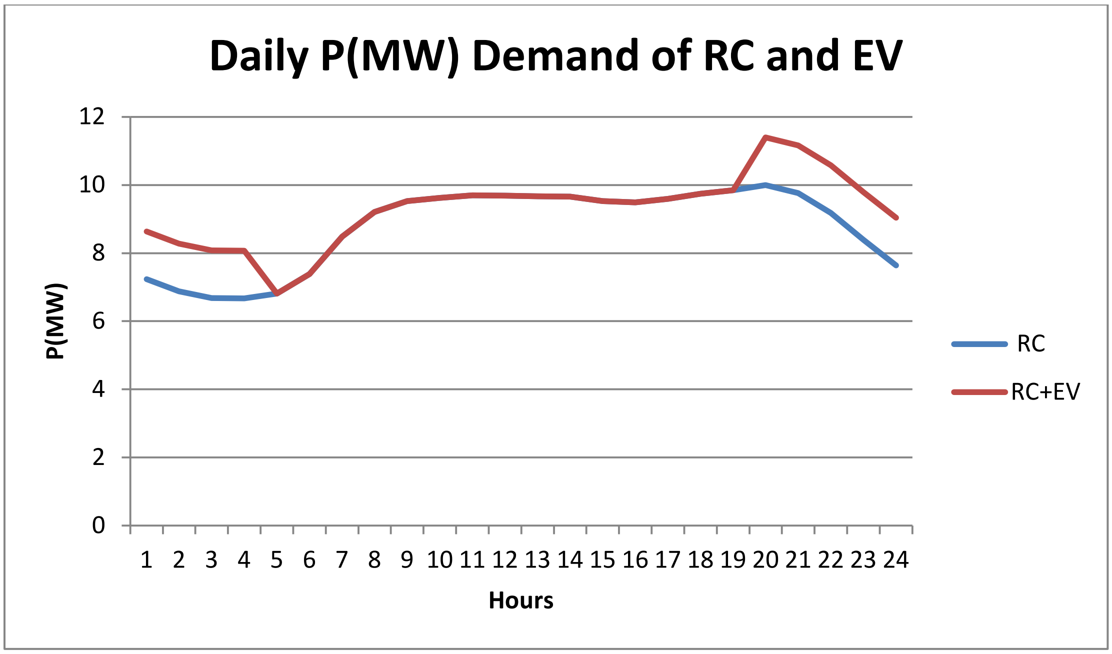

Figure 11: P (MW) Daily Demand of RCs and RCs with Charging EVs

Grouping

Given the case in Figure 6 the grouping concept can be applied to measure the feasibility of this solution. The data used for simulation can be found in Appendix F. The resulting curves can be found in Figure 7. From this figure it is clear that grouping is a feasible solution given a limited number of EVs.

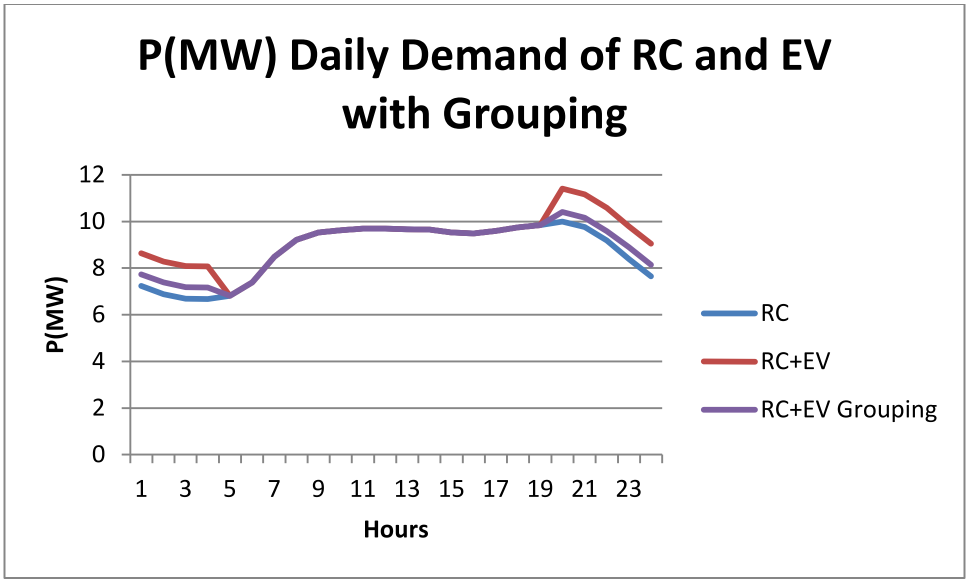

Figure 12: P (MW) Daily Demand of RCs and Grouped EVs, 10 MW

At the maximum power limit the grouping technique is not ideal. However, if the RC and EV demand maximum is lowered to 7 MW, the grouping technique will be a feasible solution. These results can be found in Figure 8. Thus, it is clear that grouping is a desirable solution, but only until a particular point.

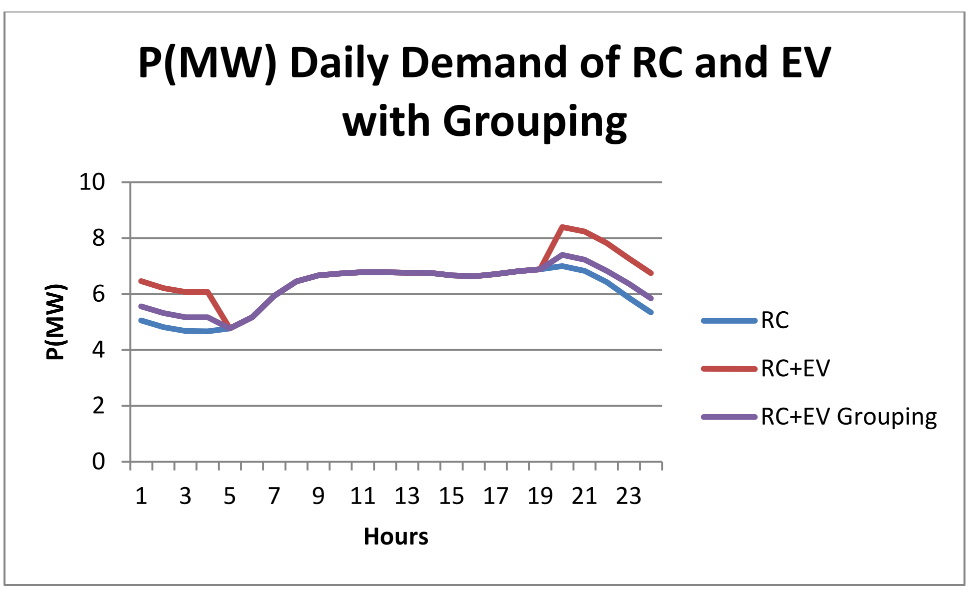

Figure 13: P (MW) Daily Demand of RCs and Grouped EVs, 7 MW

Energy Storage

The community battery solution was applied to the case illustrated in Figure 6. The data used for the model can be found in Appendix G. Figure 9 illustrates the resulting curves from the simulation. It is clear that a community battery charged by PV, is an optimal solution even when the power demand from RCs and EVs is at the maximum limit.

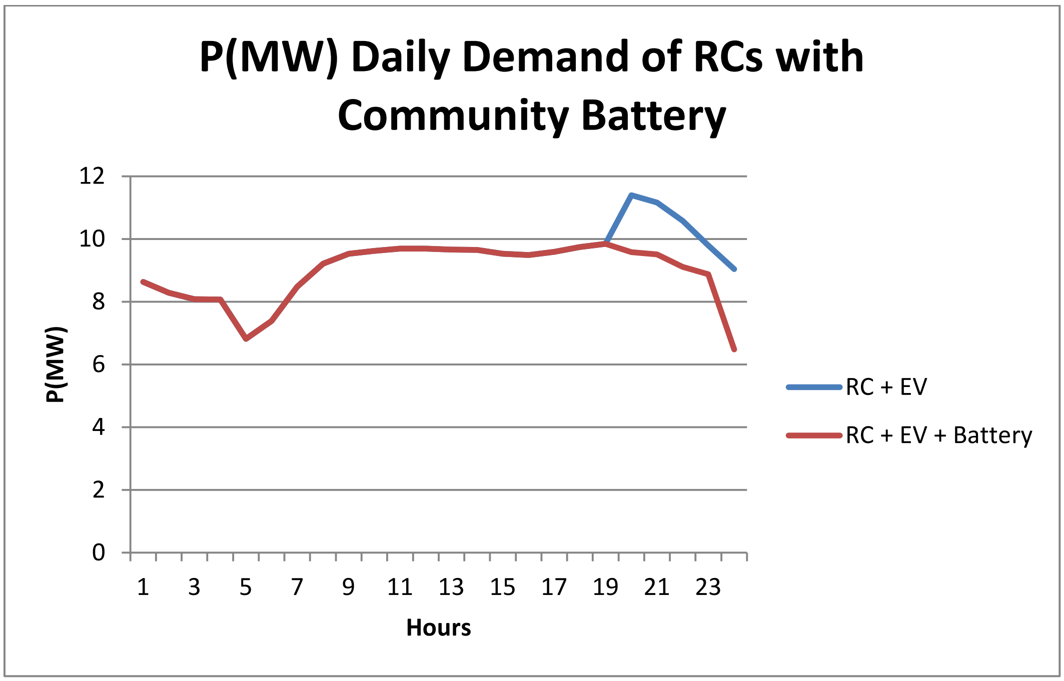

Figure 14: P (MW) Daily Demand of Residential Customers and EVs with Use of Community Battery

Conclusion

It is clear from the results that the grouping technique will only work up to a point, while a energy storage system is a more long term solution. From the results a relationship between the number of EVs and time was determined. Additionally, from the solution models it was established when either solution should be implemented. These conclusions can be found in Figure 10. Ideally, the grouping technique can be used until the power demand from residential customers and charging electric vehicles is too great. At this point, supplemental energy storage should be applied. A community battery charged via PV can be used as the optimal rectifying solution for the impending issues with the current grid technology.

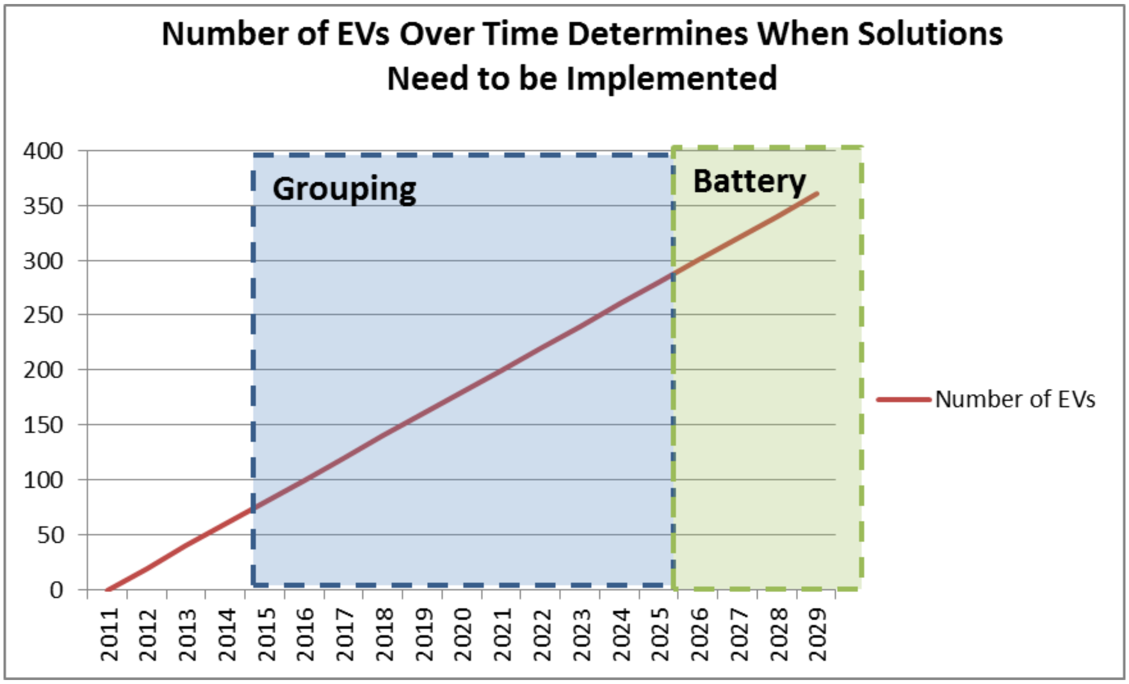

Figure 15: When Solutions need to be implemented

References

[1] Armentano, Dominick. "Three Reasons Why the US Faces Recession in 2008." *MoneyWeek*. N.p., 4 Jan. 2008. Web. 12 Apr. 2013.

