Electric Vehicles and Their Impact on the Grid

A Baccalaureate thesis submitted to the
Department of Electrical Engineering
College of Engineering and Applied Science
University of Cincinnati

In partial fulfillment of the requirements
For the degree of

Bachelor of Science

In Electrical Engineering

by:
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April 2019
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Acknowledgement

This project was performed with the help of Michael Russ and Dayton Power and Light. Using DP&L's modeling system, PSSE, a case was built based off of the projected load growth calculated from the research. The model is a IEEE 25 bus sample case.

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EXECUTIVE SUMMARY

Electric vehicles are growing in popularity and more automobile manufacturers are putting more money/focus into designing and manufacturing their own electric vehicles. To match this shift to electric vehicles, states have started providing incentives/subsidies to anyone buying an electric vehicle. Electric vehicles currently make up 3% of the vehicles on the road in the US. The issue that utilities will start to face, is how to match the load demand to charge these vehicles. One EV is equivalent to three houses on the grid and the average vehicle ownership, in Ohio, is roughly 1.39 per household. For a small scale case, the load average on the system increased by 1.70% for a 2023 projection and 3.70% for a 2025 projection. For the large scale case, the load average on the system increased by 11.40% for a 2023 projection and 25.10% for a 2025 projection. These percentage increases will lead to undervoltage and thermal issue in the areas that are further away from internal generation. This will lead to an increased loss of life for transmission transformers and increased load demand on distribution transformers, if no action is taken to provide support to the trouble areas.

INTRODUCTION

As more electric vehicles (EVs) hit the market and more people start buying them, the grid will start to experience an increase in load demand. The increase in load demand will require utilities to improve their system to better serve customers and improve reliability. To improve reliability, internal generation may need to be called on during off cost hours resulting in an increase cost for customers.

The load increase, caused by EV charging stations, will more than likely be experienced overnight, as most people will charge their vehicles while they are sleeping. This breaks the norm for the system as the grid experiences a peak load between the hours of 2-6pm and very little load overnight. This can cause off peak generation to be called on, leading to increased market prices for energy and utility cost.

Context

The load increase, caused by EV charging stations, will more than likely be experienced overnight, as most people will charge their vehicles while they are sleeping. This breaks the norm for the system as the grid experiences a peak load between the hours of 2-6pm and very little load overnight. This can cause off peak generation to be called on, leading to increased market prices for energy and utility cost.
[1]

When discussing the effect that electric vehicles have on the power grid it is important to understand the main types of charging station technologies that are being implemented today and in the future. Currently there are 3 types of charging station technologies in use ranging from level 1 to 3. Depending on the car type and model it will take a varying amount of time to fully charge an EV. In order to compare the differences between each charging station the Nissan Leaf will be used as an example. The Nissan Leaf is a four-door, five-passenger hatchback with a range of about 100 miles.

Level 1 charging stations use 120V AC, this is the same voltage from an ordinary power outlet in a home. A Leaf is able to reach a full charge from empty in about 22 hours, a rate of 4.5 miles per hour of charge. This method is the cheapest charging method for a typical residential home.

Level 2 charging stations use 240V AC, electric dryers or ovens use this voltage. Level 2 charging stations allow for a wide range of charging speeds, the high end level 2 stations go all the way up to 19.2 kilowatts (kW), or about 70 miles of range per hour of charging however a typical level 2 charging station is maxed out at 6.6 kW or around 26 miles of range per hour of charging. Leafs can only use 3.3 kW, about 12 miles of range per hour, which equates to about 8 hours for a full charge from empty due to the capability of the electronics that receive the AC power on board the car. Level 2 charging stations are reasonably affordable making them the common choice for a typical residential home. Level 1 and 2 charging stations both use AC power transmission methods. Electronics on board the car convert the AC power into DC to charge the battery. Level 3 charging stations or DC charging stations convert AC power from the electric grid and then refuel the EV with DC power.

DC charging stations are the fastest type of charging currently available. It can provide up to 40 miles of range for every 10 minutes of charging. DC charging stations are expensive making them unlikely to be found in a typical residential home.

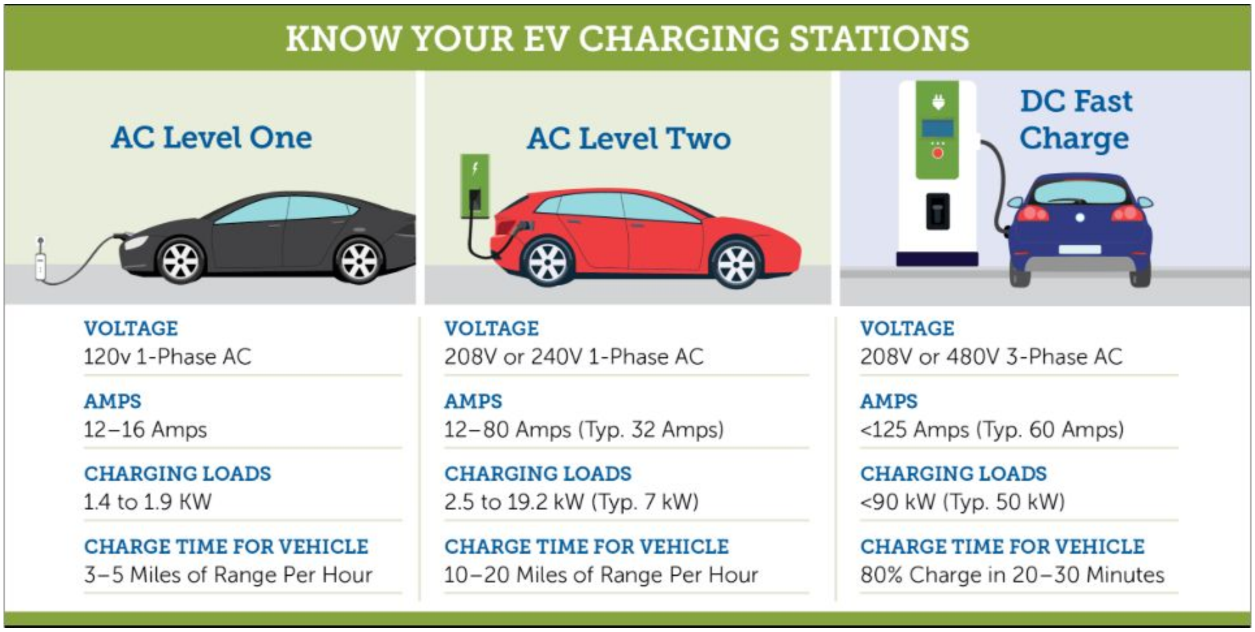

Fig 1: Charging Station Level Breakdown [2]

Scope

This project's scope has been decided as a result of the academic classes and work experience that has been completed while attending the University of Cincinnati through the College of Applied Science. Knowledge of Electrical Engineering, Power Engineering, Technical Communication, as well as Math and Physics concepts should be demonstrated. Experience gained from co-oping multiple semesters at the companies DP&L and Duke Energy along with the academic knowledge gained from the minor of Electrical Energy and Smart Grid will be applied to the project. Research concepts will be applied to a real world model in this project.

Table 1: Project Scope Steps

Step 1: Research	**Step 2: Build**	**Step 3: Test**	**Step 4: Final**
EV Scale	PSSE Case	PSSE Contingency Report	Report
Load Growth	Power World Case	Power World	Presentation
New Tech			Expo
Safety			

Credibility

Both members of the EVs Impact on the Grid team are in the Electrical Engineering Bachelor's degree program and Smart Grid and Power Technologies Minor. Both students had Co-Op rotations with local utility companies, where they had the chance to work alongside their respective Transmission Departments.

