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Electric Vehicle Battery Charging Infrastructure

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Electric Vehicle Battery Charging Infrastructure

By

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An Abstract of a Project in

Industrial Technology

Submitted in Partial Fulfillment

Of the Requirements

For the Degree of

Master of Science

December, 2021

SUNY/Buffalo State
Department of Engineering Technology

Abstract

Battery Electric Vehicle Charging Infrastructure

The progression away from internal combustion engines has been slowly gaining momentum over the last ten years. This project investigated the pathway forward regarding the charging of electric vehicles. As governments have begun enacting legislative initiatives in support of a greener and more sustainable future, we are now witnessing more rapid progress toward widespread adoption of fully electric and hybrid vehicles. This study focused directly on battery electric vehicles (BEVs). Some automotive manufacturers (each with their own timeframe) have committed to producing only these BEVs, and eliminating traditional combustion engine vehicles. This investigation was designed to examine the current state of charging infrastructure, with an eye toward the future. Several key factors emerged as critical toward future build-out initiatives: the wide variety of dissimilar charge ports currently available, variable expected charging time, locations for chargers, availability of chargers, and pricing of charging service. The investigator wholeheartedly recommends that immediate action be taken in the deployment and build-out of a nationwide charging system, before the arrival of BEVs.

Keywords: Battery Charging Infrastructure, Battery Electric Vehicles, Charging Stations, DC Fast Charge, Charge Network, EV.

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1 INTRODUCTION

In this paper, the author will be taking a hard look at the transportation infrastructure that is currently in place for electric vehicles. The interest in this topic is driven by the author's connection to the automotive field and previous ownership of electric vehicles.

The author holds two Associate degrees in applied science, the first is in Automotive Technology, and the second in Automotive Trades: Autobody Repair both from Erie Community College. Along with this, the author holds a Bachelor of Science in Economics with a concentration in Finance from SUNY/Buffalo State College.

In addition to these degrees, the author has I-Car platinum certification, various ASE certifications, and has worked in almost every aspect of the Automotive industry, including maintenance, body repair, paint, and a vehicle stamping plant. Because of this, the author has developed a deep interest in this topic.

1.1 Background

From the beginning of the 1900s to the present day, humans have had the need and want for reliable transportation. Transportation that can allow them to move long distances reliably. To achieve this internal combustion engines have been the method of powering vehicles reliably for the last one hundred years. However, major advancements in technology, moving towards sustainability, and calls for a greener environment have resulted in the adoption and movement towards electric vehicles.

There are two types of electric vehicles currently, the first being hybrid vehicles that are both gasoline-powered and electric-powered. The second is fully electric vehicles that require only electrical charging, which this paper will focus on.

1.2 Problem Statement

The problem is the current battery charging infrastructure is grossly insufficient to support the full deployment of electric vehicles.

1.3 Purpose of the Study

The purpose of this study is to discuss the viability and difficulties in fully adopting and implementing electric vehicles. Some of the areas looked at will be methods of charging, time to fully charge, placement of charging stations.

1.4 Significance of the Study

Currently, widespread adoption is being hampered because of multiple perceived issues. Range anxiety has been used by opponents of electric vehicles as a method of discrediting and slowing the adoption of these vehicles. By taking an in-depth look at the infrastructure currently in place and discussing some solutions, ideas, and methods of improving the infrastructure, full deployment of electric vehicles could be further achieved. By improving ease of use, sales of these vehicles can be improved leading to scalability and increased profits in electric vehicles.

1.5 Scope and Limitations

The author recognizes that infrastructure has many facets, for this reason, some things will not be covered in this study. Some of these limitations could include access to data regarding charging locations. Charging locations may not be listed or may be listed when not useable. Due to this, we will be relying on locations that are listed and located easily.

The scope of this study was on the charging infrastructure that currently is in place and being built, including publicly available charging and the private Tesla Supercharging Network.

1.6 Chapter Summary

This study is divided into five chapters, this chapter was an overview of the topics of this paper. Along with information on how the material will be presented and the focus of the research.

Chapter two presents a review of relevant literature.

Chapter three presents the research methodology, study design, and framework for the analysis.

Chapter four presents findings and an analysis of implications.

Chapter five presents final conclusions and recommendations.

1.7 Terms of Reference

AC – Alternating Current

ASE – National Institute for Automotive Service Excellence

BEV – Battery Electric Vehicle

CCS – Combined Charging System

DC – Direct current

EV – Electric Vehicle

ICE – Internal Combustion Engine

NEMA - National Electrical Manufacturers Association

PHEV – Plug-in hybrid electric vehicle

PV – Photovoltaic

SOC - State of Charge

2 LITERATURE REVIEW

This chapter will review charging information and relevant work that has been performed by others, this material is a building block to the subject material of this paper. Thus, it will enhance the knowledge and understanding of the reader.

