Impact of Electric Vehicles on Residential Power Grid: An Educational Review

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Abstract

As technology improves, the auto industry is rapidly moving toward and focusing on Plug-in Hybrid Electric Vehicles (PHEVs) and pure Electric Vehicles (EVs). These vehicles have an excellent fuel economy and, therefore, the potential to alleviate environmental concerns caused by fossil fuels and combustion engines. As such, these new transportation technologies are beginning to disrupt the automotive industry and are poised to capture increasing market shares. At the same time, as concerns about combustion engine emissions are ever growing, combustion engine-based transportation infrastructure is expected to shrink and diminish over time. With this new transformative and disruptive industry trend, vocational schools and institutions of higher education are introducing programs to educate and prepare students as informed citizens of the new electrification technology or as professionals with career interests in the electric vehicle industry.

As a contribution to the above educational objective, electrical engineering program at one of the universities in North Dakota offers its undergraduate and graduate students several courses with a focus on related topics such as electric drives, power electronics, renewable energy systems, electrical power systems, engineering systems reliability, etc. Each of these courses includes one or more projects and assignments related to some aspects of electric vehicle technology and industry. As a first step toward exposure to the technology, students are asked to perform and turn in a literature search and survey analysis on the latest developments in the EVs technology and its related issues that are still to be addressed. Authors experience has shown that from such an exercise students gain an understanding of the contemporary issues related to the latest technology and society. This paper presents some details of a literature search and investigative assignment on electric vehicles performed by students in the Electric Drives course. Assessment data collected on this exercise show students come to understand that as the availability of EVs increases, the effect they will have on the electric utility operation and business, the environment, and the global economy is a relevant topic of their education, learning, research work, and engineering profession. Students also learn as EVs rely heavily on power provided by the utility grid, stable and reliable operation of the grid under increasing penetration of EV charging loads need to be understood and adequately planned for. Students' performance data on this assignment and its learning objectives are collected and used to assess learning based on the latest ABET-EAC Student Outcomes (2) and (4). Using the collected data and a set of associated rubrics, the instructor evaluates and grades students' performance and learning. Data also indicate that because of this exercise, among others, a number of students in the course choose hands-on electric vehicle-related design projects for their Senior Design I and Senior Design II course sequence in the following fall and spring semesters, respectively. The authors plan to publish the details of the senior design projects on electric vehicles in future publications.

Keywords—electric vehicles, V2G, G2V, stability, power grid, ABET-EAC, student outcomes

I. Introduction

Concerns regarding environmental effects of fossil fuel production, secure supply of oil, trends in automotive technology, and consumer desire to engage in environmentally conscious practices are all contributing to an increase in development for Plugin Hybrid Electric Vehicles (PHEVs) and pure Electrical Vehicles (EVs). PHEVs are vehicles that contain a traditional combustion engine (e.g., diesel or gasoline) that is assisted by a modest rechargeable battery and an electric motor technology. Pure EVs are vehicles that run exclusively from a battery and electric motor. Compared to conventional cars, PHEVs have a higher fuel economy as they use the internal combustion engine only when the electrical power source reaches a predetermined state of charge. Both PHEV's and EV's can help in shifting the personal transportation sector away from fossil fuels to balance electricity grid services. Though PHEVs are currently under production, the real future of personal electric transportation is the pure EVs. As our electrical energy production systems move towards clean renewable resources such as wind and solar photovoltaics in an ever-increasing pace, EV's have the potential to reduce greenhouse gas emissions and contribute toward the improvement of environmental concerns such as global warming. With this new transformative and disruptive industry trend, vocational schools and institutions of higher education are introducing programs to educate and prepare students as informed citizens of the new electrification technology or as professionals with career interests in the electric vehicle industry.

As a contribution to the above educational objective, electrical engineering program at one of the universities in North Dakota offers its undergraduate and graduate students several courses with a focus on related topics such as electric drives, power electronics, renewable energy systems, electrical power systems, engineering systems reliability, etc. Each of these courses includes one or more projects and assignments related to some aspects of electric vehicle technology and industry. As a first step toward exposure to the technology, students are asked to perform and turn in a literature search and survey on the latest developments in the EVs technology and its related issues that are still to be addressed. Authors experience has shown that from such exercises students are motivated and gain a reasonable understanding of the contemporary issues related to the society and the latest technology. This paper presents some details of a literature search and investigative assignment on electric vehicles performed by students in the Electric Drives course. Assessment data collected on this exercise show students come to understand that as the availability of EVs increases, the effect they will have on the electric utility operation and business, the environment, and the global economy is a relevant topic of their education, learning, research work, and engineering profession. Students also learn as EVs rely heavily on power provided by the utility grid, stable and reliable operation of the grid under increasing penetration of EV charging loads need to be understood and adequately planned for. The collected students' performance data on this assignment and its learning objectives, are used to assess learning based on the latest ABET-EAC Student Outcomes (2) and (4). Using the collected data and a set of associated rubrics, the instructor evaluates and grades students' performance and learning. The ABET-EAC Outcomes (2), (4), and portions of the corresponding rubrics used by the instructor are listed below in Table 1 and Table 2.