[2] EcoTransportation LLC. 2012 "EV Charger" http://evcharger.com/

[3] EOS. "Energy Storage." January 2012. www.eosenergystorage.com

[4] Ford, Nick. Frost & Sullivan. " 360 Degree Perspective of the Global Electric Vehicle Market." December 2011.

[5] Hersh, Lauren. IBISWorld Business Environment Profiles. "Electric power consumption." February 2013.http://clients1.ibisworld.com.ezproxy.wpi.edu/reports/us/bed/ChartImg.axd?i=chart_0_2.png&g=cec0e6abbf5945b686b740b0da33321f

[6] ISO New England. "Hourly Load Data" 11 March 2013. http://www.isone.com/markets/hrly_data/index.html

[7] Kliesen, Kevin L. "The 2001 Recession: How Was It Different and What Developments May Have Caused It?" Federal Reserve Bank of St. Louis, Sept.-Oct. 2003. Web. 12 Apr. 2013.

8] Lachman, Desmond. "The Greek Economic Crisis and the U.S. Economy." *AEI*. American Enterprise Institute, 27 May 2010. Web. 12 Apr. 2013.

[9] Molavi, Justin. IBISWorld Industry Report OD4516. "Hybrid & electric Vehicle Manufacturing." October 2011.
http://clients1.ibisworld.com/reports/us/industry/default.aspx?entid=4516

[10] PJM. "A Survey of Transmission Cost Allocation Issues, Methods and Practices." 10 March 2010.

[11] Scheider, K.P, Chen, Y., Chassin, D.P, Pratt, R., Engel,D., Thompson, S. "Modern Grid Initiative:
Distribution taxonomy final report" US DOE: 15 Nov. 2008.

[12] U.S. Energy Information Administration. 6 Dec 2011. http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3

[13] World Resources Institute. "Power Surge: Energy Use and Emissions Continue to Rise."*Working at the Intersection of Environment & Human Needs*. World Resources Institute, n.d. Web. 12 Apr. 2013.

Appendix A: Base Model PSpice

```
.SUBCKT     RES1   A    B     C
R1          A      1    0.028
L1          1      B    1.06m       IC=0
RL1         B      C    873
LL1         B      C    4.63        IC=0
.ENDS

.SUBCKT     RES2   A    B     C
R2          A      1    0.056
L2          1      B    0.11m       IC=0
RL2         B      C    837
LL2         B      C    3           IC=0
.ENDS

.SUBCKT     RES3   A    B     C
R3          A      1    0.086
L3          1      B    53u                   IC=0
RL3         B      C    639
LL3         B      C    2.83        IC=0
.ENDS

.SUBCKT     RES4   A    B     C
R4          A      1    0.07
L4          1      B    0.13m       IC=0
RL4         B      C    600
LL4         B      C    2.68        IC=0
.ENDS

.SUBCKT     RES5   A    B     C
R5          A      1    0.07
L5          1      B    0.21n       IC=0
RL5         B      C    480
LL5         B      C    2.04  IC=0
.ENDS

.SUBCKT     RES6   A    B     C
R6          A      1    0.11
```

```
L6          1      B      0.24n         IC=0
RL6         B      C      435
LL6         B      C      1.89          IC=0
.ENDS

.SUBCKT     RES7   A      B      C
R7          A      1      0.15
L7          1      B      0.37n         IC=0
RL7         B      C      417
LL7         B      C      1.7                  IC=0
.ENDS

.SUBCKT     RES8   A      B      C
R8          A      1      0.23
L8          1      B      0.64n         IC=0
RL8         B      C      384
LL8         B      C      1.64   IC=0
.ENDS

.SUBCKT     RES9   A      B      C
R9          A      1      0.48
L9          1      B      1.25n         IC=0
RL9         B      C      330
LL9         B      C      1.19   IC=0
.ENDS

.SUBCKT     RES10  A      B      C
R10         A      1      0.48
L10         1      B      1.25n         IC=0
RL10   B    C      321
LL10   B    C      1.7    IC=0
.ENDS



V           1      0      AC     8000
R           1      2      0.028
L           2      3      0.001058      IC=0
```

```
X1        3     4     0     RES1
X2        4     5     0     RES2
X3        5     6     0     RES3
X4        6     7     0     RES4
X5        7     8     0     RES5
X6        8     9     0     RES6
X7        9     10    0     RES7
X8        10    11    0     RES8
X9        11    12    0     RES9
X10       12    13    0     RES10

.AC LIN 1    60     60
.PRINT AC    IM(R)  IP(R)
.END
```

Appendix B: Increasing RC Energy Demand Data for Models

Case 1: 1% Increase

Year 2011: Base Model

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.25	0.11	0.85	0.22	873	1746	4.63
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.47	0.25	0.84	0.4	480	768	2.04
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.55	0.3	0.83	0.46	417	639	1.7
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.72	0.43	0.8	0.58	330	447	1.19
10	0.67	0.3	0.89	0.6	321	639	1.7

Year 2012

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.13770719	0.2222	864.08641	1394.263	3.69831	0.26141176	0.85
2	0.16274486	0.2626	731.15004	1179.761	3.129339	0.30894118	0.85
3	0.18778253	0.303	633.66337	1022.459	2.712094	0.35647059	0.85
4	0.20030137	0.3232	594.05941	958.5556	2.542588	0.38023529	0.85
5	0.26095822	0.404	475.24752	735.75	1.951591	0.48095238	0.84
6	0.28705404	0.4444	432.0432	668.8636	1.774174	0.52904762	0.84
7	0.3122131	0.4646	413.25872	614.9646	1.631206	0.55975904	0.83
8	0.33936206	0.505	380.19802	565.7674	1.500709	0.60843373	0.83
9	0.43935	0.5858	327.75691	437.0092	1.159176	0.73225	0.8
10	0.31046301	0.606	316.83168	618.4312	1.640401	0.68089888	0.89

Year 2013

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.13908426	0.224422	855.5311	1380.458	3.661693	0.26402588	0.85
2	0.16437231	0.265226	723.91093	1168.08	3.098355	0.31203059	0.85
3	0.18966036	0.30603	627.38947	1012.336	2.685241	0.36003529	0.85
4	0.20230438	0.326432	588.17763	949.065	2.517414	0.38403765	0.85
5	0.2635678	0.40804	470.5421	728.4653	1.932269	0.4857619	0.84
6	0.28992458	0.448844	427.76555	662.2412	1.756608	0.5343381	0.84
7	0.31533523	0.469246	409.16705	608.8758	1.615055	0.56535663	0.83
8	0.34275568	0.51005	376.43368	560.1658	1.485851	0.61451807	0.83
9	0.4437435	0.591658	324.5118	432.6824	1.147699	0.7395725	0.8
10	0.31356764	0.61206	313.69474	612.3081	1.624159	0.68770787	0.89

Year 2014

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.14047511	0.226666	847.06049	1366.79	3.625438	0.26666614	0.85
2	0.16601604	0.267878	716.74349	1156.515	3.067678	0.31515089	0.85
3	0.19155696	0.30909	621.17769	1002.313	2.658655	0.36363565	0.85
4	0.20432743	0.329696	582.35409	939.6683	2.492489	0.38787802	0.85
5	0.26620348	0.41212	465.88327	721.2528	1.913137	0.49061952	0.84
6	0.29282383	0.453332	423.53025	655.6843	1.739216	0.53968148	0.84
7	0.31848858	0.473938	405.11589	602.8474	1.599065	0.57101019	0.83
8	0.34618324	0.515151	372.70662	554.6196	1.471139	0.62066325	0.83
9	0.44818094	0.597575	321.29881	428.3984	1.136335	0.74696823	0.8
10	0.31670332	0.618181	310.58885	606.2456	1.608079	0.69458494	0.89

Year 2015

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.14187986	0.228933	838.67376	1353.258	3.589543	0.2693328	0.85
2	0.1676762	0.270557	709.64702	1145.064	3.037305	0.3183024	0.85
3	0.19347253	0.312181	615.02742	992.3889	2.632331	0.367272	0.85
4	0.2063707	0.332993	576.58821	930.3646	2.467811	0.3917568	0.85
5	0.26886552	0.416242	461.27057	714.1117	1.894195	0.49552572	0.84
6	0.29575207	0.457866	419.33688	649.1924	1.721996	0.54507829	0.84
7	0.32167347	0.478678	401.10484	596.8786	1.583232	0.57672029	0.83
8	0.34964507	0.520302	369.01645	549.1283	1.456574	0.62686989	0.83
9	0.45266274	0.60355	318.11763	424.1568	1.125084	0.75443791	0.8
10	0.31987035	0.624362	307.51371	600.2432	1.592157	0.70153079	0.89

Year 2016

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.14329866	0.231222	830.37005	1339.859	3.554003	0.27202613	0.85
2	0.16935296	0.273263	702.62082	1133.727	3.007233	0.32148543	0.85
3	0.19540726	0.315303	608.93804	982.5633	2.606269	0.37094472	0.85
4	0.20843441	0.336323	570.87941	921.1531	2.443377	0.39567437	0.85
5	0.27155417	0.420404	456.70353	707.0412	1.875441	0.50048098	0.84
6	0.29870959	0.462444	415.18503	642.7648	1.704946	0.55052907	0.84
7	0.3248902	0.483465	397.1335	590.9689	1.567557	0.5824875	0.83
8	0.35314152	0.525505	365.36282	543.6914	1.442152	0.63313858	0.83
9	0.45718937	0.609586	314.96795	419.9573	1.113945	0.76198229	0.8
10	0.32306905	0.630606	304.46902	594.3002	1.576393	0.7085461	0.89

Year 2017

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.14473164	0.233534	822.14857	1326.593	3.518815	0.27474639	0.85
2	0.17104649	0.275995	695.66417	1122.502	2.977459	0.32470028	0.85
3	0.19736133	0.318456	602.90895	972.8349	2.580464	0.37465417	0.85
4	0.21051875	0.339686	565.22714	912.0328	2.419185	0.39963112	0.85
5	0.27426971	0.424608	452.18171	700.0408	1.856872	0.50548579	0.84
6	0.30169668	0.467069	411.07428	636.4008	1.688066	0.55603436	0.84
7	0.3281391	0.488299	393.20149	585.1177	1.552036	0.58831237	0.83
8	0.35667294	0.53076	361.74537	538.3083	1.427873	0.63946997	0.83
9	0.46176127	0.615682	311.84946	415.7993	1.102916	0.76960211	0.8
10	0.32629974	0.636912	301.45448	588.416	1.560785	0.71563156	0.89