2.1 Introduction and Re-statement of the Problem

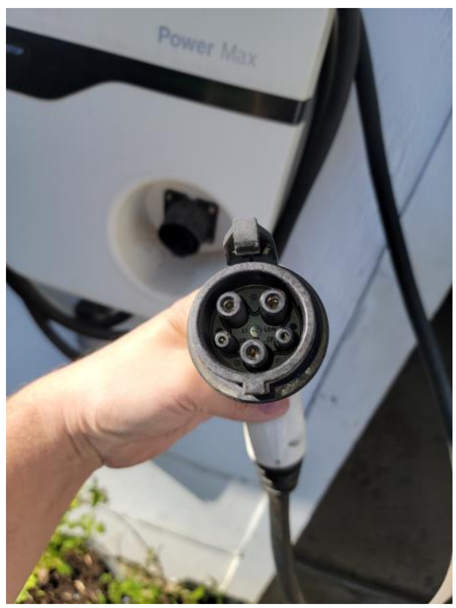
The advancements in technology over the last decade have made electric vehicles a reality. However, as vehicle manufacturers increase new electric vehicle models there is a serious problem that must be overcome. **The problem is that the current battery charging infrastructure is grossly insufficient to support the full deployment of electric vehicles.** Without reliable and easy to access charging, the adoption of electric vehicles will fail.

2.2 Types of charging

The length of time that it takes to charge a BEV is dependent on the level of charging the vehicle can achieve, and the max capability of the charger that is being used. Each automotive manufacturer creates the design choice of the maximum number of kilowatts that the car can accept per hour, which can determine the connector plug that is found on the vehicle. Based on the design of these cars charge times can vary greatly, from 20 minutes to a few hours, up to over a day. Below are the ports that are available currently in the North American market. Along with information about the ports and what kind of attachment to the electrical grid and locations that you are likely to find for each of these levels of charging.

2.2.1 Level One Charging - Port J1772

Level one charging equipment comes with all electric vehicles sold. This is a charger that plugs into a standard house three-prong outlet. It uses 120 volts Alternating Current and is very slow, these are typically only capable of adding 2 to 5 miles of charge per hour. These are not used regularly to charge BEV's as it would not be sufficient to use each day. Most Level one charging plugs use the SAE J1772 plug (see Figure 1). However, there are some exceptions such as Tesla vehicles which use their own proprietary connector. However, Tesla does provide an adaptor for their cars to make them capable of using the SAE J1772 style plug. (Alternative Fuels Data Center)



<u>Figure 1</u>: J1772 Plug, Bosch Power Max Charger. (Own photo, 2021)

2.2.2 Level Two Charging - Port J1772

Level Two charging equipment is often found installed in parking lots. Areas that use these chargers are homes (see Figure 2), businesses, parks, and even the Buffalo Zoo in Buffalo, New York. These are by far the most common charger that is found to date in public. These chargers can be Networked or Non-Networked. This charger uses 240 Volt Alternating current, depending on the maximum amperage the home or business service can provide to the charger, and the maximum amperage the charger can accept and use, these chargers are capable of charging between 10 miles and 20 miles of range per hour. Thus, providing a full charge to most BEV's overnight or while you are at work. (Alternative Fuels Data Center)

Figure 2: J1772 Plug, Level two charger, Bosch Power Max Charger – Home Install. (Own photo, 2021)

2.2.3 DC Fast Charging

Direct current fast charging is by far the best and fastest method of providing electricity to BEV's today. This method of charging is employed along mass transit corridors throughout the United States. Three different plugs are used depending on the manufacturer of the vehicle. According to the United States Department of Energy "As of 2020, over 15% of public EVSE ports in the United States were DC fast chargers."

DC Fast charging can provide 60 to 80 miles of range in as little as 20 mins. (Alternative Fuels Data Center)

2.2.3.1 CCS Combo Connector

This connector is also known as the J1772 Combo or sometimes referred to as the SAE Combo plug (see Figure 3). It is similar in appearance to the J1772 plug; however, it has two additional holes on it. When using a fast charger of this type, you simply flip the watertight cover down and plug in the fast charger cable like you would the normal J1772 plug. When you have this type of connector on your vehicle you can use the same port for level one, level two, or DC fast charging. Which simplifies the connection of your vehicle to a power source. This connection is often found in domestic automotive manufacturers' vehicles. (Alternative Fuels Data Center)

<u>Figure 3</u>: CCS Combo Plug (J1772 Combo). (Own photo, 2021)