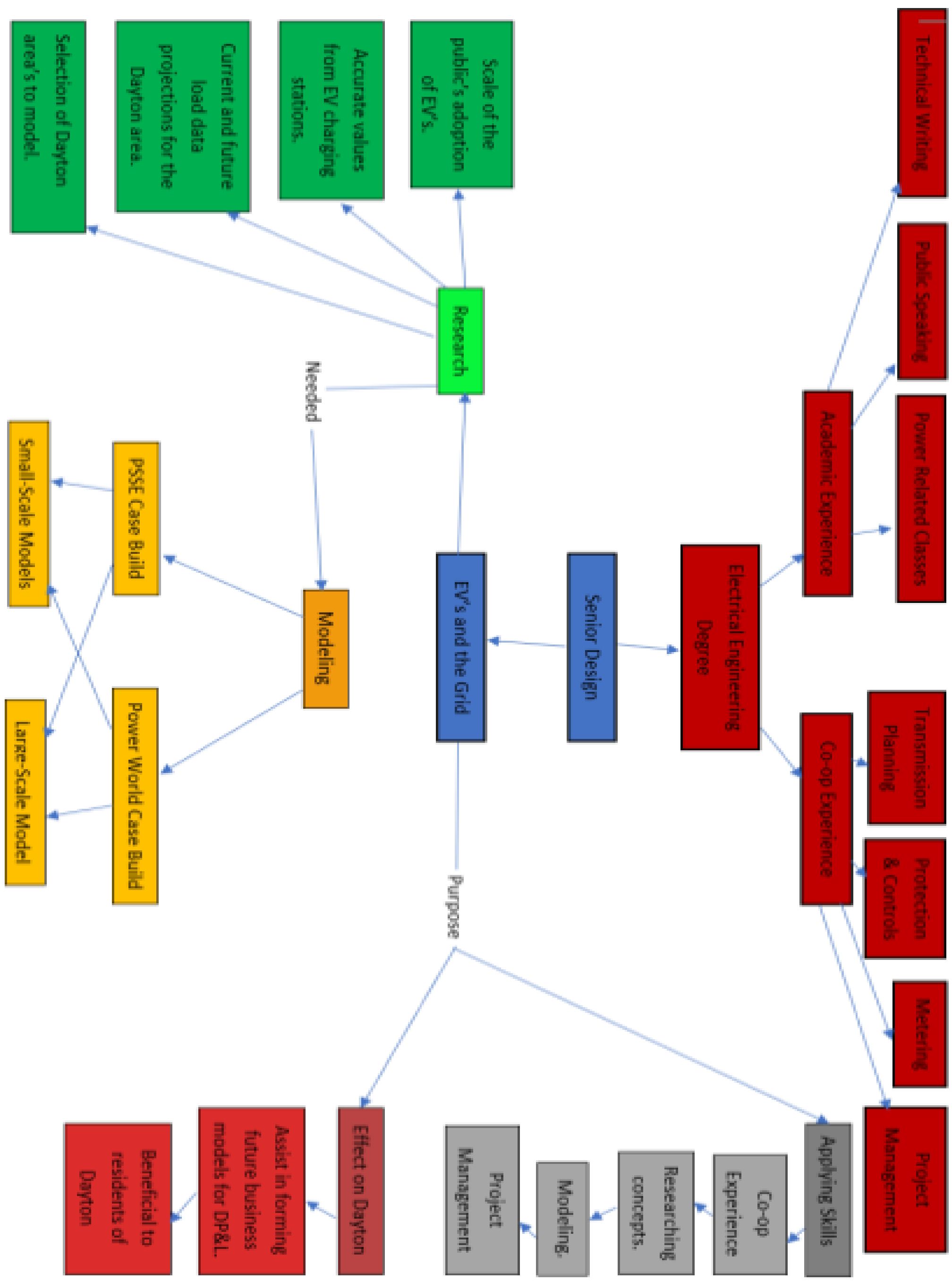

Fig. 2: Concept Map of Relevant Connections

History and Background

[3]

1828

First small-scale electric cars are created by innovators from the Netherlands and the U.S.

1832-1839

Robert Anderson develops the first crude electric vehicle, powered by non-rechargeable primary cells.

1835

American Thomas Davenport is credited with building the first practical electric vehicle. A small locomotive.

1859

French physicist Gaston Plante invents the rechargeable lead-acid storage battery.

1881

Camille Faure improves the storage on Plante's battery and invents the basic lead-acid battery used in automobiles.

1891

William Morrison creates first successful electric vehicle in the U.S.

Fig. 3: William Morrison's Electric Vehicle

1893

Different makes and models of electric vehicles are displayed in Chicago.

1897

The first electric taxis hit the streets of New York City early in the year. Pope Manufacturing Company, of Connecticut, becomes the first large-scale American electric automobile manufacturer.

1899

Thomas Edison begins mission to create a long-lasting, powerful battery for commercial automobiles. Abandons quest a decade later.

1900

Of the 4,192 cars produced in the United States, 28 percent are powered by electricity. Represent about ⅓ of all cars found on the roads of New York City, Boston, and Chicago.

1908

Henry Ford introduces the Model T.

1912

Charles Kettering invents the first practical electric automobile starter. Paves the way for the electric car's decline.

1920

Electric car ceases to be a viable commercial product, due to desire for longer distance vehicles, lack of horsepower, and readily available gasoline.

1966

Congress introduces the earliest bills recommending use of electric vehicles as a means of reducing air pollution.

1970s

Concerns about soaring oil prices and growing environmental movement result in renewed interest in electric cars.

1976

Congress passes the Electric and Hybrid Vehicle Research, Development, and Demonstration Act. To spur improved batteries, motors, and other hybrid-electric components.

1988

Roger Smith, CEO of G.M., agrees to fund research efforts to build a practical consumer electric car.

1990

California passes the Zero Emissions Vehicle Mandate, requiring two percent of the state's vehicles to have zero emissions by 1998 and ten percent by 2003.

1997

Toyota unveils the Prius, the first commercially mass-produced and marketed hybrid car, in Japan.

2006

Tesla Motors publicly unveils the ultra-sporty Tesla Roadster at the San Francisco International Auto Show in November. First Sold in 2008 for $98,950.

2009

The American Recovery and Reinvestment Act allocates $2 billion for development of electric vehicle batteries and related technologies. British government offers a $2,000 subsidy to all electric vehicle purchasers, and establishes a goal to reduce 80% of its carbon emissions by 2050.

2010-Now

Tesla's Model S (85-kWh battery 265 mile range). Tesla's Model 3 ($35,000 range of more than 200 miles). More automakers start to produce electric vehicles.

DISCUSSION

Problem

With more automobile manufactures focusing on producing long range electric vehicles and more states offering incentives for purchasing electric vehicles, understanding how these charging stations will impact the grid grows more important.