(2). An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Table 1. A portion of rubric for ABET-EAC Student Outcome (2)

Performance Criteria	Beginning 1	Developing 2	Accomplished 3	Exemplary 4
Identify specific project objectives, standards, and constraints based on general project requirements	Objectives, standards, and/or constraints not clearly identified or contain significant deficiencies	Some objectives, standards, and constraints are identified with some deficiencies	Most important objectives, standards, and constraints are identified and implemented with only minor deficiencies	All important objectives, standards, and constraints are identified and clearly implemented
Apply appropriate engineering analysis	Incorrect techniques selected	Most analysis techniques correct, but contains significant math and/or procedural errors.	Analysis generally correct with only minor procedural errors	Correct application of all appropriate analysis techniques

(4). An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

Table 2. A portion of rubric for ABET-EAC Student Outcome (4)

Performance Criteria	Beginning 1	Developing 2	Accomplished 3	Exemplary 4
Demonstrate an ability to make informed ethical and professional choices.	Evaluates and judges a situation using a biased perspective without objectivity. Uses personal value system to support actions to the exclusion of most of the other ethical standards	Evaluates and judges a situation using personal understanding of the situation, possibly applying a personal value system to support actions, but confuses personal ethics with professional ethics.	Evaluates and judges a situation, using facts and professional codes of ethics. Possibly applying a personal value system to support actions	Evaluates and judges a situation, using facts and professional codes of ethics. Uses personal value system to support actions, but understands the role of professional ethical standards.
Understand environmental effects of engineering solutions	Is aware of possible impacts of engineering solutions on the environments. Does not believe that it is relevant to engineering design	Understand the impacts of engineering solutions on the environments. Does not understand how these impact can be considered into engineering design	Understand in general the impacts of engineering solutions on the environments. Can incorporate environmental impact issues into the design process.	Can recall in global context the impacts of several engineering solutions on the environments. Can judge the acceptability of the environmental impacts of an engineering solution

Data also indicate that because of this assignment, among others, some students in the course choose hands-on electric vehicle-related design projects for their Senior Design I and Senior Design II course sequence during the following fall and spring semesters, respectively. The authors plan to publish the details of students' performance in these senior design projects on electric vehicles in future publications.

The following sections of the paper present some details of the sample literature search and survey analysis performed by students taking any of the related courses in electrical engineering as listed earlier.

II. Background

Global sales of all types of electric vehicles for 2017 reached over 1,223,600 units for 2017 [1]. This number of units is 58% higher than in 2016. 66% of sales were for pure EVs while the other

33% was for PHEVs. A bar graph of global EV sales and market shares for years 2010-17 is shown in Fig. 1 [2]. Forecasts for EV sales in 2018 predict another increase in sales to approximately 1.9 million units with a global total of over 5 million EVs in use worldwide. This is expected to continue increasing year over year as car manufacturers introduce and continue the development of EVs. Volvo has announced that every vehicle it manufactures from 2019 onward will have an electric motor [3]. Other automotive manufacturers such as Tesla exclusively produce electric vehicles [4].

EVs of all types rely on the power systems infrastructure for the charging and recharging of their batteries. It is not a stretch to say that electric vehicles run on the power source from which the utility they charge from generates its power. It is worth mentioning here that for EVs to be a truly environmentally friendly technology, the utility power source that charges them must be generated from clean sources of energy such as wind, solar, etc. The utility of EVs is heavily reliant on a reliable electrical power grid. The charging of PHEV's and EV's can be a relatively large load to the network. If the charging of EVs is unmanaged, it could potentially cause issues and grid failures. At the very least, as the number of EVs increases, the demand profile of electricity consumption will change and increase. There is a potential that the size, characteristics, and scheduling of EV charging could cause considerations for power system stability and control. Overall, in-depth research examining the penetration of EVs to the grid is of more significant interest in electric utilities. The effects of EVs on the network is not yet fully understood as the adoption of EVs is still relatively low. However, the technology is advancing rapidly, and timely research is necessary. For these reasons, the study of EV penetration to the power grid is a relevant, exciting, and essential topic of research [5].