Year 2018

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.14617896	0.23587	814.00848	1313.459	3.483975	0.27749386	0.85
2	0.17275695	0.278755	688.77641	1111.388	2.947979	0.32794728	0.85
3	0.19933494	0.321641	596.93956	963.2029	2.554915	0.37840071	0.85
4	0.21262394	0.343083	559.63083	903.0027	2.395233	0.40362743	0.85
5	0.27701241	0.428854	447.70467	693.1097	1.838487	0.51054064	0.84
6	0.30471365	0.47174	407.00424	630.0998	1.671352	0.56159471	0.84
7	0.33142049	0.493182	389.30841	579.3245	1.53667	0.5941955	0.83
8	0.36023967	0.536068	358.16373	532.9785	1.413736	0.64586467	0.83
9	0.46637888	0.621839	308.76184	411.6825	1.091996	0.77729813	0.8
10	0.32956274	0.643281	298.46978	582.5901	1.545332	0.72278788	0.89

Year 2019

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.14764075	0.238228	805.94899	1300.454	3.44948	0.28026879	0.85
2	0.17448452	0.281543	681.95684	1100.384	2.918791	0.33122676	0.85
3	0.20132829	0.324857	591.02926	953.6663	2.529619	0.38218472	0.85
4	0.21475018	0.346514	554.08993	894.0621	2.371518	0.4076637	0.85
5	0.27978253	0.433143	443.27195	686.2473	1.820285	0.51564605	0.84
6	0.30776079	0.476457	402.9745	623.8612	1.654804	0.56721066	0.84
7	0.3347347	0.498114	385.45387	573.5886	1.521455	0.60013745	0.83
8	0.36384206	0.541428	354.61756	527.7015	1.399739	0.65232332	0.83
9	0.47104267	0.628057	305.70479	407.6064	1.081184	0.78507111	0.8
10	0.33285837	0.649714	295.51463	576.8219	1.530032	0.73001576	0.89

Year 2020

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.14911716	0.240611	797.9693	1287.578	3.415327	0.28307148	0.85
2	0.17622937	0.284358	675.20479	1089.489	2.889892	0.33453902	0.85
3	0.20334158	0.328106	585.17749	944.224	2.504573	0.38600657	0.85
4	0.21689768	0.349979	548.60389	885.21	2.348037	0.41174034	0.85
5	0.28258036	0.437474	438.88312	679.4527	1.802262	0.52080251	0.84
6	0.31083839	0.481222	398.98465	617.6843	1.63842	0.57288276	0.84
7	0.33808205	0.503095	381.63749	567.9095	1.506391	0.60613883	0.83
8	0.36748049	0.546843	351.10649	522.4767	1.38588	0.65884655	0.83
9	0.47575309	0.634337	302.67801	403.5707	1.070479	0.79292182	0.8
10	0.33618695	0.656211	292.58874	571.1108	1.514883	0.73731591	0.89

Year 2021

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.15060833	0.243017	790.06862	1274.83	3.381512	0.2859022	0.85
2	0.17799166	0.287202	668.5196	1078.702	2.861279	0.33788441	0.85
3	0.20537499	0.331387	579.38365	934.8753	2.479775	0.38986663	0.85
4	0.21906666	0.353479	543.17217	876.4456	2.324789	0.41585774	0.85
5	0.28540616	0.441849	434.53774	672.7255	1.784418	0.52601054	0.84
6	0.31394678	0.486034	395.03431	611.5686	1.622198	0.57861159	0.84
7	0.34146287	0.508126	377.8589	562.2866	1.491476	0.61220021	0.83
8	0.37115529	0.552311	347.63019	517.3037	1.372158	0.66543502	0.83
9	0.48051062	0.640681	299.6812	399.5749	1.05988	0.80085104	0.8
10	0.33954882	0.662773	289.69183	565.4562	1.499884	0.74468907	0.89

Case 2: 2% Increase

Year 2011: Base Model

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.25	0.11	0.85	0.22	873	1746	4.63
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.47	0.25	0.84	0.4	480	768	2.04
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.55	0.3	0.83	0.46	417	639	1.7
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.72	0.43	0.8	0.58	330	447	1.19
10	0.67	0.3	0.89	0.6	321	639	1.7

Year 2012

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.139071	0.2244	855.615	1380.59345	3.662052	0.264	0.85
2	0.164356	0.2652	723.9819	1168.19446	3.098659	0.312	0.85
3	0.189642	0.306	627.451	1012.4352	2.685504	0.36	0.85
4	0.202285	0.3264	588.2353	949.157996	2.51766	0.384	0.85
5	0.263542	0.408	470.5882	728.536725	1.932458	0.485714	0.84
6	0.289896	0.4488	427.8075	662.306113	1.75678	0.534286	0.84
7	0.315304	0.4692	409.2072	608.935526	1.615214	0.565301	0.83
8	0.342722	0.51	376.4706	560.220684	1.485997	0.614458	0.83
9	0.4437	0.5916	324.5436	432.724814	1.147811	0.7395	0.8
10	0.313537	0.612	313.7255	612.368113	1.624319	0.68764	0.89

Year 2013

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.141852	0.228888	838.8382	1353.52299	3.590247	0.26928	0.85
2	0.167643	0.270504	709.7862	1145.28868	3.037901	0.31824	0.85
3	0.193435	0.31212	615.148	992.583525	2.632848	0.3672	0.85
4	0.20633	0.332928	576.7013	930.547055	2.468295	0.39168	0.85
5	0.268813	0.41616	461.361	714.251691	1.894567	0.495429	0.84
6	0.295694	0.457776	419.4191	649.319719	1.722333	0.544971	0.84
7	0.32161	0.478584	401.1835	596.995614	1.583543	0.576607	0.83
8	0.349577	0.5202	369.0888	549.235965	1.456859	0.626747	0.83
9	0.452574	0.603432	318.18	424.240014	1.125305	0.75429	0.8
10	0.319808	0.62424	307.574	600.360896	1.592469	0.701393	0.89

Year 2014

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.144689	0.233466	822.3904	1326.98332	3.51985	0.274666	0.85
2	0.170996	0.275914	695.8688	1122.83204	2.978334	0.324605	0.85
3	0.197303	0.318362	603.0863	973.121103	2.581223	0.374544	0.85
4	0.210457	0.339587	565.3934	912.301034	2.419897	0.399514	0.85
5	0.274189	0.424483	452.3147	700.246756	1.857418	0.505337	0.84
6	0.301608	0.466932	411.1952	636.58796	1.688562	0.555871	0.84
7	0.328043	0.488156	393.3171	585.289817	1.552493	0.588139	0.83
8	0.356568	0.530604	361.8518	538.466632	1.428293	0.639282	0.83
9	0.461625	0.615501	311.9412	415.921582	1.10324	0.769376	0.8
10	0.326204	0.636725	301.5431	588.589113	1.561244	0.715421	0.89

Year 2015

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.147583	0.238135	806.2651	1300.96404	3.450833	0.280159	0.85
2	0.174416	0.281432	682.2243	1100.81573	2.919936	0.331097	0.85
3	0.201249	0.32473	591.2611	954.040297	2.530611	0.382035	0.85
4	0.214666	0.346378	554.3073	894.412778	2.372448	0.407504	0.85
5	0.279673	0.432973	443.4458	686.516427	1.820998	0.515444	0.84
6	0.30764	0.47627	403.1325	624.105843	1.655453	0.566988	0.84
7	0.334603	0.497919	385.605	573.813547	1.522052	0.599902	0.83
8	0.363699	0.541216	354.7566	527.908463	1.400288	0.652068	0.83
9	0.470858	0.627811	305.8247	407.766257	1.081608	0.784763	0.8
10	0.332728	0.649459	295.6305	577.04815	1.530632	0.72973	0.89

Year 2016

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.150535	0.242898	790.456	1275.45494	3.38317	0.285762	0.85
2	0.177904	0.287061	668.8474	1079.23111	2.862682	0.337719	0.85
3	0.205274	0.331224	579.6677	935.333624	2.480991	0.389676	0.85
4	0.218959	0.353306	543.4385	876.875273	2.325929	0.415654	0.85
5	0.285266	0.441632	434.7508	673.055321	1.785293	0.525753	0.84
6	0.313793	0.485796	395.228	611.868473	1.622993	0.578328	0.84
7	0.341296	0.507877	378.0442	562.562301	1.492208	0.6119	0.83
8	0.370973	0.55204	347.8006	517.557316	1.372831	0.665109	0.83
9	0.480275	0.640367	299.8281	399.77084	1.0604	0.800459	0.8
10	0.339382	0.662448	289.8339	565.733481	1.500619	0.744324	0.89

Year 2017

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.153545	0.247756	774.9568	1250.44602	3.316833	0.291477	0.85
2	0.181463	0.292802	655.7327	1058.06971	2.806551	0.344473	0.85
3	0.20938	0.337849	568.3017	916.993749	2.432344	0.397469	0.85
4	0.223338	0.360372	532.7828	859.68164	2.280323	0.423967	0.85
5	0.290972	0.450465	426.2263	659.858157	1.750287	0.536268	0.84
6	0.320069	0.495511	387.4784	599.871052	1.59117	0.589895	0.84
7	0.348121	0.518035	370.6315	551.531667	1.462949	0.624138	0.83
8	0.378393	0.563081	340.981	507.409134	1.345913	0.678411	0.83
9	0.489881	0.653174	293.9491	391.932196	1.039608	0.816468	0.8
10	0.34617	0.675697	284.1508	554.640667	1.471195	0.759211	0.89

Year 2018

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.156616	0.252711	759.7616	1225.92747	3.251797	0.297307	0.85
2	0.185092	0.298658	642.8752	1037.32325	2.751521	0.351363	0.85
3	0.213567	0.344606	557.1585	899.01348	2.384651	0.405418	0.85
4	0.227805	0.367579	522.3361	842.825137	2.23561	0.432446	0.85
5	0.296791	0.459474	417.8689	646.919762	1.715968	0.546993	0.84
6	0.32647	0.505422	379.8808	588.108875	1.55997	0.601692	0.84
7	0.355084	0.528395	363.3642	540.717321	1.434263	0.636621	0.83
8	0.385961	0.574343	334.2951	497.459935	1.319522	0.691979	0.83
9	0.499678	0.666238	288.1854	384.247251	1.019223	0.832797	0.8
10	0.353093	0.689211	278.5793	543.76536	1.442348	0.774395	0.89

Year 2019

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.159748	0.257765	744.8643	1201.88968	3.188036	0.303253	0.85
2	0.188794	0.304631	630.2698	1016.98357	2.697569	0.35839	0.85
3	0.217839	0.351498	546.2338	881.385765	2.337893	0.413527	0.85
4	0.232361	0.374931	512.0942	826.299154	2.191775	0.441095	0.85
5	0.302727	0.468664	409.6754	634.235061	1.682321	0.557933	0.84
6	0.333	0.51553	372.4322	576.577328	1.529383	0.613726	0.84
7	0.362186	0.538963	356.2395	530.11502	1.406141	0.649353	0.83
8	0.39368	0.58583	327.7403	487.705819	1.293649	0.705819	0.83
9	0.509672	0.679562	282.5347	376.712991	0.999239	0.849453	0.8
10	0.360155	0.702996	273.1169	533.103294	1.414067	0.789883	0.89