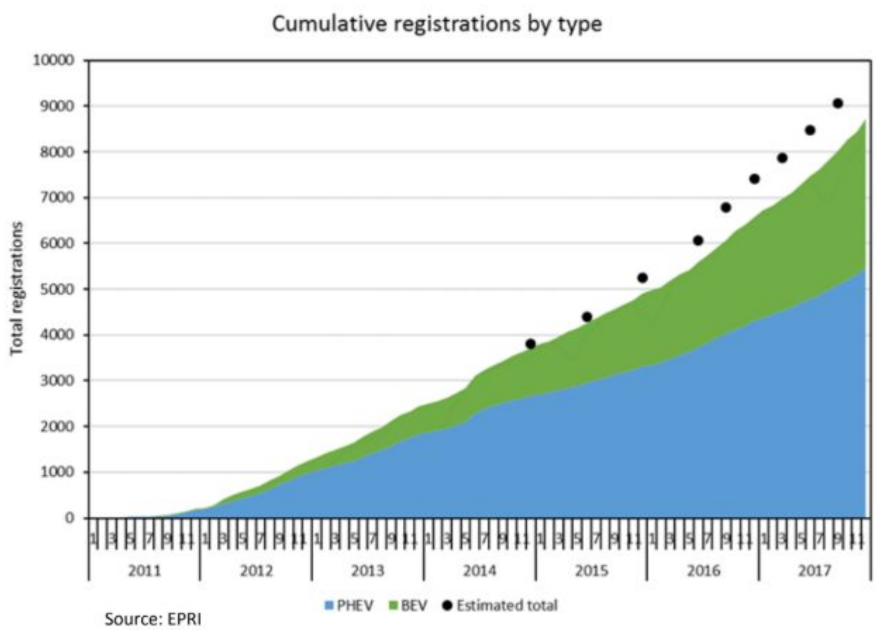

Fig 4: PUCO EV Predictions

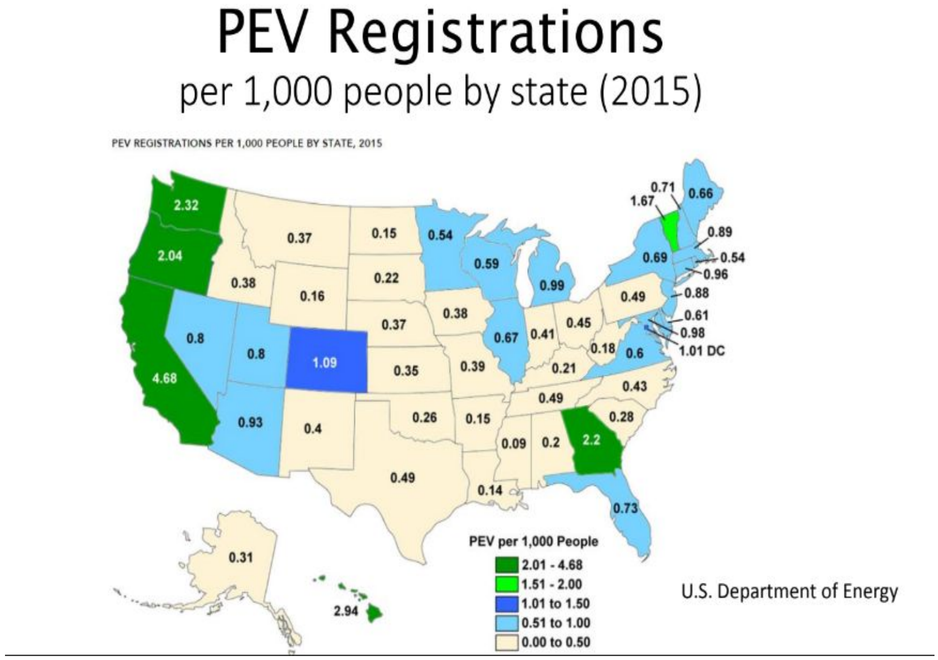

Fig 5: 2015 PEV Registration

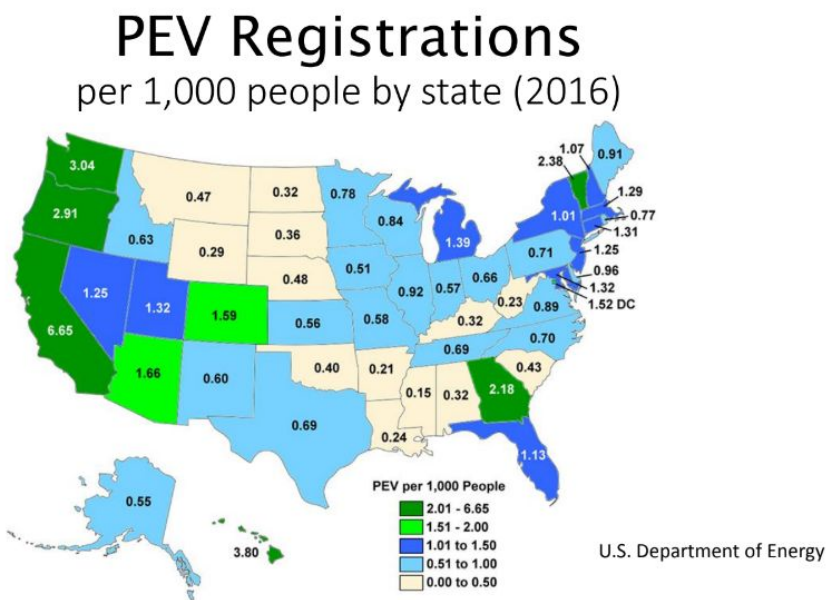

Fig 6: 2016 PEV Registration

// Global EV stock

by selected countries

	2013	2014	2015	2016	2017
China	45,120	98,490	304,810	638,310	1,212,280
USA	171,020	293,630	408,090	563,760	751,510
Norway	20,370	44,770	79,110	124,960	187,270
UK	9,550	24,050	54,700	78,680	125,940
France	31,630	48,040	75,430	109,340	149,350
Netherlands	29,410	44,500	88,270	113,640	121,540
Germany*	13,510	23,910	36,830	55,000	92,740
Japan	71,500	103,560	128,450	149,060	201,410
Sweden	2,650	7,310	16,280	29,780	49,900
Canada	5,680	11,070	18,010	29,240	47,350
Switzerland	2,600	5,020	11,250	17,180	25,130
Spain	9,010	10,970	13,830	20,010	28,340
Rest of World	19,000	44,000	74,000	124,000	224,000
Total	431,050	759,320	1,309,060	2,052,960	3,216,760

// Global EV registrations

by selected countries

	2013	2014	2015	2016	2017
China	17,640	53,830	207,380	336,000	579,000
USA	96,550	123,210	115,930	158,970	195,140
Norway	10,790	24,400	34,340	45,850	62,320
UK	4,180	14,500	28,190	36,910	47,260
France	13,950	16,570	27,770	34,750	41,720
Netherlands	23,150	15,090	43,770	26,110	9,240
Germany*	7,440	13,050	23,460	25,150	54,490
Japan	29,760	32,420	25,690	22,380	56,000
Sweden	1,550	4,670	9,000	13,570	20,310
Canada	3,180	5,410	6,990	11,350	18,390
Switzerland	1,340	2,420	6,240	5,920	8,020
Spain	1,270	1,960	2,870	6,180	8,330
Rest of World	10,000	25,000	30,000	50,000	100,000
Total	220,800	332,530	561,630	773,140	1,200,220

* rounded figures
source: ZSW

Fig. 7: Global EV Registrations [4]

With more EVs hitting the market, utilities will have a harder time with grid stabilization as each electric vehicle connected to the grid is equivalent to 3 houses. The average monthly load of a house for Dayton Power and Light is roughly 1500 kilowatts/hour (kwh). On the high end, the daily load of a house on the Dayton system is 18kW and a level 2 charging station will draw 11.4kW of load, more than half of the daily consumption.

If an EV owner were to charge their vehicle immediately after they get home from work (5 p.m.-6 p.m.), that would generate a new peak load time around 8 p.m., when most of a utilities internal generation is off [7].

Solution

Working with Dayton Power and Light (DP&L), the impact of EVs and their charging stations, on the Dayton grid, will be studied. In order to fully understand how EVs will impact the system, the following topics will be explored:

- Scope of EV deployment. How many EVs are expected to be sold and used in the Dayton area. What would a full scale deployment look like (from a peak, min, load and load profile perspective)?

- What type of technology is out there for household charging stations? How much power do they pull? How can a utility monitor this (Smart meters or another reporting capability)?
- Metropolitan and industrial customer charging stations.
- Impacts of other electric tech charging stations, like Bird scooters.
- Impact on grid protection devices.
- Scheduling for maintenance on substations and transmission/distribution lines/poles.
- Role of Solar and battery storage?
- As load demand increases will more internal/external generation need to be called on causing the customers to have to pay more in their bills?
- How will transmission/distribution teams and planning be affected. What will the increase in load demand look like and what will the peak load times look like?
- Power outage with a full car battery. Customer plugs car in to power house, what is needed to keep the utility safe from a potential backfeed.

With the data gathered from the research topics outlines above, the team will take the load growth predictions and apply them to the load information for the DP&L system. This information will be entered into a PSSE power flow program to analyze grid reliability implications of increased EV penetration. This evaluation will help us to determine the impact of EV charging on the power system and recommend mitigation measures to ensure continued reliable operations with an increased EV presence.

Implementation

1. Project Design and Development
    a. Determine research topics and potential budget.
        i. Only cost should come from travel.
2. Start Research
    a. Cover topic outlines above.
    b. Look into potential subsidies and bills that Ohio provides or has passed.

3. PSSE Case Build

   a. Travel to DP&L and use data predictions to build a case in PSSE for Shoulder, Summer, and Winter peak cases.
   b. Run contingency simulation.
      i. Identify what areas will be impacted most by the load increase and what steps may be necessary to prepare for increase EV penetration.
4. Test Improvements
   a. Test bus updates.
   b. Meet with System Operators.
5. Build Report
   a. Use all information gathered to build final report.

The team will be working with Michael Russ, Transmission Planning Supervisor for DP&L, to build the PSSE case. Each member will have shared responsibility for each aspect of the project areas.

PSSE is a Siemens produced power flow simulation program. The program allows power providers to build their system (busses, transmission lines, transformers, tie lines, load on each us) and run contingencies. These contingencies are a test of what would happen to the system if their were to be a failure somewhere. The contingency will take a transformer out and tell the user where they will see transformer voltage drop or thermal issues on transmission lines.