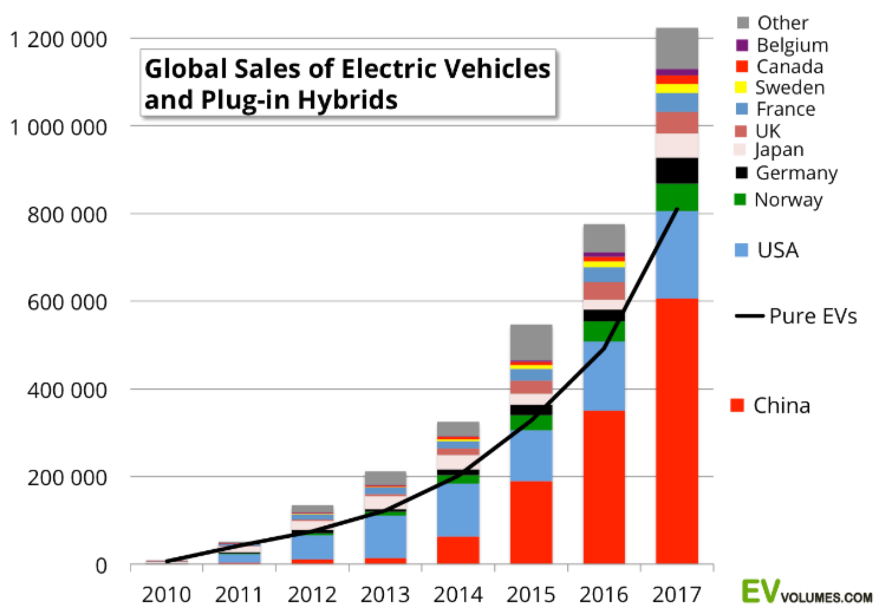

Fig. 1. Global sales of PHEVs and EVs 2010-2017 [2].

Fig. 2 shows the effects of electric vehicle life-cycle on greenhouse gas emissions. Electric cars are cleaner than conventional internal combustion engine cars over their lifetime**.** It is found that a typical electric vehicle can produce just half of the greenhouse gas emissions of an average passenger car. Furthermore, an electric vehicle using average electricity is almost 30% cleaner over its life cycle compared to even the most efficient internal combustion engine vehicle on the market [6].

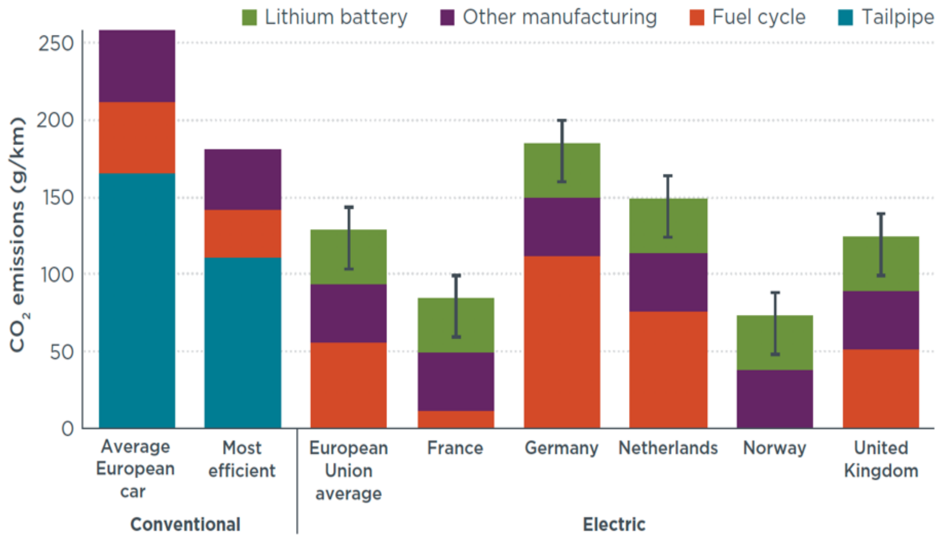

Fig. 2. Lifecycle emissions of electric and conventional vehicles in Europe in 2015 [6].