Year 2020

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.162943	0.26292	730.2591	1178.32321	3.125526	0.309318	0.85
2	0.192569	0.310724	617.9116	997.04272	2.644676	0.365558	0.85
3	0.222196	0.358528	535.5234	864.103691	2.292052	0.421797	0.85
4	0.237009	0.38243	502.0532	810.09721	2.148799	0.449917	0.85
5	0.308781	0.478037	401.6425	621.799079	1.649334	0.569092	0.84
6	0.33966	0.525841	365.1296	565.27189	1.499395	0.626001	0.84
7	0.369429	0.549743	349.2544	519.720608	1.378569	0.66234	0.83
8	0.401554	0.597546	321.314	478.14296	1.268284	0.719935	0.83
9	0.519865	0.693154	276.9948	369.326462	0.979646	0.866442	0.8
10	0.367358	0.717056	267.7617	522.650288	1.38634	0.80568	0.89

Year 2021

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.166202	0.268179	715.9403	1155.21884	3.064241	0.315504	0.85
2	0.196421	0.316939	605.7957	977.492863	2.592819	0.372869	0.85
3	0.226639	0.365698	525.0229	847.160481	2.24711	0.430233	0.85
4	0.241749	0.390078	492.209	794.212951	2.106666	0.458916	0.85
5	0.314957	0.487598	393.7672	609.606941	1.616995	0.580474	0.84
6	0.346453	0.536358	357.9702	554.188128	1.469995	0.638521	0.84
7	0.376818	0.560737	342.4062	509.530008	1.351538	0.675587	0.83
8	0.409585	0.609497	315.0137	468.767607	1.243415	0.734334	0.83
9	0.530263	0.707017	271.5636	362.084767	0.960437	0.883771	0.8
10	0.374706	0.731397	262.5115	512.402244	1.359157	0.821794	0.89

Case 3: 3% Increase

Year 2011: Base Model

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.25	0.11	0.85	0.22	873	1746	4.63
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.47	0.25	0.84	0.4	480	768	2.04
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.55	0.3	0.83	0.46	417	639	1.7
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.72	0.43	0.8	0.58	330	447	1.19
10	0.67	0.3	0.89	0.6	321	639	1.7

Year 2012

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.140434	0.2266	847.308	1367.19	3.626498	0.266588	0.85
2	0.165968	0.2678	716.9529	1156.853	3.068575	0.315059	0.85
3	0.191501	0.309	621.3592	1002.606	2.659432	0.363529	0.85
4	0.204268	0.3296	582.5243	939.9429	2.493217	0.387765	0.85
5	0.266126	0.412	466.0194	721.4636	1.913696	0.490476	0.84
6	0.292738	0.4532	423.654	655.876	1.739724	0.539524	0.84
7	0.318396	0.4738	405.2343	603.0235	1.599532	0.570843	0.83
8	0.346082	0.515	372.8155	554.7816	1.471569	0.620482	0.83
9	0.44805	0.5974	321.3927	428.5236	1.136667	0.74675	0.8
10	0.316611	0.618	310.6796	606.4228	1.608549	0.694382	0.89

Year 2013

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.144647	0.233398	822.6292	1327.369	3.520872	0.274586	0.85
2	0.170947	0.275834	696.0708	1123.158	2.979199	0.324511	0.85
3	0.197246	0.31827	603.2614	973.4036	2.581972	0.374435	0.85
4	0.210396	0.339488	565.5575	912.5659	2.420599	0.399398	0.85
5	0.274109	0.42436	452.446	700.4501	1.857958	0.50519	0.84
6	0.30152	0.466796	411.3146	636.7728	1.689052	0.55571	0.84
7	0.327947	0.488014	393.4313	585.4597	1.552944	0.587969	0.83
8	0.356465	0.53045	361.9568	538.623	1.428708	0.639096	0.83
9	0.461492	0.615322	312.0317	416.0423	1.103561	0.769153	0.8
10	0.326109	0.63654	301.6307	588.76	1.561698	0.715213	0.89

Year 2014

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.148987	0.2404	798.6691	1288.707	3.418322	0.282823	0.85
2	0.176075	0.284109	675.7969	1090.445	2.892426	0.334246	0.85
3	0.203163	0.327818	585.6907	945.0521	2.506769	0.385668	0.85
4	0.216708	0.349673	549.085	885.9863	2.350096	0.41138	0.85
5	0.282333	0.437091	439.268	680.0486	1.803842	0.520346	0.84
6	0.310566	0.4808	399.3345	618.226	1.639857	0.572381	0.84
7	0.337786	0.502654	381.9722	568.4075	1.507712	0.605608	0.83
8	0.367159	0.546364	351.4144	522.9349	1.387095	0.658269	0.83
9	0.475336	0.633782	302.9434	403.9246	1.071418	0.792227	0.8
10	0.335892	0.655636	292.8453	571.6116	1.516211	0.73667	0.89

Year 2015

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.153456	0.247612	775.4069	1251.172	3.318759	0.291308	0.85
2	0.181357	0.292632	656.1135	1058.684	2.808181	0.344273	0.85
3	0.209258	0.337653	568.6317	917.5263	2.433757	0.397238	0.85
4	0.223209	0.360163	533.0922	860.1809	2.281647	0.423721	0.85
5	0.290803	0.450204	426.4738	660.2414	1.751303	0.535957	0.84
6	0.319883	0.495224	387.7034	600.2194	1.592094	0.589552	0.84
7	0.347919	0.517734	370.8468	551.852	1.463798	0.623776	0.83
8	0.378173	0.562754	341.179	507.7038	1.346694	0.678017	0.83
9	0.489596	0.652795	294.1199	392.1598	1.040212	0.815994	0.8
10	0.345969	0.675305	284.3159	554.9628	1.47205	0.75877	0.89

Year 2016

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.15806	0.25504	752.8222	1214.73	3.222096	0.300047	0.85
2	0.186798	0.301411	637.0034	1027.849	2.726389	0.354601	0.85
3	0.215536	0.347782	552.0696	890.8022	2.362871	0.409156	0.85
4	0.229905	0.370968	517.5653	835.1271	2.215191	0.436433	0.85
5	0.299527	0.46371	414.0522	641.011	1.700294	0.552035	0.84
6	0.32948	0.510081	376.4111	582.7373	1.545722	0.607239	0.84
7	0.358357	0.533266	360.0454	535.7786	1.421163	0.642489	0.83
8	0.389518	0.579637	331.2418	492.9163	1.30747	0.698358	0.83
9	0.504284	0.672379	285.5533	380.7377	1.009914	0.840474	0.8
10	0.356348	0.695564	276.0348	538.7988	1.429175	0.781533	0.89

Year 2017

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.162802	0.262692	730.8954	1179.35	3.128249	0.309049	0.85
2	0.192402	0.310454	618.4499	997.9114	2.64698	0.36524	0.85
3	0.222002	0.358216	535.9899	864.8565	2.294049	0.42143	0.85
4	0.236802	0.382097	502.4906	810.803	2.150671	0.449526	0.85
5	0.308513	0.477621	401.9924	622.3408	1.650771	0.568596	0.84
6	0.339364	0.525383	365.4477	565.7644	1.500701	0.625456	0.84
7	0.369108	0.549264	349.5586	520.1734	1.37977	0.661764	0.83
8	0.401204	0.597026	321.594	478.5595	1.269389	0.719309	0.83
9	0.519413	0.69255	277.2362	369.6482	0.980499	0.865688	0.8
10	0.367039	0.716431	267.995	523.1056	1.387548	0.804979	0.89

Year 2018

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.167686	0.270572	709.6071	1145	3.037135	0.31832	0.85
2	0.198174	0.319767	600.4368	968.846	2.569883	0.376197	0.85
3	0.228662	0.368962	520.3786	839.6665	2.227232	0.434073	0.85
4	0.243906	0.39356	487.8549	787.1874	2.08803	0.463011	0.85
5	0.317768	0.49195	390.2839	604.2144	1.602691	0.585654	0.84
6	0.349545	0.541145	354.8036	549.2858	1.456991	0.64422	0.84
7	0.380181	0.565742	339.3773	505.0227	1.339583	0.681617	0.83
8	0.41324	0.614937	312.2271	464.6209	1.232416	0.740888	0.83
9	0.534995	0.713327	269.1613	358.8818	0.951941	0.891659	0.8
10	0.37805	0.737924	260.1893	507.8695	1.347134	0.829128	0.89

Year 2019

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.172716	0.278689	688.939	1111.65	2.948674	0.32787	0.85
2	0.204119	0.32936	582.9484	940.6272	2.495032	0.387483	0.85
3	0.235522	0.380031	505.2219	815.2102	2.162361	0.447095	0.85
4	0.251224	0.405366	473.6455	764.2596	2.027214	0.476902	0.85
5	0.327301	0.506708	378.9164	586.6159	1.55601	0.603224	0.84
6	0.360031	0.557379	344.4695	533.2872	1.414555	0.663546	0.84
7	0.391586	0.582714	329.4925	490.3133	1.300566	0.702065	0.83
8	0.425637	0.633385	303.1331	451.0882	1.196521	0.763115	0.83
9	0.551045	0.734727	261.3217	348.4289	0.924215	0.918408	0.8
10	0.389391	0.760062	252.611	493.0772	1.307897	0.854002	0.89

Year 2020

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.177898	0.28705	668.8728	1079.272	2.862791	0.337706	0.85
2	0.210243	0.339241	565.9693	913.2303	2.422361	0.399107	0.85
3	0.242588	0.391432	490.5067	791.4662	2.09938	0.460508	0.85
4	0.25876	0.417527	459.85	741.9996	1.968169	0.491209	0.85
5	0.33712	0.521909	367.88	569.53	1.51069	0.621321	0.84
6	0.370832	0.5741	334.4364	517.7545	1.373354	0.683453	0.84
7	0.403334	0.600196	319.8957	476.0323	1.262685	0.723127	0.83
8	0.438406	0.652387	294.304	437.9498	1.16167	0.786008	0.83
9	0.567576	0.756768	253.7104	338.2805	0.897296	0.945961	0.8
10	0.401073	0.782864	245.2534	478.7158	1.269803	0.879622	0.89

Year 2021

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.183235	0.295662	649.3911	1047.837	2.779409	0.347837	0.85
2	0.21655	0.349418	549.4847	886.6313	2.351807	0.41108	0.85
3	0.249865	0.403175	476.2201	768.4138	2.038233	0.474323	0.85
4	0.266523	0.430053	446.4563	720.3879	1.910843	0.505945	0.85
5	0.347234	0.537567	357.1651	552.9417	1.466689	0.63996	0.84
6	0.381957	0.591323	324.6955	502.6743	1.333354	0.703956	0.84
7	0.415434	0.618202	310.5783	462.1673	1.225908	0.744821	0.83
8	0.451559	0.671958	285.7321	425.1939	1.127835	0.809588	0.83
9	0.584604	0.779472	246.3207	328.4277	0.871161	0.974339	0.8
10	0.413105	0.80635	238.1101	464.7726	1.232819	0.906011	0.89

Appendix C: Proliferation of Electric Vehicles Data for Models

Case 1: 1% Increase

Year 2011

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.25	0.11	0.85	0.22	873	1746	4.63
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.47	0.25	0.84	0.4	480	768	2.04
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.55	0.3	0.83	0.46	417	639	1.7
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.72	0.43	0.8	0.58	330	447	1.19
10	0.67	0.3	0.89	0.6	321	639	1.7