Timeline

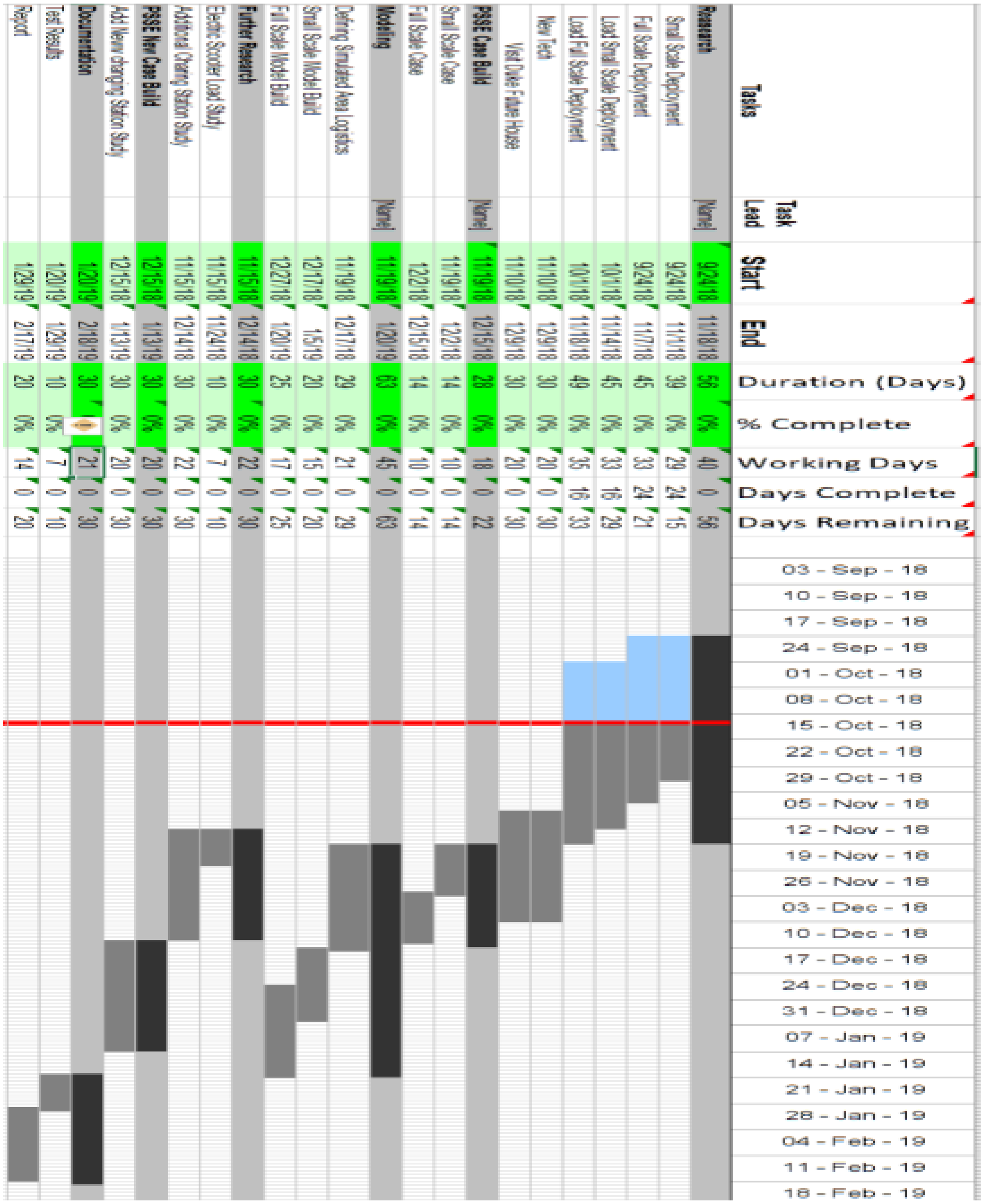

Fig. 8: Gantt Chart Timeline for Design Work

Budget

Table 2: Expenses

Item	Qty.	Price	Total	Notes
Travel	20	$2.75	$55.00	Total (avg per gallon price from summer) depends on the amount of travel between Cincinnati and DP&L
Academic Studies	3	$15.00	$45.00	Purchase of academic studies
PSSE License	4	$1,370.00	$5,480.00	Monthly License Supplied by DP&L
		Total	$5,580.00	

Table 3: Time Breakdown Estimation

Work Performed	Time (Hrs)
PSSE Case Build	8
PSSE Contingency Report	2
EV Scale Research	3
EV Load Impact Research	3
EV Technologies Research	3
Generation Impact Research	2
Safety Impact Research	3
DP&L Meetings	5
PSSE Case Revision	1
Power World Modeling	5
Duke Future House	3
Travel	5
Total	43

Table 4: Cost

Cost Estimation	
Part	Estimated Cost
Expenses	$5,580.00
Labor	$1,505.00
Total	$7,085.00

Benefits

[5]

EV's can reduce emissions and even save you money but EVs provide more than just individual benefits. EVs can help the United States have a greater diversity of fuel choices available for transportation. The U.S. used nearly nine billion barrels of petroleum last year, two-thirds of which went towards transportation. Our reliance on petroleum makes us vulnerable to price spikes and supply disruptions. EVs help reduce this threat because almost all U.S. electricity is produced from domestic sources, including coal, nuclear, natural gas, and renewable sources. EVs can also reduce the emissions that contribute to climate change and smog, improving public health and reducing ecological damage. Charging your EV on renewable energy such as solar or wind minimizes these emissions even more.

The benefits to having an accurate model of the effect electric vehicles will have on a power grid are bountiful. This model will help both the energy companies that rely on continued efficiency for their business to prosper and for the community who expect their power to function as a seamless aspect of their life. The effects to local businesses can be life altering. Some of the possible ways a blackout can affect a business are as follows:

[6]

- Lost Customers and Revenue: When power outages occur, sites may go down and result in lost customers and lost revenue. When customers can't access your website, they may have no way to purchase products. This one-time power outage could impact how they perceive your company. A damaged reputation can have long-term effects on your revenue. Gaining these customers back might require significant marketing efforts, which can be costly.
- Unturned Inventory: Inventory turnover refers to the number of times a company's inventory is sold or replaced during a specific period of time. If you experience downtime due to an outage, the speed at which you sell your inventory will decrease. If customers aren't able to make purchases, your unturned inventory will increase.
- Decreased Employee Productivity: Downtime as a result of power outages has an impact on employee productivity. Employees may not be able to complete their tasks when key equipment is down. Also, IT employees may need to work overtime to resolve problems or professionals may need to be hired to help recover lost data and get systems running again. Depending on the duration of the power outage, lower employee productivity can have a huge effect on your businesses bottom line.
- Stored Computer Data Lost: Power outages are one of the top reasons data loss occurs. Because computers and operating systems are complex, they need to shut down properly. An outage causes computers to shut down

unexpectedly. Any files you were working on could be lost or become corrupted. If power outages occur frequently, they can damage your hard drive and reduce its lifespan.

- Damaged Equipment: Power outages can cause long-term damage to your equipment. The greatest cause of equipment damage from power outages is the electrical surges that occur when the power is restored. Not having a proper backup power supply or not implementing protection from surges can cause your equipment to become damaged when the power comes back online. Also, the cost to repair equipment is an unanticipated expense that could set you back.

Power companies such as DP&L in the Dayton area depend on continuous and efficient delivery of power to their customers in order to maintain a successful business model and to sustain a stable and protected energy grid. A major concern that is always present in the power industry is the threat of cascading failures. Cascading failures is a process in a power grid in which the failure of one or few parts can trigger the failure of other parts and so on. Cascading failures may occur when one part of the system fails. When this happens, other parts must then compensate for the failed component. This in turn overloads these nodes, causing them to fail as well, prompting additional nodes to fail one after another. It is the responsibility of protection and controls engineers to create protection schemes that will not succumb to cascading failures but engineers can only prepare and plan for so much. With the threat of additional brownouts or blackouts present it creates a massive strain on the part of engineers to be able to adequately prepare for fault eventuality. Without planning for load demand growth as well as strain on already outdated equipment an unprepared power grid can experience a devastating blow in the matter of a day. This study will provide a projection of the possible load growth a city like Dayton could experience. Using that kind of data engineers can predict the kind of generation demand as well as the remaining longevity of current equipment in the field helping them prioritise the needs of their energy grid as a whole.

FINDINGS

The EV growth projections, below, only pertain to the Dayton Power and Light service area.