To understand the impact of EV charging on stability and control of the power grid, the technology of the vehicle and charging infrastructure needs to be understood. The functional block diagram of a series hybrid electric vehicle (HEV) is presented in Fig. 3, where M_s, M_a, J_{tot} respectively, denote the load torque (Nm), active torque (Nm), and total inertia (kgm^2). The main components of the system are the electric motor, which drives the wheels (it can also work as a generator during regenerative braking), the electric generator which delivers electrical energy for the electric motor, a battery, the controllers and the power electronics. The electric generator is directly connected to the internal combustion engine [7]. Fig. 4 shows a power grid integrated setup of a facility for an EV AC level 1 and level 2 charging scenario [8]. There are also similar setups for EV DC level 1 and 2 charging. Additional details of various charging standards and levels are described later in the paper.

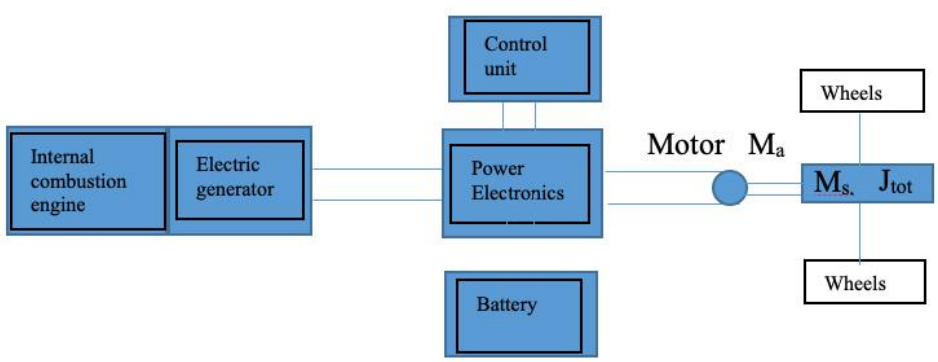

Fig. 3. A functional block diagram of a hybrid electric vehicle [7].

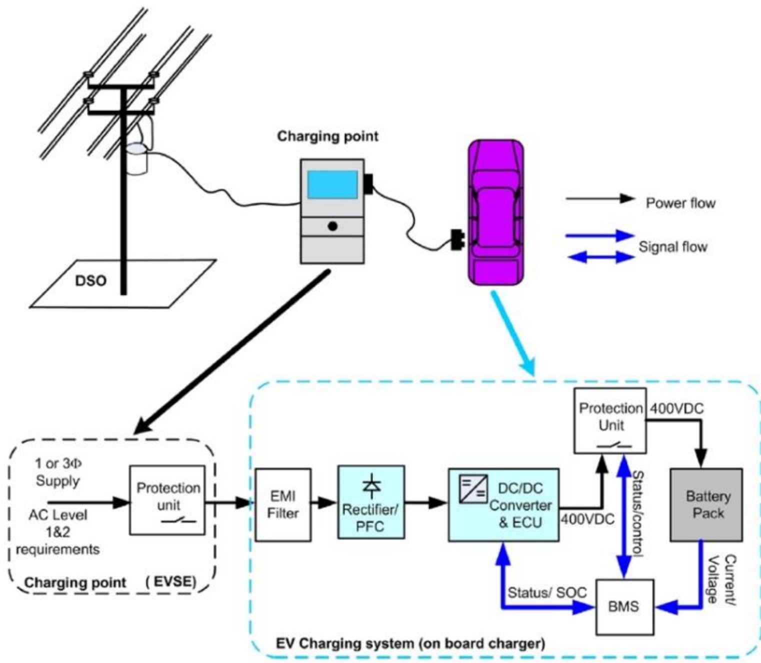

Fig. 4. Electric vehicle power grid interaction and charging configuration with an on-board AC Level 1 & 2 charger [8].

This following section provides a background to understand the technical specifications of EVs as well as the infrastructure and hardware involved in charging them. The focus here is on the charging infrastructure of electric vehicles that is primarily used in the United States. According to the Global Plug-in Vehicle Sales report [1], the United States contains the second most EVs behind China. We are focusing mostly on the United States infrastructure as the charging and power systems grid infrastructure is different between the two countries and being situated in the United States makes this discussion more immediately relevant.

A. EV batteries and charging specifications

There are many different EVs for sale on the market in 2018. A list of specs for the EVs available for the model year 2018 is given in the Appendix [9]. Nearly every major automotive manufacturer has at least one pure EV or PHEV. The core components of these EVs are Lithium-Ion batteries and an electric motor. The technical specifications and intricacies of electric vehicles are not a focus of this paper. From the perspective of power systems, the critical aspect of EVs is the load they place on the grid when they are being charged.