Year 2012

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.268235	0.141302	0.85	0.228	842.1053	1358.795	3.60423
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.485714	0.263542	0.84	0.408	470.5882	728.5367	1.932458
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.563855	0.314498	0.83	0.468	410.2564	610.4969	1.619355
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.735	0.441	0.8	0.588	326.5306	435.3741	1.154839
10	0.683146	0.311488	0.89	0.608	315.7895	616.3969	1.635005

Year 2013

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.277647	0.14626	0.85	0.236	813.5593	1312.734	3.482052
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.495238	0.268709	0.84	0.416	461.5385	714.5264	1.895295
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.573494	0.319874	0.83	0.476	403.3613	600.2364	1.592139
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.745	0.447	0.8	0.596	322.1477	429.5302	1.139337
10	0.692135	0.315586	0.89	0.616	311.6883	608.3917	1.613771

Year 2014

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.287059	0.151218	0.85	0.244	786.8852	1269.693	3.367887
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.504762	0.273877	0.84	0.424	452.8302	701.0448	1.859535
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.583133	0.32525	0.83	0.484	396.6942	590.3152	1.565823
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.755	0.453	0.8	0.604	317.8808	423.8411	1.124247
10	0.701124	0.319685	0.89	0.624	307.6923	600.5918	1.593082

Year 2015

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.296471	0.156176	0.85	0.252	761.9048	1229.386	3.26097
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.514286	0.279044	0.84	0.432	444.4444	688.0625	1.825099
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.592771	0.330626	0.83	0.492	390.2439	580.7166	1.540362
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.765	0.459	0.8	0.612	313.7255	418.3007	1.109551
10	0.710112	0.323783	0.89	0.632	303.7975	592.9894	1.572916

Year 2016

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.305882	0.161134	0.85	0.26	738.4615	1191.558	3.160632
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.52381	0.284212	0.84	0.44	436.3636	675.5522	1.791916
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.60241	0.336002	0.83	0.5	384	571.4251	1.515716
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.775	0.465	0.8	0.62	309.6774	412.9032	1.095234
10	0.719101	0.327882	0.89	0.64	300	585.577	1.553255

Year 2017

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.315294	0.166091	0.85	0.268	716.4179	1155.989	3.066285
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.533333	0.289379	0.84	0.448	428.5714	663.4888	1.759917
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.612048	0.341378	0.83	0.508	377.9528	562.4263	1.491847
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.785	0.471	0.8	0.628	305.7325	407.6433	1.081282
10	0.72809	0.33198	0.89	0.648	296.2963	578.3477	1.534079

Year 2018

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.324706	0.171049	0.85	0.276	695.6522	1122.482	2.977407
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.542857	0.294547	0.84	0.456	421.0526	651.8486	1.729042
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.621687	0.346754	0.83	0.516	372.093	553.7065	1.468717
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.795	0.477	0.8	0.636	301.8868	402.5157	1.067681
10	0.737079	0.336079	0.89	0.656	292.6829	571.2946	1.51537

Year 2019

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.334118	0.176007	0.85	0.284	676.0563	1090.863	2.893537
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.552381	0.299714	0.84	0.464	413.7931	640.6099	1.69923
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.631325	0.35213	0.83	0.524	366.4122	545.253	1.446294
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.805	0.483	0.8	0.644	298.1366	397.5155	1.054418
10	0.746067	0.340177	0.89	0.664	289.1566	564.4116	1.497113

Year 2020

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.343529	0.180965	0.85	0.292	657.5342	1060.977	2.814262
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.561905	0.304882	0.84	0.472	406.7797	629.7521	1.67043
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.640964	0.357506	0.83	0.532	360.9023	537.0537	1.424546
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.815	0.489	0.8	0.652	294.4785	392.638	1.04148
10	0.755056	0.344276	0.89	0.672	285.7143	557.6924	1.47929

Year 2021

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.352941	0.185923	0.85	0.3	640	1032.684	2.739215
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.571429	0.310049	0.84	0.48	400	619.2562	1.642589
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.650602	0.362882	0.83	0.54	355.5556	529.0973	1.403441
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.825	0.495	0.8	0.66	290.9091	387.8788	1.028856
10	0.764045	0.348374	0.89	0.68	282.3529	551.1313	1.461887

Case 2: 2% Increase

Year 2011

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.25	0.11	0.85	0.22	873	1746	4.63
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.47	0.25	0.84	0.4	480	768	2.04
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.55	0.3	0.83	0.46	417	639	1.7
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.72	0.43	0.8	0.58	330	447	1.19
10	0.67	0.3	0.89	0.6	321	639	1.7

Year 2012

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.277647	0.14626	0.85	0.236	813.5593	1312.734	3.482052
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.495238	0.268709	0.84	0.416	461.5385	714.5264	1.895295
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.573494	0.319874	0.83	0.476	403.3613	600.2364	1.592139
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.745	0.447	0.8	0.596	322.1477	429.5302	1.139337
10	0.692135	0.315586	0.89	0.616	311.6883	608.3917	1.613771

Year 2013

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.296471	0.156176	0.85	0.252	761.9048	1229.386	3.26097
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.514286	0.279044	0.84	0.432	444.4444	688.0625	1.825099
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.592771	0.330626	0.83	0.492	390.2439	580.7166	1.540362
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.765	0.459	0.8	0.612	313.7255	418.3007	1.109551
10	0.710112	0.323783	0.89	0.632	303.7975	592.9894	1.572916

Year 2014

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.315294	0.166091	0.85	0.268	716.4179	1155.989	3.066285
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.533333	0.289379	0.84	0.448	428.5714	663.4888	1.759917
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.612048	0.341378	0.83	0.508	377.9528	562.4263	1.491847
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.785	0.471	0.8	0.628	305.7325	407.6433	1.081282
10	0.72809	0.33198	0.89	0.648	296.2963	578.3477	1.534079

Year 2015

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.334118	0.176007	0.85	0.284	676.0563	1090.863	2.893537
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.552381	0.299714	0.84	0.464	413.7931	640.6099	1.69923
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.631325	0.35213	0.83	0.524	366.4122	545.253	1.446294
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.805	0.483	0.8	0.644	298.1366	397.5155	1.054418
10	0.746067	0.340177	0.89	0.664	289.1566	564.4116	1.497113

Year 2016

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.352941	0.185923	0.85	0.3	640	1032.684	2.739215
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.571429	0.310049	0.84	0.48	400	619.2562	1.642589
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.650602	0.362882	0.83	0.54	355.5556	529.0973	1.403441
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.825	0.495	0.8	0.66	290.9091	387.8788	1.028856
10	0.764045	0.348374	0.89	0.68	282.3529	551.1313	1.461887

Year 2017

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.371765	0.195839	0.85	0.316	607.5949	980.3961	2.60052
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.590476	0.320384	0.84	0.496	387.0968	599.2802	1.589603
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.66988	0.373634	0.83	0.556	345.3237	513.8715	1.363054
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.845	0.507	0.8	0.676	284.0237	378.6982	1.004505
10	0.782022	0.356571	0.89	0.696	275.8621	538.4616	1.42828

Year 2018

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.390588	0.205755	0.85	0.332	578.3133	933.1481	2.475194
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.609524	0.330719	0.84	0.512	375	580.5527	1.539928
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.689157	0.384386	0.83	0.572	335.6643	499.4975	1.324927
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.865	0.519	0.8	0.692	277.4566	369.9422	0.981279
10	0.8	0.364768	0.89	0.712	269.6629	526.3614	1.396184

Year 2019

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.409412	0.215671	0.85	0.348	551.7241	890.2447	2.361392
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.628571	0.341054	0.84	0.528	363.6364	562.9602	1.493263
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.708434	0.395138	0.83	0.588	326.5306	485.9057	1.288875
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.885	0.531	0.8	0.708	271.1864	361.5819	0.959103
10	0.817978	0.372965	0.89	0.728	263.7363	514.793	1.365499

Year 2020

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.428235	0.225587	0.85	0.364	527.4725	851.1131	2.257594
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.647619	0.351389	0.84	0.544	352.9412	546.4025	1.449344
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.727711	0.40589	0.83	0.604	317.8808	473.034	1.254732
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.905	0.543	0.8	0.724	265.1934	353.5912	0.937908
10	0.835955	0.381163	0.89	0.744	258.0645	503.7222	1.336133

Year 2021

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.447059	0.235503	0.85	0.38	505.2632	815.2768	2.162538
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.666667	0.361724	0.84	0.56	342.8571	530.791	1.407934
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.746988	0.416643	0.83	0.62	309.6774	460.8267	1.222352
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.925	0.555	0.8	0.74	259.4595	345.9459	0.917629
10	0.853933	0.38936	0.89	0.76	252.6316	493.1175	1.308004

Case 3: 3% Increase

Year 2011

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.25	0.11	0.85	0.22	873	1746	4.63
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.47	0.25	0.84	0.4	480	768	2.04
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.55	0.3	0.83	0.46	417	639	1.7
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.72	0.43	0.8	0.58	330	447	1.19
10	0.67	0.3	0.89	0.6	321	639	1.7

Year 2012

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.287059	0.151218	0.85	0.244	786.8852	1269.693	3.367887
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.504762	0.273877	0.84	0.424	452.8302	701.0448	1.859535
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.583133	0.32525	0.83	0.484	396.6942	590.3152	1.565823
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.755	0.453	0.8	0.604	317.8808	423.8411	1.124247
10	0.701124	0.319685	0.89	0.624	307.6923	600.5918	1.593082

Year 2013

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.315294	0.166091	0.85	0.268	716.4179	1155.989	3.066285
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.533333	0.289379	0.84	0.448	428.5714	663.4888	1.759917
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.612048	0.341378	0.83	0.508	377.9528	562.4263	1.491847
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.785	0.471	0.8	0.628	305.7325	407.6433	1.081282
10	0.72809	0.33198	0.89	0.648	296.2963	578.3477	1.534079

Year 2014

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.343529	0.180965	0.85	0.292	657.5342	1060.977	2.814262
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.561905	0.304882	0.84	0.472	406.7797	629.7521	1.67043
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.640964	0.357506	0.83	0.532	360.9023	537.0537	1.424546
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.815	0.489	0.8	0.652	294.4785	392.638	1.04148
10	0.755056	0.344276	0.89	0.672	285.7143	557.6924	1.47929

Year 2015

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.371765	0.195839	0.85	0.316	607.5949	980.3961	2.60052
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.590476	0.320384	0.84	0.496	387.0968	599.2802	1.589603
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.66988	0.373634	0.83	0.556	345.3237	513.8715	1.363054
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.845	0.507	0.8	0.676	284.0237	378.6982	1.004505
10	0.782022	0.356571	0.89	0.696	275.8621	538.4616	1.42828

Year 2016

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.4	0.210713	0.85	0.34	564.7059	911.1917	2.416954
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.619048	0.335887	0.84	0.52	369.2308	571.6211	1.516236
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.698795	0.389762	0.83	0.58	331.0345	492.6078	1.306652
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.875	0.525	0.8	0.7	274.2857	365.7143	0.970064
10	0.808989	0.368867	0.89	0.72	266.6667	520.5129	1.380671

Year 2017

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.428235	0.225587	0.85	0.364	527.4725	851.1131	2.257594
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.647619	0.351389	0.84	0.544	352.9412	546.4025	1.449344
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.727711	0.40589	0.83	0.604	317.8808	473.034	1.254732
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.905	0.543	0.8	0.724	265.1934	353.5912	0.937908
10	0.835955	0.381163	0.89	0.744	258.0645	503.7222	1.336133