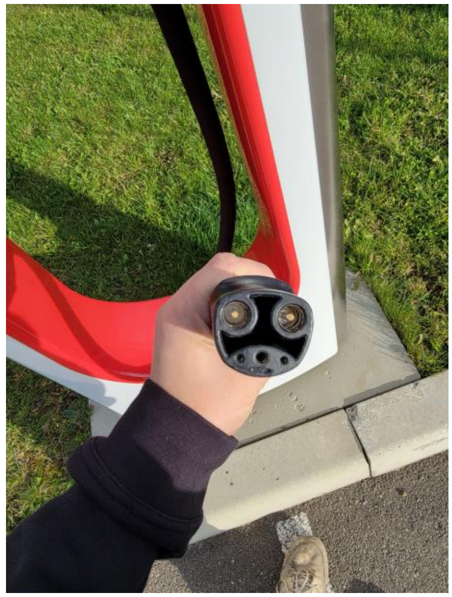
2.2.3.2 CHAdeMO

The CHAdeMo connector is often found on non-domestic vehicles (see Figure 4). The connecter is capable of communication with the vehicle which is one reason it is favored in export markets. There are discussions of phasing this connection out and moving to the CCS Combo Connector in Europe and the United States. (Alternative Fuels Data Center) However, this has not taken place yet.

<u>Figure 4</u>: CHAdeMo plug. (Own photo, 2021)

2.2.3.3 Tesla connector

The Tesla connector is the same connector they use for all charging of their vehicles. The plug is a proprietary connector (see Figure 7) and plug (see Figure 5) and (see Figure 6). Tesla also provides a connection adaptor with their vehicles to use J1772 plugs. There is also an adaptor to use CHAdeMO plugs, that can be purchased separately. (Alternative Fuels Data Center).



<u>Figure 5</u>: Tesla plug, Tesla Charger. (Own photo, 2021)

<u>Figure 6</u>: Tesla Charger with Tesla name on the cord. (Own photo, 2021)

<u>Figure 7</u>: Tesla Vehicle with charge port cover open. (Own photo, 2021)

2.2.3.4 Connecting chargers to grid

The method by which these chargers connect to the grid can vastly decrease or increase the amount of time spent charging your vehicle's battery each day. Depending on the manufacturer of the charger, the vehicle, and the connection you have available where you charge. When using a Level one charge, there are two different electrical outlets in North America, the NEMA 5-15 outlet (see Figure 8) and the NEMA 5-20 outlet (see Figure 9). (Benoit, 2019) The difference between using these are a forty percent increase in charge speed. The reason for this is that the NEMA 5-20 outlet has a top amperage of 20 amps whereas the NEMA 5-15 outlet's top amperage is 15 amps. Currently, the only manufacturer that has a connector to use either is Tesla. (Benoit, 2019)

Figure 8: NEMA 5-15 wall outlet. (Own photo, 2021)

Figure 9: NEMA 5-20 wall outlet. (Own photo, 2021)

Moving onto 240-volt connections commonly referred to as is Level Two charging, there is the option of Hardwiring a dedicated charger or installing an outlet that can be used with portable level two chargers. Four main 240 volt outlets are regularly found and used for this purpose. (Benoit, 2019) The NEMA 14-50 outlet is found in kitchens with electric stoves, and at RV Parks, it is a fifty-amp outlet (see Figure 10). There is also NEMA 6-50 outlet that comes in at 50 amps (see Figure 11), which is found in some garages, and is used for portable welders, this outlet and the previous one are the highest AC power outlet currently available for charging. Next is the

NEMA 14-30, (see Figure 12) which is used for electric dryers, this is a thirty-amp outlet. This outlet is commonly found in many homes, it could also be installed for a reasonable price. Lastly, is the NEMA 6-20 outlet (see Figure 13), which is used for some older air compressors, air conditioning units, and portable heaters. This can provide a max amperage of 20 amps. These outlets are commonly used and can be found in public buildings or private homes. Other than these different outlets can be used; however, several are becoming obsolete standards, therefore we have not covered them.

Figure 10: NEMA 14-50 Outlet. (Own photo, 2021)

Figure 11: NEMA 6-50 Outlet. (Own photo, 2021)

Figure 12: NEMA 14-30 Outlet. (Own photo, 2021)

Figure 13: NEMA 6-20 Outlet. (Own photo, 2021)

2.2.3.5 Other standards

There are other connector standards, along with faster levels of charging that are used by Commercial fleets, Bus's, Semis, and New BEV manufacturers. There are also many higher Kilowatt chargers in development. It is good to be aware of the existence of these things, however, they are not commercially available yet and not widespread, therefore I will not be including these in this paper.

2.3 Charging networks

There are different companies providing access to charging BEVs. These charging networks, except for the Tesla Supercharging network, are open to the public. Anyone can use chargers if you have the correct connector on your vehicle. Many of the electric vehicle chargers are interconnected, using an application on your phone you can monitor the State of Charge or reserve a time slot to charge. To begin charging, something is normally required to activate the station, such as a scan card, code, or phone application.

There are also chargers that are non-networked, which are installed mainly in homes and businesses. However, some are also found in parking lots, many of these are not listed.