The power demand of charging an EV is a function of the voltage and current of the charger system. The capacity of the battery is the determining factor for the length of time that the battery of the EV needs to charge. A typical EV battery capacity can range from 5 kWh to 100 kWh. The standard daily energy requirement of an EV may be on the order of 5-200 kWh. Thus, charging requirements for one EV per day would fall somewhere in this range.

B. EV charging infrastructure

There are two primary methods that consumers can charge their EVs. The two ways are using adapters and charging at their household, or using charging stations that are constructed at various locations. Charging stations currently can be found most often in larger cities or high traffic areas along major interstates and highways. Within these two methods, there are various levels of charging. Fig. 4 in above illustrates the AC level 1 and level 2 charging methods. Each of these different charging methods and levels poses different electricity demand requirements on the grid. Any interface of an EV and the electric grid is said to be "vehicle to grid" (V2G) and "grid to vehicle" (G2V) connection. EV charging is a G2V interface. In the future, charging technology will be a two-way exchange where power can be drawn from EV into the grid (V2G) during times when load shifting needs to occur [10]. V2G and G2V can theoretically be controlled by load sensing capabilities with two-way communication to control charging and discharging of EVs. This is a potential future state of EVs in a "Smart Grid."

1) Levels of charging

Most of the charging of electric vehicles at consumer households can be described by two different levels of charging, level 1 and level 2. However, the Society of Automotive Engineers defines three levels of charging as well as other technical standards regarding charging of EVs. The three levels of charging and their specifications are discussed below, and a table outlining the specifications of each level is shown in Table 3.

Level 1 charging systems are the lowest level of EV charging. They consist of hardware that accesses power directly from a household electrical system. Level 1 charging makes use of a residence's typical 120-volt electricity system and doesn't require any excess hardware outside of the specialized plug system that transfers power from the outlet to the vehicle. While level 1 charging is convenient for a user, it is lower powered and thus takes longer to charge the vehicle fully. Charging times (from empty to full) for an EV under level 1 can take anywhere between 7-12 hours depending upon size [11].

Level 2 charging can also be installed at a household; however, special hardware is required. Level 2 provides a higher power charge, and thus a lower full charging time in the range of 4-6 hours. Level 2 charging runs at 240 volts and around 30-40 amperes [11]. As stated, due to the higher power specifications of level 2 systems, specific hardware is required to be installed. The equipment to be installed is capable of delivering 240V AC as well as 40A. Level 2 charging systems can often be purchased from the manufacturer of EV that a consumer drives [12-13].

Level 3 charging is the highest level of EV charging infrastructure. It is also the highest power that can charge EVs the quickest. Level 3 is also known as "fast charging." Some level 3 chargers charge vehicles through a 480V or 600V plug. Because of the higher power capabilities of these systems, many level 3 chargers can provide approximately 80% charge in 30-45 minutes. Level 3 charging stations are not typically designed for consumer or household use. They are often found at charging stations located at car dealerships, gas stations, rest stops, or other high traffic places in major cities or along major roadways. Because of the high-power charging capabilities, not all EVs can be charged by a level 3 charger. Tesla has a special variation of level 3 chargers called "Tesla Superchargers." The Superchargers can bring a Tesla EV to half of its full charge in approximately 20 minutes, and about 70% charge in 30 minutes [12-14]. For these charging times to be realized, a considerable amount of power is required. Reduction in charging time between the three levels of chargers is achieved by the ability to supply larger current to recharge batteries [13].

Table 3. SAE J1772 Standards for charging station levels

SAE J1772 EV Charging Classifications		
Type/Level	**Voltage**	**Power Level**
Level 1	120V AC	1.2 - 2kW
Level 2 (low)	208-240V AC	2.8 – 3.8 kW
Level 2 (high)	208-240V AC	6-15kW
Level 3 (AC)	480V AC	>15 – 96kW
Level 3 (DC)	600V DC	>15 – 240kW

There are various components necessary that make up the hardware of an EV charging system. However, there are general components and circuitry that are found in all of them regardless of the level. Fig. 5 displays a general block diagram for an EV battery charging system and the circuitry necessary for charging. As can be seen and inferred from the figure, the load posed by battery charger circuitry is nonlinear due to the required rectifiers and converters.

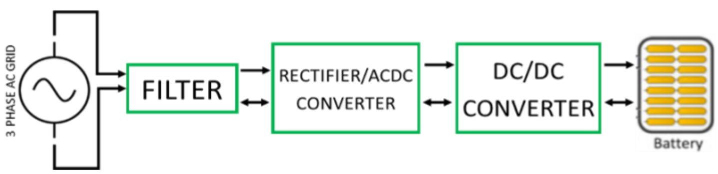

Fig. 5. Generic EV battery charger block diagram.