Year 2018

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.465882	0.245419	0.85	0.396	484.8485	782.3363	2.075163
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.685714	0.372059	0.84	0.576	333.3333	516.0468	1.368825
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.766265	0.427395	0.83	0.636	301.8868	449.2336	1.191601
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.945	0.567	0.8	0.756	253.9683	338.6243	0.898208
10	0.87191	0.397557	0.89	0.776	247.4227	482.9501	1.281035

Year 2019

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.494118	0.260293	0.85	0.42	457.1429	737.6314	1.956582
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.714286	0.387562	0.84	0.6	320	495.405	1.314072
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.795181	0.443523	0.83	0.66	290.9091	432.8978	1.14827
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.975	0.585	0.8	0.78	246.1538	328.2051	0.870571
10	0.898876	0.409852	0.89	0.8	240	468.4616	1.242604

Year 2020

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.522353	0.275166	0.85	0.444	432.4324	697.7594	1.850821
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.742857	0.403064	0.84	0.624	307.6923	476.3509	1.26353
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.824096	0.459651	0.83	0.684	280.7018	417.7084	1.10798
8	0.6	0.31	0.83	0.5	384	618	1.64
9	1.005	0.603	0.8	0.804	238.806	318.408	0.844583
10	0.925843	0.422148	0.89	0.824	233.0097	454.8171	1.206411

Year 2021

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.56	0.294998	0.85	0.476	403.3613	650.8512	1.726396
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.780952	0.423734	0.84	0.656	292.6829	453.1143	1.201895
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.862651	0.481155	0.83	0.716	268.1564	399.0399	1.058461
8	0.6	0.31	0.83	0.5	384	618	1.64
9	1.045	0.627	0.8	0.836	229.6651	306.2201	0.812255
10	0.961798	0.438542	0.89	0.856	224.2991	437.8146	1.161312

Appendix D: Increasing Residential Customer Energy Demand and Number of Electric Vehicles Data for Models

Case 1: 1% Increase

Year 2011

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.25	0.11	0.85	0.22	873	1746	4.63
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.47	0.25	0.84	0.4	480	768	2.04
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.55	0.3	0.83	0.46	417	639	1.7
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.72	0.43	0.8	0.58	330	447	1.19
10	0.67	0.3	0.89	0.6	321	639	1.7

Year 2012

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.162496966	0.2622	732.26545	1181.561	3.134113	0.308471	0.85
2	0.162744863	0.2626	731.15004	1179.761	3.129339	0.308941	0.85
3	0.187782535	0.303	633.66337	1022.459	2.712094	0.356471	0.85
4	0.20030137	0.3232	594.05941	958.5556	2.542588	0.380235	0.85
5	0.286795668	0.444	432.43243	669.4662	1.775772	0.528571	0.84
6	0.287054042	0.4444	432.0432	668.8636	1.774174	0.529048	0.84
7	0.339093261	0.5046	380.49941	566.2159	1.501899	0.607952	0.83
8	0.339362063	0.505	380.19802	565.7674	1.500709	0.608434	0.83
9	0.46935	0.6258	306.80729	409.0764	1.085083	0.78225	0.8
10	0.330955617	0.646	297.21362	580.1382	1.538828	0.725843	0.89

Year 2013

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.164121935	0.344822	556.80902	1169.862	3.103082	0.405673	0.85
2	0.164372312	0.265226	723.91093	1168.08	3.098355	0.312031	0.85
3	0.18966036	0.30603	627.38947	1012.336	2.685241	0.360035	0.85
4	0.202304384	0.326432	588.17763	949.065	2.517414	0.384038	0.85
5	0.289663625	0.52844	363.33359	662.8378	1.75819	0.629095	0.84
6	0.289924583	0.448844	427.76555	662.2412	1.756608	0.534338	0.84
7	0.342484194	0.589646	325.6191	560.6098	1.487029	0.710417	0.83
8	0.342755684	0.51005	376.43368	560.1658	1.485851	0.614518	0.83
9	0.4740435	0.712058	269.64096	405.0261	1.07434	0.890073	0.8
10	0.334265173	0.73246	262.13036	574.3943	1.523592	0.822989	0.89

Year 2014

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.290207818	0.46827	410.01967	661.5949	1.754894	0.550906	0.85
2	0.166016035	0.267878	716.74349	1156.515	3.067678	0.315151	0.85
3	0.191556963	0.30909	621.17769	1002.313	2.658655	0.363636	0.85
4	0.204327428	0.329696	582.35409	939.6683	2.492489	0.387878	0.85
5	0.422264248	0.653724	293.70175	454.6916	1.206078	0.778243	0.84
6	0.292823829	0.453332	423.53025	655.6843	1.739216	0.539681	0.84
7	0.480847456	0.715542	268.32789	399.295	1.059138	0.862099	0.83
8	0.34618324	0.515151	372.70662	554.6196	1.471139	0.620663	0.83
9	0.629383935	0.839179	228.79516	305.0602	0.809178	1.048973	0.8
10	0.440480716	0.859785	223.31175	435.8874	1.1562	0.96605	0.89

Year 2015

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.39226899	0.632953	303.3401	489.4601	1.298303	0.74465	0.85
2	0.167676195	0.270557	709.64702	1145.064	3.037305	0.318302	0.85
3	0.193472533	0.312181	615.02742	992.3889	2.632331	0.367272	0.85
4	0.206370702	0.332993	576.58821	930.3646	2.467811	0.391757	0.85
5	0.52983668	0.820262	234.07165	362.3758	0.961209	0.976502	0.84
6	0.295752067	0.457866	419.33688	649.1924	1.721996	0.545078	0.84
7	0.593176584	0.882698	217.51497	323.681	0.85857	1.063491	0.83
8	0.349645073	0.520302	369.01645	549.1283	1.456574	0.62687	0.83
9	0.755677774	1.00757	190.55741	254.0765	0.673943	1.259463	0.8
10	0.526855955	1.028382	186.70097	364.426	0.966647	1.155486	0.89

Year 2016

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.520140548	0.839282	228.76685	369.131	0.979127	0.987391	0.85
2	0.169352957	0.273263	702.62082	1133.727	3.007233	0.321485	0.85
3	0.195407258	0.315303	608.93804	982.5633	2.606269	0.370945	0.85
4	0.208434409	0.336323	570.87941	921.1531	2.443377	0.395674	0.85
5	0.664322285	1.028464	186.68612	289.0163	0.766622	1.224362	0.84
6	0.298709588	0.462444	415.18503	642.7648	1.704946	0.550529	0.84
7	0.733509167	1.091525	175.90071	261.7554	0.694311	1.31509	0.83
8	0.353141524	0.525505	365.36282	543.6914	1.442152	0.633139	0.83
9	0.913234552	1.217646	157.68129	210.2417	0.55767	1.522058	0.8
10	0.634587553	1.238666	155.00543	302.5587	0.802543	1.39176	0.89

Year 2017

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.674080594	1.087675	176.52327	284.8324	0.755524	1.279618	0.85
2	0.171046487	0.275995	695.66417	1122.502	2.977459	0.3247	0.85
3	0.197361331	0.318456	602.90895	972.8349	2.580464	0.374654	0.85
4	0.210518753	0.339686	565.22714	912.0328	2.419185	0.399631	0.85
5	0.825990193	1.278749	150.14676	232.4483	0.616574	1.52232	0.84
6	0.301696683	0.467069	411.07428	636.4008	1.688066	0.556034	0.84
7	0.902125239	1.34244	143.02314	212.8308	0.564538	1.617398	0.83
8	0.356672939	0.53076	361.74537	538.3083	1.427873	0.63947	0.83
9	1.102366898	1.469823	130.62802	174.1707	0.461991	1.837278	0.8
10	0.763889076	1.491053	128.76806	251.3454	0.666699	1.67534	0.89

Year 2018

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.854349815	1.378552	139.27657	224.7323	0.596107	1.621826	0.85
2	0.172756952	0.278755	688.77641	1111.388	2.947979	0.327947	0.85
3	0.199334944	0.321641	596.93956	963.2029	2.554915	0.378401	0.85
4	0.212623941	0.343083	559.63083	903.0027	2.395233	0.403627	0.85
5	1.015112228	1.571536	122.17344	189.1416	0.501702	1.870877	0.84
6	0.30471365	0.47174	407.00424	630.0998	1.671352	0.561595	0.84
7	1.099307636	1.635865	117.36913	174.6554	0.463277	1.970921	0.83
8	0.360239668	0.536068	358.16373	532.9785	1.413736	0.645865	0.83
9	1.323390567	1.764521	108.81141	145.0819	0.384833	2.205651	0.8
10	0.914976222	1.785963	107.505	209.8415	0.556609	2.006701	0.89

Year 2019

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	1.061211501	1.712338	112.12742	180.9253	0.479908	2.014515	0.85
2	0.174484521	0.281543	681.95684	1100.384	2.918791	0.331227	0.85
3	0.201328294	0.324857	591.02926	953.6663	2.529619	0.382185	0.85
4	0.21475018	0.346514	554.08993	894.0621	2.371518	0.407664	0.85
5	1.23196293	1.907252	100.66841	155.8488	0.413392	2.270538	0.84
6	0.307760787	0.476457	402.9745	623.8612	1.654804	0.567211	0.84
7	1.325342019	1.972223	97.352066	144.8683	0.384266	2.376172	0.83
8	0.363842065	0.541428	354.61756	527.7015	1.399739	0.652323	0.83
9	1.576624472	2.102166	91.334368	121.7792	0.323022	2.627707	0.8
10	1.088066847	2.123823	90.40301	176.4597	0.468063	2.386318	0.89

Year 2020

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	1.294931578	2.089461	91.88973	148.2704	0.39329	2.458189	0.85
2	0.176229366	0.284358	675.20479	1089.489	2.889892	0.334539	0.85
3	0.203341577	0.328106	585.17749	944.224	2.504573	0.386007	0.85
4	0.216897682	0.349979	548.60389	885.21	2.348037	0.41174	0.85
5	1.476819588	2.286324	83.977589	130.0091	0.344852	2.721815	0.84
6	0.310838395	0.481222	398.98465	617.6843	1.63842	0.572883	0.84
7	1.58051691	2.351945	81.634548	121.4792	0.322226	2.833669	0.83
8	0.367480486	0.546843	351.10649	522.4767	1.38588	0.658847	0.83
9	1.862390717	2.483188	77.319973	103.0933	0.273457	3.103985	0.8
10	1.283380986	2.505061	76.64483	149.6048	0.39683	2.814676	0.89

Year 2021

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	1.555778629	2.510356	76.48319	123.4109	0.32735	2.953359	0.85
2	0.17799166	0.287202	668.5196	1078.702	2.861279	0.337884	0.85
3	0.205374992	0.331387	579.38365	934.8753	2.479775	0.389867	0.85
4	0.219066659	0.353479	543.17217	876.4456	2.324789	0.415858	0.85
5	1.749962259	2.709188	70.869956	109.7167	0.291026	3.225223	0.84
6	0.313946779	0.486034	395.03431	611.5686	1.622198	0.578612	0.84
7	1.865123713	2.775465	69.177601	102.9422	0.273056	3.343934	0.83
8	0.37115529	0.552311	347.63019	517.3037	1.372158	0.665435	0.83
9	2.181014624	2.908019	66.024317	88.03242	0.233508	3.635024	0.8
10	1.501140874	2.930112	65.526507	127.9027	0.339265	3.292261	0.89

Case 2: 2% Increase

Year 2011

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.25	0.11	0.85	0.22	873	1746	4.63
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.47	0.25	0.84	0.4	480	768	2.04
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.55	0.3	0.83	0.46	417	639	1.7
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.72	0.43	0.8	0.58	330	447	1.19
10	0.67	0.3	0.89	0.6	321	639	1.7