2.3.1 Tesla Supercharger Network

The Tesla supercharger network is a private network that can be found across the entire United States and in many other countries. It is a proprietary network of chargers that Tesla only allows their vehicles to use (see Figure 14) (see Figure 15). It is currently the most widespread charging network in North America. According to the United States Department of Energy, this network boasts 5,616 Stations with over 23,134 plugs. Out of these, 1,177 Stations have 11,892 DC Fast Charge Plugs (Alternative Fuels Data Center). This is a proprietary network that has been in development before the availability of vehicles that could use it. (Bhargava et al., 2021). The network currently spans the entirety of the United States on all major routes and can be used to travel coast to coast on all major corridors if you own a Tesla vehicle. However, there are plans to open the network to non-Tesla customers. To advance this goal, Tesla has started a pilot program in the Netherlands for this purpose. (Tesla, 2021).

Figure 14: Tesla Superchargers. Salamanca, NY. (Own photo, 2021)

Figure 15: Tesla Supercharger, At Seneca-Niagara Casino, Salamanca, NY. (Own photo, 2021)

2.3.2 Publicly Accessible Charging Networks

There are many different companies that currently provide chargers to install. Each one is building their own network in hopes that they become the dominant player in the publicly accessible vehicle charging market. Some of these companies according to the US Department of Energy, include but are not limited to AmpUp, Blink, ChargeLab, ChargePoint, Electrify America, EV Charging Solutions, EV Connect, evGateway, EVgo, FLO, FPL Evolution, Francis, Greenlots, Livingston Energy Group, OpConnect, PowerFlex, SemaConnect, Volta, Webasto, ZEF Network. (Alternative Fuels Data Center).

Currently, the largest publicly accessible charger manufacturer with the widest deployment is Chargepoint. Chargepoint has been in business since 2007 and has chargers across the United State and Europe. According to the United States Department of Energy, their North American network includes 26,505 Stations to date with a total of over 47,954 plugs. Included in this number they boast a total of 1,618 DC Fast Charger Ports (see Figure 16) and (Figure 17) at 1,616 Locations. (Alternative Fuels Data Center). This is a larger amount of DC fast chargers than any other publicly available charger company.

When looking at the combined total of all publicly available chargers in North America, the total number of chargers stands at 45,554 Locations with a combined 112,007 Plugs, including Tesla locations, as of November 17th, 2021 (Alternative Fuels Data Center). This number is ever-changing. When this paper was started there were far fewer locations and plugs than there are today. Even during the course of this investigation, we have rechecked the number of reported chargers and have seen dramatic increases. Availability is changing rapidly.

<u>Figure 16</u>: Chargepoint Network (DC Fast Charger). (Own photo, 2021)

<u>Figure 17</u>: Chargepoint Network (Up-close With both DC Combo and CHAdeMO plug). (Own photo, 2021)

2.3.3 Non-Networked Chargers

Non-Networked chargers are also on the rise, this is partly because the cost to install these chargers and to maintain them can be much lower than Networked chargers. This is because there is less maintenance required, no internet connection is needed and these chargers do not have the smart features such as SOC monitoring, time slot/waitlist when busy, and the billing features. These units are just a plug and occasionally a stop button, these units are installed on homes and businesses. However, you can also find them in some parks and stores. Much of the time these are not listed online unless done so by the owner of the location.

2.4 Parking Lot Charging

Charging your Electric vehicle as shown can be a time-consuming process. Many people will charge their BEV overnight in their own home, however, locations to charge may not be available to those in rental units or other places that a charger cannot be installed. By far the second most common location for a car to be parked for any period would be in a parking lot where an individual works or shops. For this reason, businesses have begun installing chargers in these locations. However, the cost to provide these chargers in the quantity that is required to move forward with the full adoption of BEVs is quite substantial. (*Overcoming barriers to electric-vehicle deployment: interim report*. 2013)

Figure 18: **BTCpower powered by EV Connect. (Hwy. 86, Jamestown, NY). (Own photo, 2021)**

Figure 19: **BTCPower powered by EV Connect (Close-up w/ J1772 Plug). (Own photo, 2021)**

2.5 Time of use, Peak, off-peak energy usage.

A very important factor when it comes to charging EVs is the concept of **time of use** - commonly referred to as "peak" and "off-peak" hours. Areas in which time of use is in place will have smart meters on their homes that track usage and send the data back to the electric supplier. Many places in North America have this distinction between electrical usage at different times of the day, and season. The peak hours are generally 8:00 a.m. to 9:00 p.m., Monday through Friday and off-peak hours are from

9:00 p.m. to 8:00 a.m., Monday through Friday, all day Saturday, Sunday, and holidays. During peak hours when energy usage is the highest, there are additional charges added onto the cost of the electricity you are using based on how much you use.