2) Charging station infrastructure

Charging stations are the electronic equivalent to a gas station. Charging stations often contain level 2 or level 3 charging infrastructure for faster charges. Charging stations are designed to be used as drivers travel. As an example, Tesla has deployed a network of supercharger stations throughout the United States. The map in Fig. 6 shows the location of existing Tesla charging stations as well as future stations to be deployed.

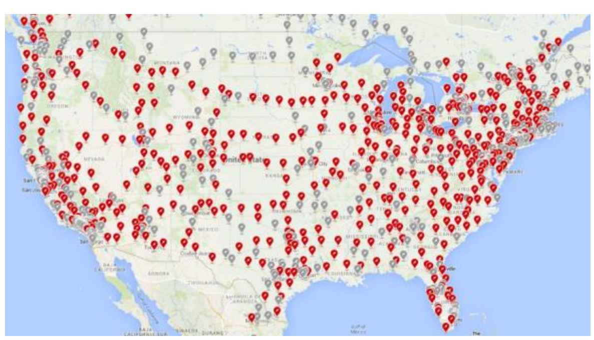

Fig. 6. Location of Tesla charging stations in the United States.

Charging stations pose considerable increases in power demand compared to residential charging. Most residential loads draw on the order of 1-4 kW for 4-10 hours depending upon charging needs. In general, EV battery charging capacity can range from 2 kWh – 100 kWh which is on the order of what a typical household may demand at any given time. Charging stations are on the higher order of power demand and may require up to 250 kW. A full list of available EVs and their battery specifications are found in the Appendix of this paper. While many EVs available currently have much power capabilities and capacities, their loads are relatively simple from a power grid perspective.

III. CONSIDERATIONS FOR POWER SYSTEMS

The effect that EVs will have on power systems will primarily be felt at the distribution level. With EVs, there will be an increase in overall power demand. Thus power generation will, of course, be affected but not to the same degree as distribution systems. At this time, this increase in load is worth noting, but not substantial enough to be of concern. EPRI reports that if EVs replace all cars on the road by 2050, only an 8% increase in power generation above expected would be required [15]. For this reason, this report places more focus on considerations at the distribution level. Most EV charging will occur at consumer residences, which are served by the distribution level of power systems. Additionally, some charging stations may also be served by residential level utilities, though it is conceivable that higher rated kV lines will feed charging stations as they would be considered an industrial load.

A. Controlled and uncontrolled charging demand

The most obvious consideration for operators of the utility grid is the increase in power demand that comes with the charging of EVs. As EVs are deployed, the standard electric power demand profile will change. This change may be disruptive to power systems and may cause challenges in meeting this demand in real time.

Various studies have examined the charging behavior of homes with EVs. Analysis of smart meter data has identified many different charging scenarios [16-18]. In any case, there are two ways that charging of EVs can be classified. These classifications are controlled or uncontrolled. Controlled charging means that the user or the utility manage the scheduling of the charging of an EV. This can be accomplished through demand response programs, in conjunction with charging hardware that communicates directly with the user and or the utility. Uncontrolled charging is merely the act of people plugging in their EVs at any time that is convenient to them and the charging of the battery taking place regardless of grid considerations such as price or stability. Due to the size of the load posed by charging EVs, the demand profile of a region with EVs could drastically change as EVs are integrated [19]. To aid this transition, achieve more stable operation, and reduce the cost of power used to charge EVs, controlled charging is proposed. Uncontrolled charging of many EVs on a large scale would make for difficult load forecasting and cause challenges for power quality and equipment lifespan.

B. Power Quality

EVs charge by drawing AC power and converting it to DC power to charge the Li-ion batteries. This process involves an AC to DC rectifier and passing the rectified power through a DC/DC converter with filters involved in various steps depending on the specific level of the charger. According to [20], the rectification and conversion of power produce voltage distortion and current harmonics in distribution networks. The harmonic distortion comes from the nonlinear elements of the charging load such as the inverters and rectifiers associated with chargers. These harmonics can cause problems such as hot-spots and unbalanced neutral currents. Adverse effects of harmonics have been observed [21]. As the utilization of EVs and residential charging increases, these challenges could increase in magnitude [19].

New designs of charging hardware can reduce overall distortion and improve any effect that these systems can have on the power factor. However, some research shows that certain types of chargers produce total harmonic distortion (THD) as high as 25% at certain times of charging. Other chargers claim to have as little as 1-2% THD with unity power factor.