Make/Model	Type	US Registrations 2015	US Registrations 2016	US Registrations 2017	US Registrations 2018	Total	US Percentage*
Tesla Model S	EV	25202	29421	27060	25745	107428	0.51
Tesla Model X	EV	214	18223	21315	26100	65852	0.31
Tesla Model 3	EV	0	0	1770	139782	141552	0.67
Nissan Leaf	EV	17269	14006	11230	14715	57220	0.27
Toyota Prius C	Hybrid	38469	20452	12415	8399	79735	0.38
Chevy Volt	Hybrid	15393	24739	20439	18306	78877	0.37
Total		96547	106841	94229	233047	530664	2.51

Fig 9: EV/Hybrid Sales 2015-2018

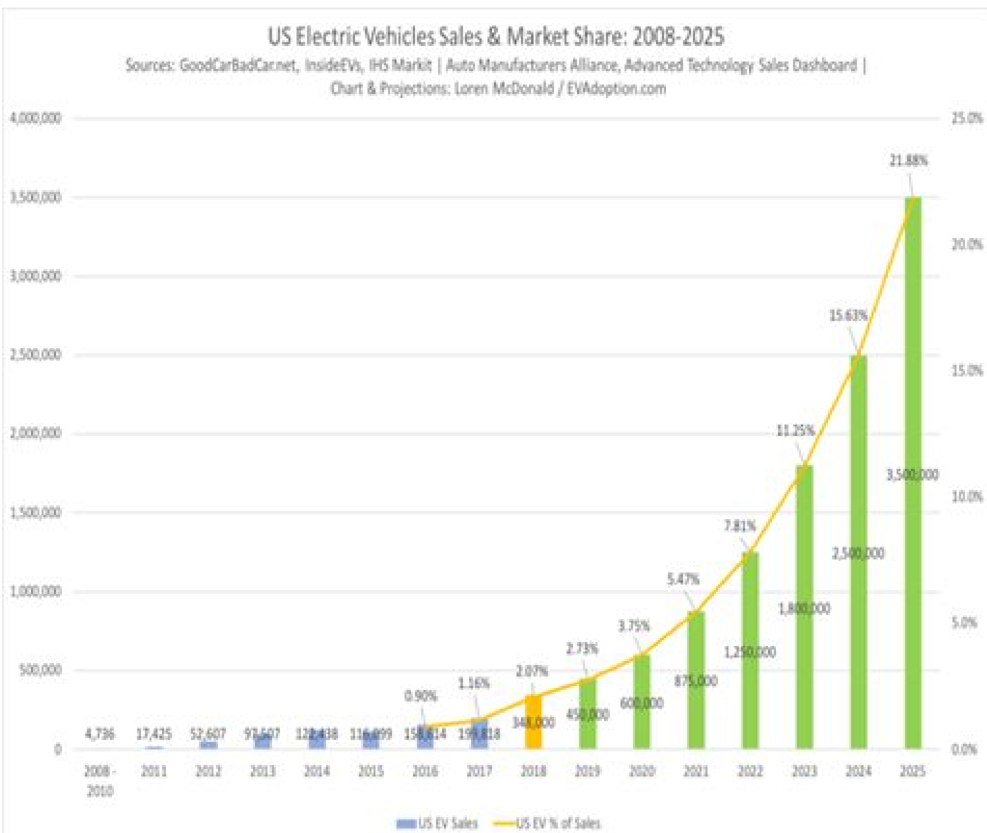

Fig 10: Projected EV sales

Using the percentages from Fig 10, the percentage of EVs expected in the Dayton area were calculated.

	Dayton Total EVs	2019	2020	2021	2022	2023	2024	2025
Small Scale	21684	592	813	1245	1694	2439	3389	4744
Large Scale	722800	19732	27105	41489	56451	81315	112974	158149

Fig 11: EVs Projected for the Dayton Area 2019-2025

Using the projected values in Fig. 11 and the total load demand for level 2 and 3 charging stations, the kW load demand for the years of 2019-2025 was calculated.

Year	Small Scale Level 2 Load kW	Large Scale Level 2 Load kW	Small Scale Level 3 Load kW	Large Scale Level 3 Load kW
2019	6,808	226,923	71,037	2,367,893
2020	9,351	311,708	97,578	3,252,600
2021	14,314	477,120	149,359	4,978,646
2022	19,475	649,183	203,222	6,774,082
2023	28,054	935,123	292,734	9,757,800
2024	38,976	1,299,197	406,705	13,556,837
2025	54,561	1,818,709	569,335	18,977,837

Fig 12: Added EV Yearly kW Demand

The KVA demand for level 2 and 3 charging stations were calculated by dividing the power factor of the charging station into the kW load demand of the charging station. Using this KVA value, the total yearly KVA demand was calculated using the values from Fig. 11 and multiplying by the charging station KVA demand.

	Year	Small Scale Level 2 Load KVA	Large Scale Level 2 Load KVA	Small Scale Level 3 Load KVA	Large Scale Level 3 Load KVA
Level 2 KVA	2019	7,564	252,137	78,930	2,630,992
12.8	2020	10,390	346,342	108,420	3,614,000
	2021	15,904	530,134	165,955	5,531,829
Level 3 KVA	2022	21,639	721,314	225,803	7,526,757
133.3	2023	31,171	1,039,025	325,260	10,842,000
	2024	43,307	1,443,552	451,895	15,063,152
	2025	60,624	2,020,788	632,595	21,086,485

Fig 13: Added EV Yearly KVA

Using the values from Fig. 11 and Fig. 12 the total kvar was found by the following equation:
$sqrt((KVA^2) - (kW^2)) = kvar$

Year	Small Scale Level 2 Load kvar	Large Scale Level 2 Load kvar	Small Scale Level 3 Load kvar	Large Scale Level 3 Load kvar
2019	3,297	109,904	34,405	1,146,823
2020	4,529	150,967	47,259	1,575,306
2021	6,932	231,080	72,338	2,411,269
2022	9,432	314,414	98,425	3,280,837
2023	13,587	452,900	141,778	4,725,918
2024	18,877	629,230	196,976	6,565,876
2025	26,425	880,841	275,742	9,191,386

Fig 14: Added EV Yearly kvar

The projected kW, kVAR, and KVA values were used to calculate the expected kW, kVAR, and KVA due to a percentage of vehicles charging at a given time ("Online/Charging %"). The value of 50% for the small scale case states that at any given time 50% of the expected EV fleet that year will be charging on the grid.

		Small Scale		
	Online/Charging %	kW	kVAR	KVA
2019	50%	5,010	2,426	5,566
2020	50%	11,891	5,759	13,212
2021	50%	22,424	10,860	24,915
2022	50%	36,755	17,801	40,839
2023	50%	57,399	27,800	63,777
2024	50%	86,080	41,691	95,645
2025	50%	126,230	61,136	140,256

Table 4: Small Scale Load Growth From 50% Vehicles Charging

The projected kW, kVAR, and KVA values were used to calculate the expected kW, kVAR, and KVA due to a percentage of vehicles charging at a given time ("Online/Charging %"). The value of 10% for the large scale case states that at any given time 10% of the expected EV fleet that year will be charging on the grid. This value had to be used due to the fact that the case would not build in PSSE as the values were too large as a result of more vehicles charging. This number is expected to be larger.

		Large Scale		
	Online/Charging %	kW	kVAR	KVA
2019	10%	33,397	16,175	37,107.95
2020	10%	79,272	38,393	88,080.41
2021	10%	149,492	72,402	166,102.25
2022	10%	245,035	118,676	272,260.89
2023	10%	382,660	185,331	425,178.27
2024	10%	573,868	277,937	637,631.47
2025	10%	841,535	407,574	935,038.78

Table 5: Large Scale Load Growth From 10% Vehicles Charging

The values from Figures 11-14 were used to build a PSSE case in order to run contingency reports to see what areas would be impacted by the added load growth. For the simulations, a sample IEEE 25 bus case was used.
The base case voltage plot, how the system is responding without the added EV load growth, is shown in Figure 15.