The reasoning behind this is to try and decrease the demand for energy during heavy consumption times, thereby increasing the reliability of the electrical grid. An example of this is during the summer months in California when it is the hottest, it is expected that homes are going to use a large amount of electricity to cool them. So, during these months you will see a higher rate and additional charges during peak hours. This is an attempt to change the behavior of customers. However, even with this effort California and other states still have brownouts and blackouts from time to time. Much of this is because the electrical grid is aging and has not kept up with the increase in population in these areas. Many rural areas do not have peak and off-peak usage, however as the demand rises it is likely that you will begin to see that change.

2.6 Impact of increased demand on the grid

The effects of increased demand from the full deployment of electric vehicles must be considered. A major increase in the electricity demand is something that has been discussed and researched many times and by many different organizations. Currently, the system being built out for charging EVs is an unmanaged system, it is solely reliant on the customer to decide when to charge. During daytime hours the electricity demand is much higher than at night when many people are asleep, and most electronics are powered down at home. If every customer plug's in their BEV and begins charging at the same time, this can cause major issues with the electrical grid. In parts of the country, the electrical grid is already overtaxed and failing. During the summer months, places such as California are known to have brownouts and blackouts. This happens when energy consumption is more than the grid can provide. Adding random spikes in electric usage via BEV's being plugged in could create even more grid problems than exist today. (Hussain et al, 2020, p. 1-2). In the research by Hussain et al (2020) the issues were laid out as such:

> There are many problems caused because of Electric Vehicle (EV) penetration into the power system. Among these problems are overloading, voltage instability, voltage sag, voltage unbalance, energy losses, harmonics, frequency variation and consequently, reductions in supply quality due to high EV penetration. (p. 2)

These are all issues that currently exist, and each could have very dire consequences over the next five to ten years, as the amount of BEV's and charging stations drastically increase.

2.7 Renewable Energy, Nanogrid, Battery Storage system's

The location in which we charge can affect the electrical grid, in a study by Tulpule (2013) he considered, "A Day-time photovoltaic (PV) based, plug-in electric vehicle charging station located in a workplace parking garage" (p. 1). He found that charging in parking garages could be economically viable for both owners of BEV's and the owners of the parking garage. A parking structure lends itself to a clear view of the sky with very few obstructions. Because of this, they are the ideal place to put solar panels. Tuluple's (2013) study found the following:

> Apart from the quantitative benefits, calculated in this paper, such parking structures have other benefits, such as (1) reducing the charging load from the power grid, (2) increasing the penetration of renewable energy sources in transportation and the power industry, (3) reducing the impact of PEV charging on the distribution grid, and (4) encouraging people with no access to power plug at home to buy PEV's and charge them at the workplace. (p. 331)

This method has also been studied, expanded, and implemented by Novoa et al (2018) in which:

> A nanogrid testbed, containing PV as the power supply, twenty EV charging stations, a Battery Energy Storage System (BESS), and a smart-inverter is connected to a primary feeder on the University of California, Irvine (UCI) Microgrid." (p. 166)

The findings of this study were focused on producing enough energy, to charge BEVs without drawing power from the grid during peak hours. To meet this goal multiple strategies were implemented. The first was charging the batteries during off-peak hours, such as late at night into the early morning, from the main electrical grid. Secondly using the batteries in conjunction with energy production from the PV panels during peak hours. This is when one finds the highest cost to use energy and the largest strain on the main electrical grid. (Novoa et al, 2018, p. 167-170) This work shows that integration of renewable energy generation and storage at locations in which chargers are installed is possible and very beneficial for the expansion of the electrical charging infrastructure.

2.8 Optimization of routes for long-distance travel

Many individuals use their vehicles for long-distance traveling such as vacations, work trips, or any event that is not in the regular area in which they live. In a gasoline vehicle, this is not a concern because of the readily available amount of gas stations in North America. According to the US Bureau of Labor Statistics (2021), there are approximately 105,000 gas stations as listed under the industry subsection NAICS 447 – Gasoline stations. According to the U.S. Department of Transportation (2019), there are approximately 276,000,000 registered vehicles on the road. According to the Alternative Fuel Data Center (June 2021) Out of 276 million vehicles registered in North America, there are about 1,000,000 BEV's. This is not a major amount currently, but as this number grows finding an available charging station will become more difficult.

Charging stations that have been installed up till now are mainly in major metropolitan areas, not including the Tesla Supercharger network due to it being a private network at this time. Whereas gasoline stations are spread out in all areas and population densities. This is significant because it shows a major difference in the current refueling options available to vehicle owners. Because of this difference researchers have been looking at methods of improvement in this area.