There seems to be a lack of uniform consensus among EV manufacturers on a specific and standard charging technologies, as many charging systems, though they follow SAE standards, are proprietary and unique to each brand of the respective vehicle [19, 22].

C. Phase Imbalances

Along with power quality considerations, phase imbalances of EV remains a serious concern. The non-linear nature of the loads that are associated with EV charging can create an imbalance in three-phase systems. Some studies have shown that phase imbalances have been insignificant [19]; however, as more EVs are introduced there is some concern that current and voltage imbalances could occur in one or more phases. This would result in zero-sequence components and possibly lead to excessive currents in the neutral line and overheating of conductors [23]. Many hardware components of distribution systems are negatively affected by imbalances, over-currents, and overheating. To preserve the integrity and lifespan of these components, further research is required related to phase imbalance under EV penetration.

D. Transformer Maintenance and Failure

A typical neighborhood transformer is a 25-kVA transformer and serves 5-7 residences. As discussed in this paper, a home with an EV would contain either level 1 or level 2 charging capabilities. The power demands of residential EV charging are then somewhere on the order of 2-8 kW. This demand for power increases the load served by a transformer to the equivalent of somewhere on the order of 1/3 of a residence to a full residence depending on the load. This also was discussed above and is intuitive as the charging demand of an EV can be nearly the same as the entire demand required by a residence. Theoretically, if each house in a neighborhood owned an EV, this could double the demand served by that neighborhood's transformer. The load served by distribution transformers is worth analyzing as the increased load can pose maintenance and failure concerns to transformers [19].

A study performed by the Pacific Northwest National Laboratory (PNNL) found that the introduction of an EV load to a distribution transformer increased the failure rate by 0.02% per year [24]. Reasonably exceeding standard operation ratings have not been found to increase the likelihood of sudden transformer failures significantly. However, research indicates that increased load does impact the operation lifespan. A study [25] analyzed how the number of EVs at different charging levels affected the aging of a transformer. The results of this study are shown in Table 4.

Results indicate that multiple EVs under higher levels of charging can significantly reduce the lifespan of secondary transformers in the distribution system [19, 25].

Table 4. Aging per year of the transformer under varying conditions

Aging Per Year (% of Normal Lifespan)				
# EV	**Level 1 (peak)**	**Level 1 (off peak)**	**Level 2 (peak)**	**Level 2 (off peak)**
0	0.60%	0.60%	0.60%	0.60%
1	1.05%	0.64%	1.72%	0.84%
2	1.99%	0.71%	9.16%	2.75%
3	3.99%	0.83%	69.02%	20.22%

Results and survey of literature indicate that increased load, harmonic distortion, increased temperature, number of vehicles per transformer, and specific charging characteristics all play a role in decreasing a transformer operational lifespan. Since EVs can cause harmonic distortion, increased temperature, and increased load, it can generally be concluded that transformer degradation is an essential consideration as EV penetration increases [20, 23, 25].

Table 4 shows that the combination of high numbers of EVs and charging during peak times is very stressful on transformers. Moderate numbers of EVs and charging in off-peak times only modestly affects transformer lifespan. However, lifespan is drastically affected by charging during peak times. This is also more troublesome because as EVs develop, level 2 charging is likely to become the standard practice even in residential settings. This is occurring because battery capacity is increasing, and level 2 charging can perform the charging in a reasonable amount of time relative to the battery size. However, as shown, level 2 charging has a more drastic effect on transformer lifespan. Extrapolating from this study, one could conclude that level 3 charging would be pragmatically infeasible using traditional secondary distribution transformers. This study provides further evidence that scheduled or coordinated charging of EVs would be beneficial. In this case, planned or coordinated charging could help preserve the operational lifecycle of distribution transformers.

E. Other distribution hardware

Harmonic distortion of current can affect the interruption capability of circuit breakers. Load distortion can result in drastic and sudden changes in current at zero crossing, making the overload interruption more stressful on breakers and other components. Also, in situations where the RMS current is used for overcurrent sensing, the effect of heat and overcurrent could alter the proper functioning of circuit breakers [19]. Overall, harmonic distortion causes a suboptimal current which damages component in the distribution system [5, 19, 26, 27]. Regarding fuses, there are two aspects which would see the most effect under harmonic distortions that could arise under EV load. One is the thermal influence, and the other is different current distributions. The one aspect under consideration affects two fuse functions, the behavior in steady-state and the interruption of overcurrent values [19]. Since the fuse is an electronic device that reacts to the heat generated by the current through it, its characteristic curves, based on RMS values, are not affected by the harmonic content [19, 25].