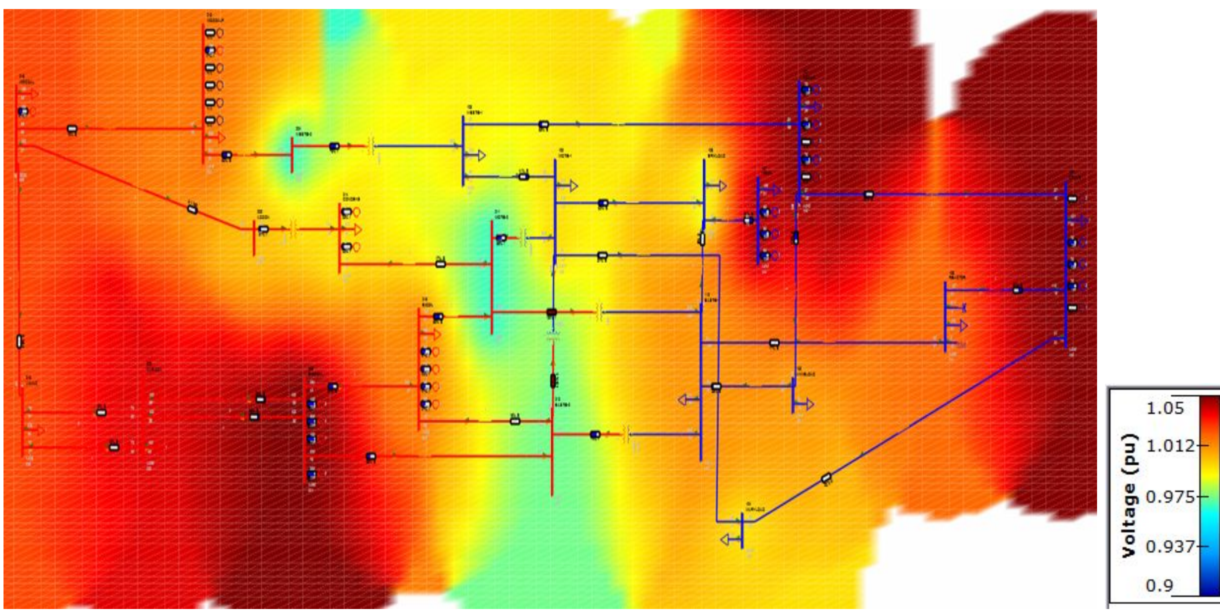

Fig 15: IEEE 25 Bus Base Case Voltage Plot

The areas highlighted in red are operating as expected, with the darker red areas being a bus with generation at that site. The power being generated is getting funneled to the center of the system to support the buses that are operating slightly under load demand in that area.

Adding the projected EV load growth to the case build, the system is heavily impacted, see Figure 16. A majority of the system does not have the power to support the load demand of the vehicles. The areas operating in blue are unable to meet the load demand of the customers off of that bus. This will lead to inconsistent power to the customer, load shed (dropping customers in order to provide power to high risk areas), rolling blackouts, etc.

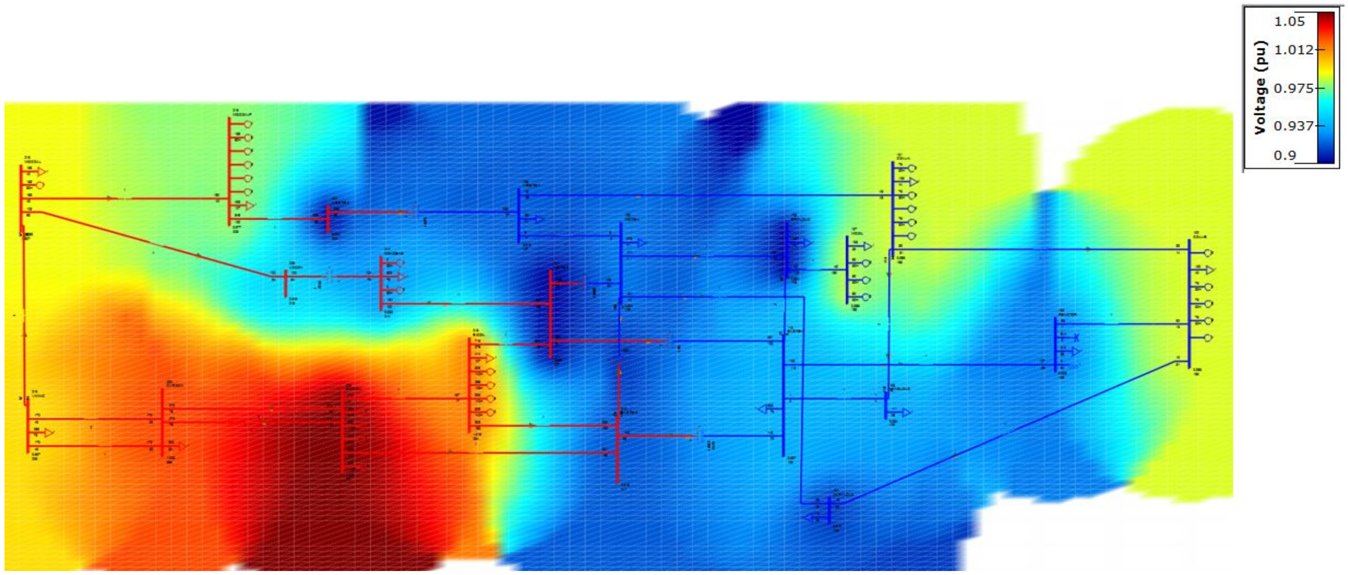

Fig 16: IEEE 25 Bus Large Scale 25% Load Growth Case Voltage Plot

From the same case build, thermal plots were obtained to see how hot the system was running. Figure 17 shows how the system is operating under current day stress.

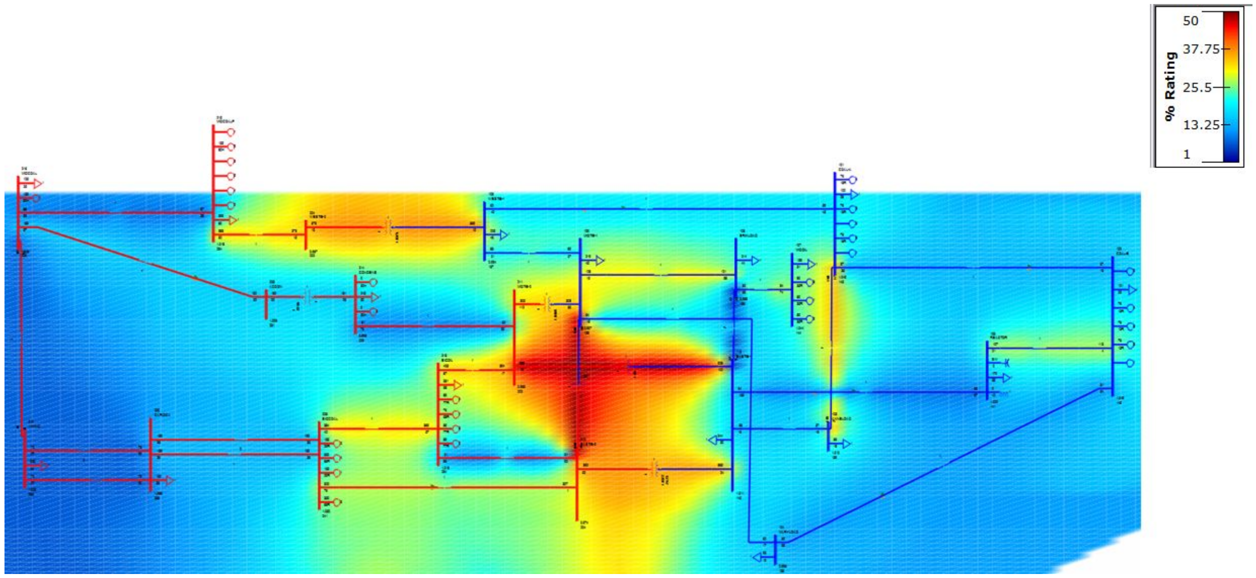

Fig 17: IEEE 25 Bus Base Case Thermal Plot

The areas in blue are operating at an ideal thermal level while the areas in red are operating at a temperature that is higher than ideal.

Adding the projected EV load growth to the case build, the system is heavily impacted, see Figure 18. A majority of the system is now running hot. This will lead to an increase in component loss of life, as transformers are now operating above nameplate value for extended periods of time.

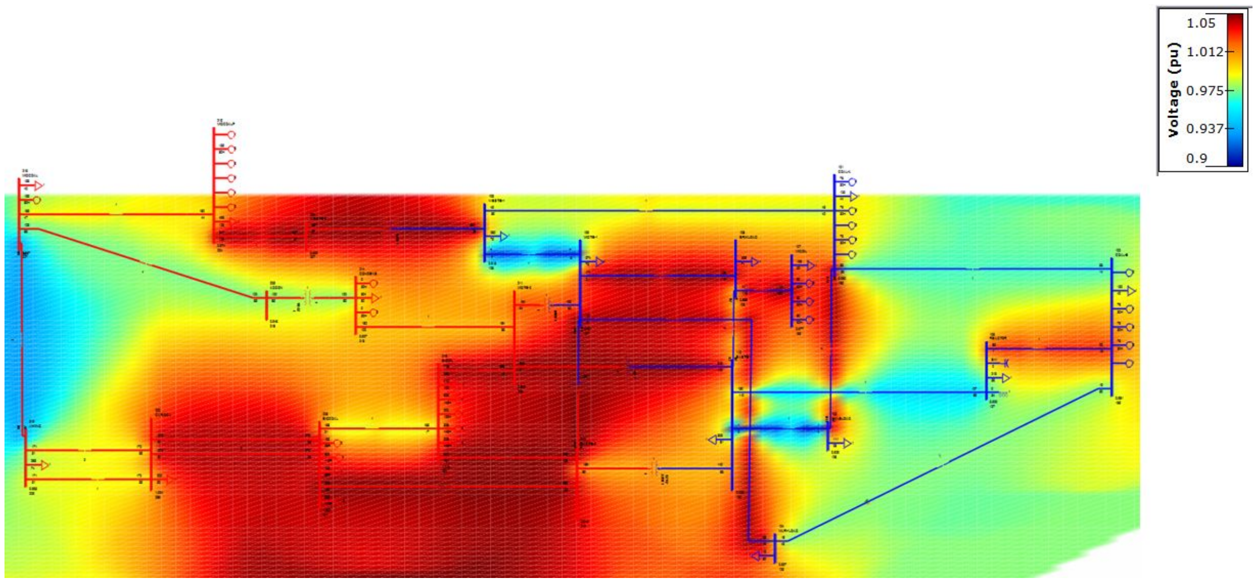

Fig 18: IEEE 25 Bus Large Scale 25% Load Growth Case Thermal Plot

Through an email (M, Russ, personal communication, April 4, 2019) the following was stated through an attached file.