One such study by Nie et al (2013), looked at the creation of a nationwide charging network that would be installed in locations that would normally induce users of BEVs to have range anxiety. The options considered were Level 2 chargers, DC fast chargers, or a battery swap solution. These routes are one in which you travel great distances, such as main highways and interstate roads, on these roads, there are currently very few places in which you can stop to charge your vehicle. The findings of Nie et al (2013) were as follows:

> To achieve a reasonable level of service, the level 3 charging method is needed to minimize the social cost. This finding justifies the investment on level 3 charging, which will not only help the EV adoption, but also reduce social cost because of the savings on batteries.
> Our baseline model shows that reducing the unit battery manufacturing cost offers larger benefits than reducing the unit charging power installation cost. Therefore, advancing battery technology seems to promise larger impacts than the charging technology. We caution that other parameters might affect this relative sensitivity, which are not fully explored in this study.

> Battery Swapping enables the use of smaller batteries and to achieve higher level of service. Yet, when the level of service requirement is modest, battery swapping can be more costly than charging, especially when the cost of constructing swapping and charging stations (excluding the installation cost of chargers) is close. If existing infrastructure can be remodeled to support battery swapping and charging operations, charging could be a socially optimal solution for modest levels of service. (p. 189)

The ideas that are put forth in this study are very interesting and leave a lot of things to be considered. The “corridor-centric approach” (Nie et al, 2013, p. 1-2) seems to be a viable method when considering the buildout and placement of new charger locations.

2.9 Retail store charging locations

The daily use of a vehicle for transportation includes more than driving from your home to work. Such as picking up things that are needed for day-to-day life such as groceries, toiletries, and other homes goods. This can require stopping at multiple retail locations. When making these stops a substantial amount of time can be spent during which the option of charging your BEV could be helpful. (Gilleran et al, 2021, p. 7) According to a study by Gilleran et al (2021) parking in retail stores otherwise known as big box stores, such as Walmart, Target, Lowes, Tops, etc., must be considered. (p. 8). The reasoning for this is that “Electric vehicle charging stations will greatly affect a building site’s power demand, especially with the onset of fast charging with power levels as high as 350kW per charger.” (Gilleran et al, 2021, p. 1) The amount of power drawn by installing chargers at these locations, especially DC Fast chargers will be larger than the stores own average power consumption each month. (Gilleran et al, 2021, p. 5) The conclusions that are found in the study by Gilleran et al (2021) are as follows:

> We find that fast charging can make a significant impact on a site's peak power demand (increasing monthly peak power demand at the site by over 250% in some cases) but comparatively little difference to its monthly electricity use. This effect becomes stronger as per-port power levels increase. In addition, we find that cold-climate areas (with lower AC loads) paired with rate structures incorporating high demand chargers are most susceptible for significant changes to the annual electricity bill, with increases as high as 88%. (p. 8)

The implications of charging at retail locations will need to be considered by all parties involved. The retail stores must consider the cost of installing these chargers, paired with the major increase in power usage. At the same time, the customer will have to be mindful of the costs associated with using DC Fast chargers during Peak hours, as it will be substantially higher than charging during off-peak hours with a level-2 charger.

2.10 Grid Enhancements / build-out

The electrical grid is maintained by electric utility companies which own the lines, transformers, power stations, and all the various components that bring power from the generation plant to the meter on your home or business. The transmission of electricity to its destination is not a small task. This takes planning and resources including employees to maintain the grid that we currently have in place. Upgrades to the system have been long due in many areas, as the population has increased and taxed the aging infrastructure. According to Venkateshwara (December 2020):

> Electric utilities will have to plan for an increased peak on the distribution system, increasing make-ready infrastructure costs. Actions that will be required and will increase make-ready costs include reconductoring of existing lines, adding entire stretches of new

> line, enhancing transformer capacity, or installing new transformers with higher ratings (to replace old, ageing transformers), and installing new meters, as needed. (p. 5)

Upgrades to the electrical grid are regularly being made already, and much of the work that needs to be performed has begun. However, the cost of the upgrades will become a centerpiece as more BEVs become available for purchase. The method in which local distribution is sized and upgraded is dependent on the peak electricity usage for the area. As more BEVs are purchased in a community the potential for them being charged at the same time increases, which also increases the probability of overloading the local grid. (Overcoming barriers to electric-vehicle deployment: Interim report, 2013, p. 49). As the utility companies and public policy so far have been leaning towards subsidizing all upgrade costs through Make-Ready programs funded by the United States government, and bypassing the cost onto all consumers in the form of higher electric rates. (Venkateshwara, 2020, p. 14-15) Many customers may be resistant to the implementation of BEV's due to the increases in electrical costs they may have passed onto them in their utility bills.

2.11 Chapter Summary

In this chapter we have explored the current systems in place for charging electric vehicles, much research has been performed by many different parties. Each with their own ideas, thoughts, and insight into the methods, solutions, and problems that occur with such a momentous change in an industry, this one being the transportation industry. Among these issues being faced are the many different charger plugs, methods of charging, and cross-compatibility of different vehicle manufactures. Other factors that must be considered are the demand placed on the grid when charging

BEVs, locations of chargers, demand scheduling, and changing consumer behavior. The material in this literature review is the building block of this research. In chapter three the methodology will be discussed on how we collected and compiled targeted data.