Year 2012

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.188650177	0.3044	630.749	1017.757	2.69962	0.358118	0.85
2	0.164356199	0.2652	723.9819	1168.194	3.098659	0.312	0.85
3	0.189641768	0.306	627.451	1012.435	2.685504	0.36	0.85
4	0.202284552	0.3264	588.2353	949.158	2.51766	0.384	0.85
5	0.31521686	0.488	393.4426	609.1045	1.615662	0.580952	0.84
6	0.289896162	0.4488	427.8075	662.3061	1.75678	0.534286	0.84
7	0.369064644	0.5492	349.5994	520.2341	1.379931	0.661687	0.83
8	0.342722083	0.51	376.4706	560.2207	1.485997	0.614458	0.83
9	0.5037	0.6716	285.8845	381.1793	1.011086	0.8395	0.8
10	0.354522116	0.692	277.4566	541.5741	1.436536	0.777528	0.89

Year 2013

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.291582274	0.470488	408.0869	658.4762	1.746621	0.553515	0.85
2	0.167643323	0.270504	709.7862	1145.289	3.037901	0.31824	0.85
3	0.193434603	0.31212	615.148	992.5835	2.632848	0.3672	0.85
4	0.206330243	0.332928	576.7013	930.5471	2.468295	0.39168	0.85
5	0.424870988	0.65776	291.8998	451.9019	1.198679	0.783048	0.84
6	0.295694085	0.457776	419.4191	649.3197	1.722333	0.544971	0.84
7	0.48396659	0.720184	266.5985	396.7216	1.052312	0.867692	0.83
8	0.349576525	0.5202	369.0888	549.236	1.456859	0.626747	0.83
9	0.633774	0.845032	227.2103	302.9471	0.803573	1.05629	0.8
10	0.443582989	0.86584	221.75	432.839	1.148114	0.972854	0.89

Year 2014

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.446152561	0.71989776	266.7045	430.3461	1.141502	0.846939	0.85
2	0.170996189	0.27591408	695.8688	1122.832	2.978334	0.324605	0.85
3	0.197303295	0.3183624	603.0863	973.1211	2.581223	0.374544	0.85
4	0.210456848	0.33958656	565.3934	912.301	2.419897	0.399514	0.85
5	0.588393093	0.9109152	210.777	326.3125	0.86555	1.084423	0.84
6	0.301607966	0.46693152	411.1952	636.588	1.688562	0.555871	0.84
7	0.654926902	0.97458768	197.0064	293.1625	0.777619	1.174202	0.83
8	0.356568056	0.530604	361.8518	538.4666	1.428293	0.639282	0.83
9	0.82644948	1.10193264	174.2393	232.3191	0.616231	1.377416	0.8
10	0.575410296	1.1231568	170.9467	333.6749	0.885079	1.261974	0.89

Year 2015

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.6533938	1.054295715	182.1121	293.8504	0.779444	1.240348	0.85
2	0.174416113	0.281432362	682.2243	1100.816	2.919936	0.331097	0.85
3	0.201249361	0.324729648	591.2611	954.0403	2.530611	0.382035	0.85
4	0.214665985	0.346378291	554.3073	894.4128	2.372448	0.407504	0.85
5	0.806860535	1.249133504	153.7065	237.9593	0.631192	1.487064	0.84
6	0.307640126	0.47627015	403.1325	624.1058	1.655453	0.566988	0.84
7	0.883066748	1.314079434	146.1099	217.4241	0.576722	1.583228	0.83
8	0.363699417	0.54121608	354.7566	527.9085	1.400288	0.652068	0.83
9	1.08297847	1.443971293	132.9666	177.2888	0.470262	1.804964	0.8
10	0.750859365	1.465619936	131.0026	255.707	0.678268	1.646764	0.89

Year 2016

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.914359412	1.47538163	130.1358	209.9831	0.556984	1.735743	0.85
2	0.177904435	0.287061009	668.8474	1079.231	2.862682	0.337719	0.85
3	0.205274348	0.331224241	579.6677	935.3336	2.480991	0.389676	0.85
4	0.218959305	0.353305857	543.4385	876.8753	2.325929	0.415654	0.85
5	1.081372221	1.674116174	114.6874	177.5522	0.470961	1.992995	0.84
6	0.313792928	0.485795553	395.228	611.8685	1.622993	0.578328	0.84
7	1.169529717	1.740361022	110.3219	164.1686	0.43546	2.096821	0.83
8	0.370973405	0.552040402	347.8006	517.5573	1.372831	0.665109	0.83
9	1.404638039	1.872850719	102.5175	136.69	0.362573	2.341063	0.8
10	0.970802631	1.894932335	101.3229	197.7745	0.524601	2.129137	0.89

Year 2017

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	1.230123883	1.984889262	96.73084	156.0818	0.41401	2.335164	0.85
2	0.181462524	0.292802229	655.7327	1058.07	2.806551	0.344473	0.85
3	0.209379835	0.337848726	568.3017	916.9937	2.432344	0.397469	0.85
4	0.223338491	0.360371974	532.7828	859.6816	2.280323	0.423967	0.85
5	1.413049036	2.187598498	87.76748	135.8764	0.360415	2.604284	0.84
6	0.320068787	0.495511464	387.4784	599.8711	1.59117	0.589895	0.84
7	1.515482272	2.255168243	85.13777	126.6923	0.336054	2.71707	0.83
8	0.378392873	0.56308121	340.981	507.4091	1.345913	0.678411	0.83
9	1.7927308	2.390307733	80.32439	107.0992	0.284083	2.987885	0.8
10	1.236129978	2.412830981	79.57458	155.3235	0.411999	2.711046	0.89

Year 2018

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	1.60178319	2.584587047	74.28653	119.8664	0.317948	3.040691	0.85
2	0.185091774	0.298658274	642.8752	1037.323	2.751521	0.351363	0.85
3	0.213567432	0.3446057	557.1585	899.0135	2.384651	0.405418	0.85
4	0.227805261	0.367579414	522.3361	842.8251	2.23561	0.432446	0.85
5	1.803034283	2.791350468	68.78391	106.4872	0.282459	3.323036	0.84
6	0.326470163	0.505421694	379.8808	588.1089	1.55997	0.601692	0.84
7	1.922114205	2.860271608	67.12649	99.89001	0.26496	3.44611	0.83
8	0.385960731	0.574342834	334.2951	497.4599	1.319522	0.691979	0.83
9	2.248585416	2.998113888	64.04026	85.38702	0.226491	3.747642	0.8
10	1.547749087	3.021087601	63.55327	124.0511	0.329048	3.39448	0.89

Year 2019

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	2.03045523	3.276278788	58.60307	94.56008	0.250822	3.854446	0.85
2	0.18879361	0.304631439	630.2698	1016.984	2.697569	0.35839	0.85
3	0.21783878	0.351497814	546.2338	881.3858	2.337893	0.413527	0.85
4	0.232361366	0.374931002	512.0942	826.2992	2.191775	0.441095	0.85
5	2.252494129	3.487177477	55.05886	85.23885	0.226098	4.151402	0.84
6	0.332999566	0.515530128	372.4322	576.5773	1.529383	0.613726	0.84
7	2.390639104	3.55747704	53.97083	80.31325	0.213032	4.286117	0.83
8	0.393679945	0.585829691	327.7403	487.7058	1.293649	0.705819	0.83
9	2.773557124	3.698076165	51.91889	69.22518	0.183621	4.622595	0.8
10	1.906585794	3.721509353	51.59197	100.7036	0.267118	4.181471	0.89

Year 2020

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	2.517280258	4.061804364	47.26963	76.27279	0.202315	4.778593	0.85
2	0.192569482	0.310724068	617.9116	997.0427	2.644676	0.365558	0.85
3	0.222195556	0.358527771	535.5234	864.1037	2.292052	0.421797	0.85
4	0.237008593	0.382429622	502.0532	810.0972	2.148799	0.449917	0.85
5	2.762618068	4.276921026	44.89211	69.49929	0.184348	5.091573	0.84
6	0.339659557	0.52584073	365.1296	565.2719	1.499395	0.626001	0.84
7	2.922294827	4.348626581	44.15187	65.70179	0.174275	5.239309	0.83
8	0.401553544	0.597546284	321.314	478.143	1.268284	0.719935	0.83
9	3.369028267	4.492037689	42.74229	56.98973	0.151166	5.615047	0.8
10	2.313584451	4.51593954	42.51607	82.98811	0.220128	5.074089	0.89

Year 2021

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	3.063421334	4.943040451	38.84249	62.67502	0.166247	5.815342	0.85
2	0.196420871	0.316938549	605.7957	977.4929	2.592819	0.372869	0.85
3	0.226639467	0.365698326	525.0229	847.1605	2.24711	0.430233	0.85
4	0.241748765	0.390078214	492.209	794.213	2.106666	0.458916	0.85
5	3.33461938	5.162459447	37.19158	57.57779	0.152726	6.145785	0.84
6	0.346452748	0.536357545	357.9702	554.1881	1.469995	0.638521	0.84
7	3.518343992	5.235599112	36.67202	54.57113	0.144751	6.307951	0.83
8	0.409584615	0.60949721	315.0137	468.7676	1.243415	0.734334	0.83
9	4.036408832	5.381878443	35.67528	47.56703	0.126173	6.727348	0.8
10	2.769708297	5.406258331	35.5144	69.32138	0.183876	6.074448	0.89

Case 3: 3% Increase

Year 2011

Load	S(MVA)	Q(Mvar)	PF	P(MW)	R (Ω)	X (Ω)	L (H)
1	0.25	0.11	0.85	0.22	873	1746	4.63
2	0.31	0.17	0.85	0.26	837	1128	3
3	0.35	0.18	0.85	0.3	639	1068	2.83
4	0.37	0.19	0.85	0.32	600	1011	2.68
5	0.47	0.25	0.84	0.4	480	768	2.04
6	0.52	0.27	0.84	0.44	435	711	1.89
7	0.55	0.3	0.83	0.46	417	639	1.7
8	0.6	0.31	0.83	0.5	384	618	1.64
9	0.72	0.43	0.8	0.58	330	447	1.19
10	0.67	0.3	0.89	0.6	321	639	1.7

Year 2012

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.214803	0.3466	553.95268	893.8406515	2.37093	0.407765	0.85
2	0.165968	0.2678	716.95295	1156.852763	3.068575	0.315059	0.85
3	0.191501	0.309	621.35922	1002.605728	2.659432	0.363529	0.85
4	0.204268	0.3296	582.52427	939.9428696	2.493217	0.387765	0.85
5	0.343638	0.532	360.90226	558.7274128	1.482036	0.633333	0.84
6	0.292738	0.4532	423.65402	655.8759568	1.739724	0.539524	0.84
7	0.399036	0.5938	323.34119	481.1595635	1.276285	0.715422	0.83
8	0.346082	0.515	372.81553	554.7816482	1.471569	0.620482	0.83
9	0.53805	0.7174	267.63312	356.8441595	0.946536	0.89675	0.8
10	0.378089	0.738	260.1626	507.81746	1.346996	0.829213	0.89