"**PSSE Transmission Study**

Using the PSSE load flow software, simulations were run using projected 2023 system conditions combined with a sharp increase of EV penetration. Using the forecasted peak loads provided by the research team, simulations were conducted on Summer peak, Winter peak, and Shoulder peak 2023 load flow cases. The simulations used in this research analyzed both thermal and voltage performance of the transmission system. Utility companies have certain planning criteria for thermal and voltage performance that must be met with a normal system and under different outage scenarios. If there are large scale increases in EV load on the system, this could have a major impact on the performance of the transmission system to meet thermal and voltage performance criteria. It is critical that utilities plan for these increases and build the necessary infrastructure in advance to meet future load demands.

Shoulder Study

The shoulder peak loading condition typically happens during the evening hours of a summer day or during the afternoon on a warm spring/fall day. EV's are likely to have the largest impact during evening hours of a summer day. Currently, load would decrease during the evening hours but if EV's are being plugged back in for storage, the load may stay steady and not decrease during these hours. This could be further complicated with solar going offline after dusk. The results of the incremental EV load on a present-day shoulder peak case showed new voltage and thermal performance issues on the system. These could potentially be mitigated by bringing additional generation online depending on location or through planned transmission system upgrades.

Winter Study

The traditional winter peak occurs during the morning hours when temperatures are coldest and commercial and industrial load comes online at the beginning of the work day. The impact of EV's on the winter peak case were not as strong as the shoulder case. This can be attributed largely due to increased line ratings during the winter loading seasons. As the ambient temperatures drop outside, transmission lines can operate at higher ratings during winter months. Therefore, the increase in line ratings cancels out the incremental impact of EV's on the grid. It did not surface as an issue for the Dayton system which is summer peaking, but winter peaking systems may see a greater impact.

Summer Study

The summer study replicates the peak summer loading conditions of the grid which typically occurs during the late afternoon or early evening hours. The impact of EV's into this model produced new thermal and voltage performance issues onto the system. Most of this EV load is likely to come online after the system actually peaks so it is not likely there will not be a significant peak load contribution as demonstrated in this specific study. However, the industry needs to research this assumption in greater detail to determine hourly EV peaks to better understand how/when to accurately model this load. In the event that EV load does significantly increase peak load as demonstrated in this scenario, future grid and generation upgrades may be required.

Key Questions Facing Industry

· Will the auto industry transition completely to EV's and if so, at what rate?

· At a snapshot in time, what will be the breakdown be between Level 1, 2, and 3 charging stations. Due to the vast difference in power requirements, it is critical to understand this for load forecasting.

· Will Level 2 and Level 3 kW demands increase in efforts to shorten charge times?

· The research team believes Level 2 charging stations will account for a large percentage of the EV load, what will be the standard size of a Level 2 charging station going forward? This could have a major impact on utility transformer sizing.

· If electrification of trucking fleets occurs, what impact will this have on the grid in addition to an increase in EV personal vehicles. How will utilities plan for large scale Level 3 installations?

o Side Note: Think about a large truck stop like Pilot, how many semi diesel pumps do they have today? What if these were all Level 3 charging stations, what type of loads might we be looking at? Also, since it takes 30 minutes to charge on a Level 3, there are likely to be significantly more charging stations than pumps. Charging/Fueling stations may become a major utility load.

· Timing – what time of day and what percentage of total EV load will we see the bulk of the EV load on the grid? Depending on the assumptions, these variables could have a major impact on grid loading."

FUTURE RESEARCH

Tesla has started to research and produce electric semis, as outlined above, how will a fleet of electric semi trucks impact the grid. How often and how long will they need to charge. Truck stops will more than likely have to be outfitted with a charging station at each parking spot so that there are a minimal amount of trucks waiting on charge. Today a truck can just pull up, refuel at a diesel pump, and pull out relatively quick. If the truck were electric they now have to wait 30 minutes for the truck to charge and have a 400 mile battery life [8].

If electric vehicles are one-percent adopted, what will a standard gas station look like? Will the pumps be replaced with level 3 charging stations/DC fast charge stations. What would a standard city street and highway look like?

Will there be a battery exchange system put in place? This system would allow a EV owner to take their low battery out of their EV and exchange it for a full battery at a location similar to a gas station. This could reduce the amount of vehicle on the grid charging at random intervals of time.

What incentive will be provided? Will more states start to provide monetary incentives for purchasing EVs, will more utilities incentivise customers for charging their vehicle on off peak times?

CONCLUSION

Electric Vehicles are increasing in popularity across the globe as some countries have set goals for the amount of EVs that need to be manufactured and stating that carbon emission vehicles are not permitted to be manufactured. It can be seen that the state of Ohio is slowly making the switch to cleaner energy with most of the utilities in Ohio closing their coal burning generation facilities. With the current predictions for the increase in EV usage it is seen that understanding how the load demand caused by the charging of these vehicles gains importance.

RESOURCES

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[8]	Howard, Bill. "Tesla Semi: 500-Mile Range, Cheaper Than Diesel, Quick to Charge." ExtremeTech, 17 Nov. 2017, www.extremetech.com/extreme/259195-tesla-semi-500-mile-range-cheaper-diesel-quick-charge.

APPENDIX

Table 1a: EV Time-to-Charge

*CHARGE TIMES ARE IN HOURS

CLIPPERCREEK®

RELIABLE. POWERFUL. MADE IN AMERICA.