3 METHODOLOGY

This chapter describes how this research was performed and how the data was gathered. It also provides the framework for how the findings were to be handled.

3.1 Re-statement of the Problem

The advancements in technology over the last decade have made electric vehicles a reality. However, as vehicle manufacturers increase new electric vehicle models there is a serious problem that must be overcome. **The problem is that the current battery charging infrastructure is grossly insufficient to support the full deployment of electric vehicles.** Without reliable and easy to access charging, the adoption of electric vehicles will fail.

3.2 Approach

The approach that was taken in this study is qualitative. The reason for this is the problem being looked at mainly from a non-numerical standpoint. The bulk of my research will be based on an analysis of the charging infrastructure currently in place. During which it will also show the structure of the charging gird and its current deficits. Based on these findings, solutions and methods for improving the full deployment of electric vehicles will be discussed.

3.3 Framework for the Analysis

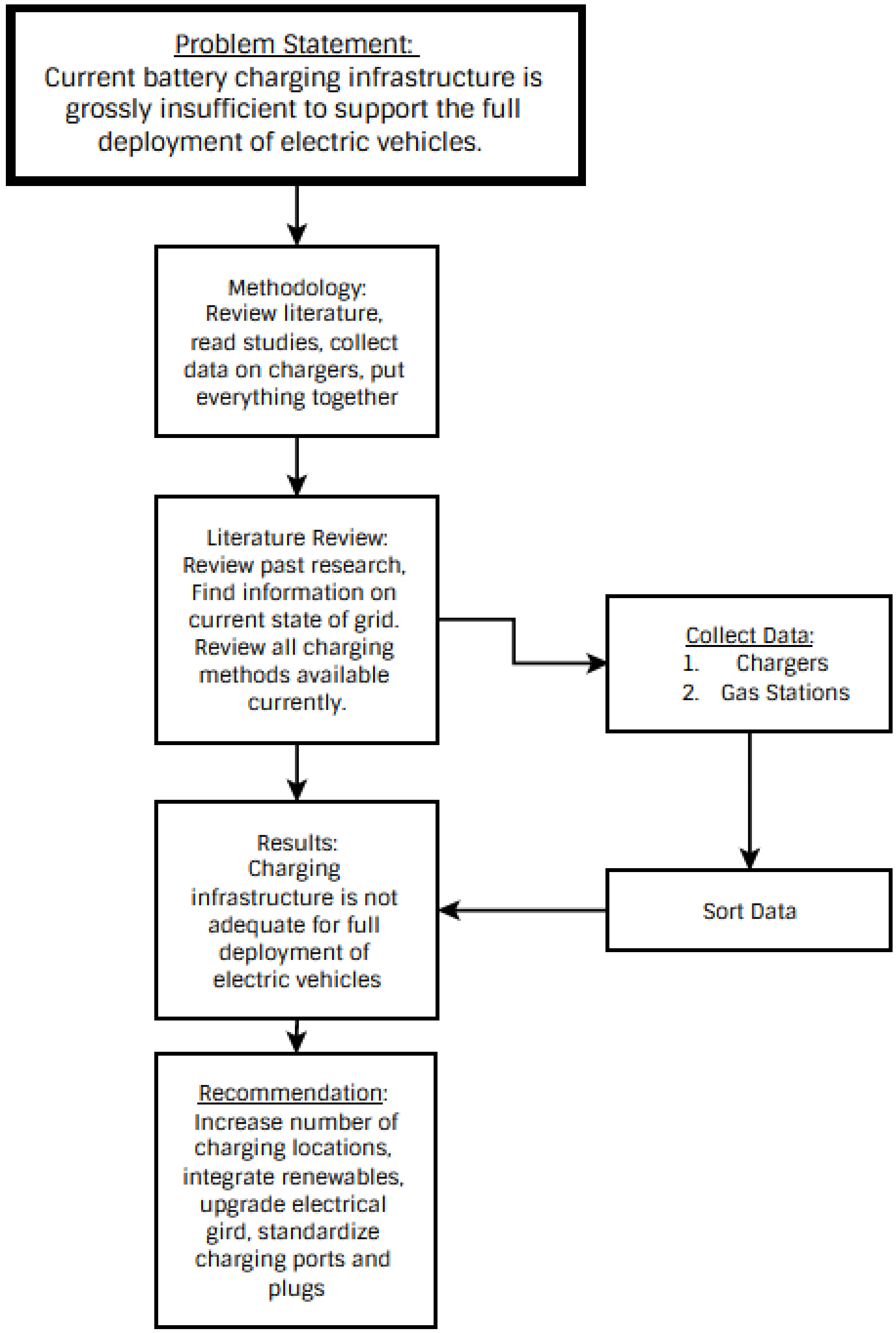


Figure 20: Framework for Analysis Diagram

3.4 Research Design

The structure of this investigation was based on a comprehensive literature review, which describes and shows the infrastructure currently in place, along with ideas put forward by other researchers. This provided a basis for then considering improvements that would facilitate the full adoption of Battery Electric Vehicles. Many articles have been published in recent years regarding improvements to the electrical grid. Some of these methods will prove instrumental towards the pursuit of full deployment of BEVs.