Year 2013

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.369986	0.596998	321.60912	518.9383713	1.376494	0.702351	0.85
2	0.170947	0.275834	696.07083	1123.158022	2.979199	0.324511	0.85
3	0.197246	0.31827	603.26138	973.403619	2.581972	0.374435	0.85
4	0.210396	0.339488	565.55755	912.5658928	2.420599	0.399398	0.85
5	0.508972	0.78796	243.66719	377.2310569	1.000613	0.938048	0.84
6	0.30152	0.466796	411.31458	636.7727736	1.689052	0.55571	0.84
7	0.572288	0.851614	225.45426	335.4953639	0.889908	1.026041	0.83
8	0.356465	0.53045	361.95683	538.6229594	1.428708	0.639096	0.83
9	0.734192	0.978922	196.13411	261.5121532	0.693666	1.223653	0.8
10	0.512387	1.00014	191.97312	374.7168251	0.993944	1.123753	0.89

Year 2014

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.604194	0.974908	196.94167	317.778897	0.842915	1.146951	0.85
2	0.176075	0.284109	675.79692	1090.444681	2.892426	0.334246	0.85
3	0.203163	0.327818	585.69066	945.0520573	2.506769	0.385668	0.85
4	0.216708	0.349673	549.085	885.9863037	2.350096	0.41138	0.85
5	0.756778	1.171599	163.87862	253.7071424	0.672963	1.39476	0.84
6	0.310566	0.4808	399.33454	618.2259938	1.639857	0.572381	0.84
7	0.831378	1.237162	155.19385	230.9418264	0.612578	1.490557	0.83
8	0.367159	0.546364	351.4144	522.9349121	1.387095	0.658269	0.83
9	1.026217	1.36829	140.32117	187.0948875	0.496273	1.710362	0.8
10	0.712192	1.390144	138.11517	269.5902234	0.715093	1.56196	0.89

Year 2015

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	0.919797	1.484155	129.36653	208.7417639	0.553692	1.746065	0.85
2	0.181357	0.292632	656.11351	1058.684157	2.808181	0.344273	0.85
3	0.209258	0.337653	568.63171	917.5262692	2.433757	0.397238	0.85
4	0.223209	0.360163	533.09223	860.1808774	2.281647	0.423721	0.85
5	1.089531	1.686747	113.82859	176.2226494	0.467434	2.008032	0.84
6	0.319883	0.495224	387.70344	600.2194114	1.592094	0.589552	0.84
7	1.178882	1.754277	109.44678	162.8662413	0.432006	2.113587	0.83
8	0.378173	0.562754	341.17903	507.7037981	1.346694	0.678017	0.83
9	1.417004	1.889338	101.62288	135.4971702	0.359409	2.361673	0.8
10	0.979469	1.911849	100.42637	196.0245701	0.519959	2.148144	0.89

Year 2016

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	1.319237	2.12868	90.196749	145.5386409	0.386044	2.504329	0.85
2	0.186798	0.301411	637.00341	1027.848696	2.726389	0.354601	0.85
3	0.215536	0.347782	552.06962	890.8022031	2.362871	0.409156	0.85
4	0.229905	0.370968	517.56527	835.1270654	2.215191	0.436433	0.85
5	1.509778	2.337349	82.144338	127.1709798	0.337324	2.782559	0.84
6	0.32948	0.510081	376.41111	582.7372926	1.545722	0.607239	0.84
7	1.61745	2.406906	79.770473	118.70534	0.314868	2.899886	0.83
8	0.389518	0.579637	331.24177	492.9163089	1.30747	0.698358	0.83
9	1.909514	2.546019	75.411864	100.5491515	0.266709	3.182523	0.8
10	1.316242	2.569204	74.731318	145.8698056	0.386923	2.886746	0.89

Year 2017

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	1.80503	2.91254	65.921836	106.3694045	0.282147	3.426518	0.85
2	0.192402	0.310454	618.44991	997.9113552	2.64698	0.36524	0.85
3	0.222002	0.358216	535.98992	864.8565079	2.294049	0.42143	0.85
4	0.236802	0.382097	502.49055	810.8029761	2.150671	0.449526	0.85
5	2.020146	3.12747	61.391483	95.04264394	0.252103	3.723178	0.84
6	0.339364	0.525383	365.44768	565.7643618	1.500701	0.625456	0.84
7	2.149817	3.199113	60.01664	89.30993325	0.236896	3.854353	0.83
8	0.401204	0.597026	321.59395	478.5595232	1.269389	0.719309	0.83
9	2.506799	3.342399	57.443769	76.5916923	0.203161	4.177999	0.8
10	1.724596	3.36628	57.036252	111.3303927	0.295306	3.782337	0.89

Year 2018

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	2.379766	3.839916	50.001088	80.68018537	0.214006	4.517549	0.85
2	0.198174	0.319767	600.43681	968.8459759	2.569883	0.376197	0.85
3	0.228662	0.368962	520.37857	839.6665125	2.227232	0.434073	0.85
4	0.243906	0.39356	487.85491	787.1873555	2.08803	0.463011	0.85
5	2.623337	4.061294	47.275576	73.18923557	0.194136	4.834873	0.84
6	0.349545	0.541145	354.80357	549.2857881	1.456991	0.64422	0.84
7	2.778795	4.135086	46.431922	69.09470264	0.183275	4.982032	0.83
8	0.41324	0.614937	312.22714	464.6208963	1.232416	0.740888	0.83
9	3.212003	4.282671	44.831835	59.77577974	0.158556	5.353339	0.8
10	2.206679	4.307269	44.575814	87.00857285	0.230792	4.839628	0.89

Year 2019

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	3.046114	4.915114	39.063184	63.03112691	0.167191	5.782487	0.85
2	0.204119	0.32936	582.94836	940.6271611	2.495032	0.387483	0.85
3	0.235522	0.380031	505.22191	815.2102063	2.162361	0.447095	0.85
4	0.251224	0.405366	473.64554	764.2595684	2.027214	0.476902	0.85
5	3.322135	5.143133	37.331334	57.79415193	0.1533	6.122777	0.84
6	0.360031	0.557379	344.46948	533.2871729	1.414555	0.663546	0.84
7	3.507283	5.219139	36.787679	54.74323689	0.145208	6.288119	0.83
8	0.425637	0.633385	303.13315	451.0882488	1.196521	0.763115	0.83
9	4.028363	5.371151	35.746527	47.66203603	0.126424	6.713939	0.8
10	2.764702	5.396487	35.578704	69.44690426	0.184209	6.063468	0.89

Year 2020

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	3.806821	6.142567	31.257289	50.4357791	0.133782	7.22655	0.85
2	0.210243	0.339241	565.96928	913.2302535	2.422361	0.399107	0.85
3	0.242588	0.391432	490.50671	791.4662197	2.09938	0.460508	0.85
4	0.25876	0.417527	459.85004	741.999581	1.968169	0.491209	0.85
5	4.119411	6.377427	30.106188	46.60860971	0.12363	7.592174	0.84
6	0.370832	0.5741	334.43639	517.7545368	1.373354	0.683453	0.84
7	4.338265	6.455713	29.741099	44.25731949	0.117393	7.777967	0.83
8	0.438406	0.652387	294.30403	437.9497561	1.16167	0.786008	0.83
9	4.959214	6.612286	29.036858	38.71581052	0.102694	8.265357	0.8
10	3.400944	6.638381	28.922714	56.45492126	0.149748	7.458855	0.89

Year 2021

Load	Q(Mvar)	P(MW)	R (Ω)	X (Ω)	L (H)	S(MVA)	PF
1	4.664719	7.526844	25.508698	41.16003397	0.109178	8.855111	0.85
2	0.21655	0.349418	549.48474	886.6313141	2.351807	0.41108	0.85
3	0.249865	0.403175	476.22011	768.4138055	2.038233	0.474323	0.85
4	0.266523	0.430053	446.45635	720.3879427	1.910843	0.505945	0.85
5	5.018116	7.768749	24.714403	38.26136892	0.101489	9.248511	0.84
6	0.381957	0.591323	324.69553	502.6743076	1.333354	0.703956	0.84
7	5.274818	7.849384	24.460517	36.39935796	0.09655	9.45709	0.83
8	0.451559	0.671958	285.73206	425.193938	1.127835	0.809588	0.83
9	6.007991	8.010654	23.96808	31.95743963	0.084768	10.01332	0.8
10	4.11775	8.037533	23.887928	46.62740477	0.12368	9.030935	0.89

Appendix E: Residential Customer and Residential Customer load with Charging EV Daily P(MW) Demand Data for Models

	Residential Customers	Residential Customers + Electric Vehicles
Hours	P(MW)	P(MW)
1	7.230199614	8.630199614
2	6.881841597	8.281841597
3	6.681262073	8.081262073
4	6.671603348	8.071603348
5	6.813264649	6.813264649
6	7.387314874	7.387314874
7	8.481326465	8.481326465
8	9.211526079	9.211526079
9	9.529942048	9.529942048
10	9.624275596	9.624275596
11	9.693818416	9.693818416
12	9.687701223	9.687701223
13	9.666773986	9.666773986
14	9.656793303	9.656793303
15	9.527688345	9.527688345
16	9.4871217	9.4871217
17	9.593367675	9.593367675
18	9.741468126	9.741468126
19	9.846748229	9.846748229
20	10	11.4
21	9.764971024	11.16497102
22	9.181584031	10.58158403
23	8.392788152	9.792788152
24	7.641017386	9.041017386

Appendix F: Residential Customer and Residential Customer load with Charging EV Daily P(MW) with Grouping Data for Models

Hours	Residential Customers P(MW)	Residential Customers + Electric Vehicles P(MW)	Residential Customers +Grouping Electric Vehicles P (MW)
1	7.230199614	8.630199614	7.730199614
2	6.881841597	8.281841597	7.381841597
3	6.681262073	8.081262073	7.181262073
4	6.671603348	8.071603348	7.171603348
5	6.813264649	6.813264649	6.813264649
6	7.387314874	7.387314874	7.387314874
7	8.481326465	8.481326465	8.481326465
8	9.211526079	9.211526079	9.211526079
9	9.529942048	9.529942048	9.529942048
10	9.624275596	9.624275596	9.624275596
11	9.693818416	9.693818416	9.693818416
12	9.687701223	9.687701223	9.687701223
13	9.666773986	9.666773986	9.666773986
14	9.656793303	9.656793303	9.656793303
15	9.527688345	9.527688345	9.527688345
16	9.4871217	9.4871217	9.4871217
17	9.593367675	9.593367675	9.593367675
18	9.741468126	9.741468126	9.741468126
19	9.846748229	9.846748229	9.846748229
20	10	11.4	10.4
21	9.764971024	11.16497102	10.16497102
22	9.181584031	10.58158403	9.581584031
23	8.392788152	9.792788152	8.892788152
24	7.641017386	9.041017386	8.141017386

Appendix G: Residential Customer and Residential Customer load with Charging EV Daily P(MW) with Supplemental Battery Data for Models

	Residential Customers + Electric Vehicles	Residential Customers + Electric Vehicles + Battery
Hours	**P(MW)**	**P(MW)**
1	8.630199614	8.63019961
2	8.281841597	8.2818416
3	8.081262073	8.08126207
4	8.071603348	8.07160335
5	6.813264649	6.81326465
6	7.387314874	7.38731487
7	8.481326465	8.48132646
8	9.211526079	9.21152608
9	9.529942048	9.52994205
10	9.624275596	9.6242756
11	9.693818416	9.69381842
12	9.687701223	9.68770122
13	9.666773986	9.66677399
14	9.656793303	9.6567933
15	9.527688345	9.52768835
16	9.4871217	9.4871217
17	9.593367675	9.59336768
18	9.741468126	9.74146813
19	9.846748229	9.84674823
20	11.4	9.58367347
21	11.16497102	9.5119098
22	10.58158403	9.11219628
23	9.792788152	8.87442081
24	9.041017386	6.48340605