ESTIMATED CHARGE TIMES CHART FOR (Pure) ELECTRIC VEHICLES

VEHICLE	ACCEPTANCE RATE (kW)	BATTERY SIZE (kWh)	LEVEL 1 ACS-15 1.4 kW	LEVEL 1 PCS-15 1.4kW	LEVEL 2 LCS-20 3.8kW	LEVEL 2 LCS-25 4.8kW	LEVEL 2 LCS-30 5.8kW	LEVEL 2 HCS-40 7.7kW	LEVEL 2 HCS-50 9.6kW	LEVEL 2 HCS-60 11.5kW	LEVEL 2 HCS-80 15.4kW
BMW ActiveE	7	32	23	23	8.5	6.5	5.5	4.5	4.5	4.5	4.5
BMW i3 2014-2016	7.4	23	16.5	16.5	6	5	4	3	3	3	3
BMW i3 2017 (60 Ah battery)	7.4	23	16.5	16.5	6	5	4	3	3	3	3
BMW i3 2017 (90 Ah battery)	7.4	32	23	23	8.5	6.5	5.5	4.5	4.5	4.5	4.5
Chevy Bolt	7.2	60	43	43	16	12.5	10.5	8.5	8.5	8.5	8.5
Chevy Spark	3.3	23	16.5	16.5	7	7	7	7	7	7	7
Coda	6.6	31	22	22	8	6.5	5.5	4.5	4.5	4.5	4.5
Fiat 500E	6.6	24	17	17	6.5	5	4	3.5	3.5	3.5	3.5
Ford Focus EV	6.6	23	16.5	16.5	6	5	4	3.5	3.5	3.5	3.5
Ford Focus EV 2017-2018	6.6	33.5	24	24	9	7	6	5	5	5	5
Honda Clarity EV	6.6	25.5	18	18	6.5	5.5	4.5	4	4	4	4
Hyundai Ioniq	6.6	28	20	20	7.5	6	5	4	4	4	4
Kia Soul	6.6	27	19.5	19.5	7	5.5	4.5	4	4	4	4
Jaguar I-Pace	7	90	64.5	64.5	23.5	19	15.5	13	13	13	13
Mercedes B Class B250e	9.6	28	20	20	7.5	6	5	3.5	3	3	3
Mitsubishi i-MiEV	3.3	16	11.5	11.5	5	5	5	5	5	5	5
Nissan Leaf 2011-12	3.3	24	17	17	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Nissan Leaf 2013-16 S	3.3	24	17	17	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Nissan Leaf S 2013-15	6.6	24	17	17	6.5	5	4	3.5	3.5	3.5	3.5
Nissan Leaf S 2016	6.6	24	17	17	6.5	5	4	3.5	3.5	3.5	3.5
Nissan Leaf S 2016	6.6	30	21.5	21.5	8	6.5	5	4.5	4.5	4.5	4.5
Nissan Leaf 2017	3.3	30	21.5	21.5	9	9	9	9	9	9	9
Nissan Leaf 2017	6.6	30	21.5	21.5	8	6.5	5	4.5	4.5	4.5	4.5
Nissan Leaf 2018	6.6	40	28.5	28.5	10.5	8.5	7	6	6	6	6
Smart Car	3.3	17.6	12.5	12.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Smart Fortwo ED 2017	7.2	17.6	12.5	12.5	4.5	3.5	3	2.5	2.5	2.5	2.5
Tesla Model 3 Standard	7.7	50	35.5	35.5	13	10.5	8.5	6.5	6.5	6.5	6.5
Tesla Model 3 Long Range	11.5	70	50	50	18.5	14.5	12	9	7.5	6	6
Tesla Model S 60 Single	9.6	60	43	43	16	12.5	10.5	8	6.5	6.5	6.5
Tesla Model S 70 Single	9.6	70	50	50	18.5	14.5	12	9	7.5	7.5	7.5
Tesla Model S 75 & 75D	11.5	75	53.5	53.5	19.5	15.5	13	9.5	8	6.5	6.5
Tesla Model S 85 Single	9.6	85	60.5	60.5	22.5	17.5	14.5	11	9	9	9
Tesla Model S 90 Single	9.6	90	64.5	64.5	23.5	19	15.5	11.5	9.5	9.5	9.5
Tesla Model S 60 Dual	19.2	60	43	43	16	12.5	10.5	8	6.5	5	4
Tesla Model S 70 Dual	19.2	70	50	50	18.5	14.5	12	9	7.5	6	4.5
Tesla Model S 85 Dual	19.2	85	60.5	60.5	22.5	17.5	14.5	11	9	7.5	5.5
Tesla Model S 90 Dual	19.2	90	64.5	64.5	23.5	19	15.5	11.5	9.5	8	6
Tesla Model S 100D & P100D	17.2	100	71.5	71.5	26.5	21	17	13	10.5	8.5	6.5
Tesla Model X 60 Single	11.5	60	43	43	16	12.5	10.5	8	6.5	5	5
Tesla Model X 75 Single	11.5	75	53.5	53.5	19.5	15.5	13	9.5	8	6.5	6.5
Tesla Model X 90 Single	11.5	90	64.5	64.5	23.5	19	15.5	11.5	9.5	8	8
Tesla Model X 60 Dual	17.2	60	43	43	16	12.5	10.5	8	6.5	5	4
Tesla Model X 75 Dual	17.2	75	53.5	53.5	19.5	15.5	13	9.5	8	6.5	5
Tesla Model X 90 Dual	17.2	90	64.5	64.5	23.5	19	15.5	11.5	9.5	8	6
Tesla Model X 100D & P100D	17.2	100	71.5	71.5	26.5	21	17	13	10.5	8.5	6.5
Tesla Roadster	17.2	56	40	40	14.5	11.5	9.5	7.5	6	5	3.5
Toyota Rav4	9.6	41.8	30	30	11	8.5	7	5.5	4.5	4.5	4.5
VW e-Golf	3.6	24	17	17	6.5	6.5	6.5	6.5	6.5	6.5	6.5
VW e-Golf	7.2	24	17	17	6.5	5	4	3.5	3.5	3.5	3.5
VW e-Golf 2017	7.2	35.8	25.5	25.5	9.5	7.5	6	5	5	5	5

Table 1b: EV Time-to-Charge

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ESTIMATED CHARGE TIMES CHART FOR (Plug-In Hybrid) ELECTRIC VEHICLES

VEHICLE	ACCEPTANCE RATE (kW)	BATTERY SIZE (kWh)	LEVEL 1 ACS-15 1.4 kW	LEVEL 1 PCS-15 1.4kW	LEVEL 2 LCS-20 3.8kW	LEVEL 2 LCS-25 4.8kW	LEVEL 2 LCS-30 5.8kW	LEVEL 2 HCS-40 7.7kW	LEVEL 2 HCS-50 9.6kW	LEVEL 2 HCS-60 11.5kW	LEVEL 2 HCS-80 15.4kW
Audi A3 E-Tron	3.3	8.8	6.5	6.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
BMW 330e	3.6	7.6	5.5	5.5	2	2	2	2	2	2	2
BMW 530e	3.6	9.2	6.5	6.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
BMW 740e	3.6	9.2	6.5	6.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
BMW i8	3.6	7.1	5	5	2	2	2	2	2	2	2
BMW X5 xDrive-40e	3.6	9	6.5	6.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Cadillac CT6	3.6	18.4	13	13	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Cadillac ELR	3.3	16.5	12	12	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Chevy Volt	3.3	16.5	12	12	4	4	4	4	4	4	4
Chevy Volt 2016/2017	3.6	18.4	13	13	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Chrysler Pacifica	6.6	16	11.5	11.5	4	3.5	3	2.5	2.5	2.5	2.5
Fisker Karma	3.3	20	14.5	14.5	5	5	5	5	5	5	5
Ford C Max Energi	3.3	7.6	5.5	5.5	2	2	2	2	2	2	2
Ford Fusion Energi	3.3	7.6	5.5	5.5	2	2	2	2	2	2	2
Honda Accord	6.6	6.7	5	5	2	1.5	1.25	1	1	1	1
Honda Clarity Plug-In	6.6	17	12	12	4.5	3.5	3	2.5	2.5	2.5	2.5
Hyundai Ioniq Plug-in	3.3	8.9	6.5	6.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Hyundai Sonata	3.3	9.8	7	7	3	3	3	3	3	3	3
Karma Revero	6.6	21.4	15.5	15.5	5.5	4.5	3.5	3	3	3	3
Kia Niro	3.3	8.9	6.5	6.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Kia Optima	3.3	9.8	7	7	3	3	3	3	3	3	3
Mercedes C350 Hybrid	3.3	6.2	4.5	4.5	2	2	2	2	2	2	2
Mercedes GLC 350e	3.7	8.7	6	6	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Mercedes GLE 550e	3.3	8.8	6.5	6.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Mercedes S550 Hybrid	3.3	8.7	6	6	2.5	2.5	2.5	2.5	2.5	2.5	2.5
MINI Cooper SE Countryman ALL4	3.3	7.6	5.5	5.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Mitsubishi Outlander	3.3	12	8.5	8.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Porsche Cayenne S E-Hybrid	3.6	10.8	7.5	7.5	3	3	3	3	3	3	3
Porsche Cayenne S E-Hybrid Upgrade	7.2	10.8	7.5	7.5	3	2.5	2	1.5	1.5	1.5	1.5
Porsche Panamera S E-Hybrid	3.6	9.4	6.5	6.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Porsche Panamera S E-Hybrid Upgrade	7.2	9.4	6.5	6.5	2.5	2	1.5	1.25	1.25	1.25	1.25
Porsche Panamera 4 E-Hybrid	3.6	14.1	10	10	4	4	4	4	4	4	4
Porsche Panamera 4 E-Hybrid Upgrade	7.2	14.1	10	10	3.5	3	2.5	2	2	2	2
Porsche 918 Spyder	3.6	6.8	5	5	2	2	2	2	2	2	2
Toyota Prius EV	3.3	4.4	3	3	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Toyota Prius Prime EV	3.3	8.8	6.5	6.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
VIA Motors Truck	17.3	23	16.5	16.5	6	5	4	3	2.5	2	1.5
VIA Motors Van	17.3	23	16.5	16.5	6	5	4	3	2.5	2	1.5
Volvo V60	3.3	11.2	8	8	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Volvo S90 T8	3.6	10.4	7.5	7.5	3	3	3	3	3	3	3
Volvo XC60 T8	3.6	10.4	7.5	7.5	3	3	3	3	3	3	3
Volvo XC90 T8	3.3	9.2	6.5	6.5	3	3	3	3	3	3	3