A U.S. Department of Energy study of the effects of PHEVs on various distribution systems and related infrastructure reports that the most common component found prone to failure from overloading was the protective fuse. The load posed by EVs would undoubtedly increase the load on fuses in distribution systems. There is limited literature that examines the probability and effects of fuse failures. This is likely because fuses are easy to replace, and vulnerable fuses can be replaced by higher rated fuses to overcome the vulnerability. Additionally, it is relatively cheap to replace or upgrade fuses. However, what is overlooked is other hardware upgrades associated with distribution systems that would need an upgrade in addition to fuses. This is where additional costs and considerations should be understood [16, 22].

IV. Conclusion

A classroom student-based literature search and survey exercise on the effects of electric vehicle penetration on the power grid with associated circuitry and standard details is presented in this paper. Students' performance data on this assignment and its learning objectives are collected and used to assess learning based on the latest ABET-EAC Student Outcomes (2) and (4). Using the collected data and a set of associated rubrics, the instructor evaluates and grades students' performance and learning. Data also indicate that because of this exercise, students become motivated to learn more about EV technologies and their impact on power grid, environment, and global economy. From the related existing literature and this assignment, students learn the following key points:

- The grid is capable of handling the load posed by charging of EVs. However, there are still challenges to consider as this technology is evolving.
- Research indicates that inter-operability and stability challenges constituted by EV charging arise mostly from harmonic distortions due to increasing loads that are non-linear.
- The load of charging an EV is on the order of the size of the load of a typical residence. This load is considerable, but the grid can be reliable to supply power to it with the proper planning and allocation of properly rated equipment.
- Changes to consider in the existing network would be higher rated fuses and other related components.
- The wear on secondary distribution transformer is a consideration when penetration of EVs is high. Coupled with pricing considerations for power in peak and off-peak periods, the wear on transformers is a sufficient reason to implement demand response programs for charging of EV where penetration is sufficiently high.
- Penetration of EVs increases the load served by secondary distribution components and can cause issues under high-stress periods and high penetration.

V. References

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VI. APPENDIX: 2018 EV SPECIFICATIONS [9]

Brand	**Model**	**Battery SZ kWh**	**Peak power kW**	**Peak Power hp**
Audi	A3 Sportback	8.8	75	150
BMW	330e	7.6	65	180
BMW	530e	9.4	70	184
BMW	530e	9.4	70	184
BMW	740e	9.2	80	255
BMW	i3	21.6	125	
BMW	i3	33.2	125	
BMW	i3 Rex	33.2	125	34
BMW	i8	7.1	96	231
BMW	X5	9	80	240
Cadillac	CT6	18.4	149	335
Chevrolet	Bolt EV	60	150	
Chevrolet	Volt	18.4	111	101
Chrysler	Pacifica	16		248
Fiat	500e	24	83	
Ford	C-Max Energi	7.6	88	141
Ford	Focus Electric	33.5	107	
Ford	Fusion Energi	7.6	88	141
Honda	Clarity	25.5	120	

Honda	Clarity PI	17	135	
Hyundai	IONIQ	28	88	
Hyundai	Sonata	9.8	50	154
Karma	Revero	21.4	301	260
Kia	Optima	9.8	50	154
Kia	Soul EV-e	27	81.4	
Kia	Soul EV	34	81.4	
Mercedes	B-Class	36	132	
Mercedes	C350e	6.2	60	241
Mercedes	GLE550e	8.8	85	329
Mercedes	S550e	8.7	80	329
MINI	Cooper S.E	7.6	65	136
Nissan	Leaf	30	80	
Nissan	Leaf40	40	110	
Porsche	Cayenne	10.8	70	333
Porsche	Panamera	14.1	100	330
Porsche	Panamera Turbo	14.14	100	550
Smart	fortwo	17.6	60	
Tesla	Model 3 Standard			
Tesla	Model 3 LR			
Tesla	Model S 75	75	235	
Tesla	Model S 75D	75		
Tesla	Model S 100D	100		
Tesla	Model S P100DL	100		
Tesla	Model X 75	75		
Tesla	Model X 100D	100		
Tesla	Model X P100DL	100		
Toyota	Prius Prime	8.8	68	
Volkswagen	e-Golf	35.8	100	
Volkswagen	e-Golf SE	24.2	85	
Volvo	XC60	10.4		
Volvo	XC90	9.2	64	