By reviewing the locations in which chargers are installed, methods of increasing capacity to the electrical grid, cost reduction to charger location owners, and alternative methods of charging, solutions can be developed to improve current charging infrastructure. Data was collected from publicly accessible sources. These data will help show what is currently in place regarding charging infrastructure.

3.5 Data Collection

The research performed was collected by using multiple sources. The first was the SUNY/Buffalo State library and Inter-library loan system, using this resource we were able to access past studies and publications that were relevant to this research. The second was the US Department of Energy which manages the Alternative Fuels Data Center (AFDC), this site houses a multitude of raw data on charger locations using their search tool, this is free and accessible to everyone. The third was the US Bureau of Labor Statistics Website, this site houses data on different employment sectors along with data on businesses, which is free and accessible to everyone. The fourth, by performing web searches information was found via news article searches and manufacturer websites. The fifth and final method of data collection was by driving to charger locations to obtain equipment photographs.

3.6 Data Reporting and Analytical Techniques Used

We were able to compile information on charging stations and gas stations in North America. We found and compiled the number of charging stations and level of charging available currently, along with the number of gas stations. A comparative analysis of literature was conducted to draw final conclusions and recommendations.

3.7 Chapter Summary

In this chapter, the methodology was described. In the next chapter, we will present the study findings and then analyze the meaning and implications of these findings.

4 PRESENTATION OF FINDINGS AND ANALYSIS

4.1 Re-statement of the Problem

The advancements in technology over the last decade have made electric vehicles a reality. However, as vehicle manufacturers increase new electric vehicle models there is a serious problem that must be overcome. **The problem is that the current battery charging infrastructure is grossly insufficient to support the full deployment of electric vehicles.** Without reliable and easy to access charging, the adoption of electric vehicles will fail.

4.2 Presentation and Analysis of Findings

There are many issues that could potentially arise when moving towards a full electric consumer vehicle world; many potential problems can be found. The problems this research focused on are ones regarding the transportation infrastructure that must be in place before the full implementation of Battery Electric Vehicles (BEV).

4.2.1 Charging connectors Vehicle and Station

There are major issues that exist, due to the number of different charging plugs that are currently available to charge different BEVs. With different charger ports depending on the manufacturer of the vehicle you have, a situation is created, in which owners of vehicles will not be able to charge at the same charging locations. The only manufacture that planned for this is Tesla. This company has its own proprietary connector port; however, they do provide adaptors to use all other charger plugs. However, vehicle owners are not going to want to purchase and carry multiple adaptors to use different chargers, and currently, if you do not own a Tesla, that is not even an option. (Benoit, 2019)

4.2.2 Portable Chargers

Portable chargers can be quite useful for charging your vehicle. However, issues can arise caused by the type of outlet you can plug a portable level two charger into, if you have a charger that cannot interchange power connector plugs then you will be stuck with only the plug and the subsequent amperage that the corresponding household NEMA power outlet can provide. (Benoit, 2019) This means that portable chargers will be much less portable as different places may not have the corresponding power outlet to your portable charger.

4.2.3 DC Fast Charging

Currently, on all major corridors of North America, you can find Gasoline Stations to fill your vehicle. In contrast to this, there is not a publicly accessible DC Fast Charge network. The only company that currently has this type of network is Tesla, however, only owners of their vehicles can connect and charge. (Bhargava et al., 2021) Without a method to charge vehicles at a speed that is somewhat comparable to the fuelling of a gasoline vehicle, consumers will always have range anxiety when making longer trips.

4.2.4 Increased Demand on Electric Grid

Increase demand on the current electrical grid has been found to cause many issues, in its current form it will be unable to sustain the increase in demand caused by charging of these vehicles without upgrades to the system. As the concentration of

BEVs increases, local areas will have demand that is generally seen at peak times. This could overload components and increase the possibility of blackouts. (Overcoming barriers to electric-vehicle deployment: interim report, 2013 p. 49-51) To mitigate this, it has been suggested that utility companies implement time of use strategies into their electric rates. Doing so would encourage consumers to not plug in and charge until hours of historically low energy consumption. (Novoa et al, 2018, p. 177) These strategies paired with upgrades have been shown in research to be able to help stabilize the grid. Increased charging demand will impact the electrical grid system in a major way, however it is an absolute pre-requisite to transition to a BEV dominant future. (Hussain et al, 2020, p. 11)

4.2.5 Time of use, Peak, and Off-Peak

The use and implementation of Time of use, Peak, and Off-peak power usage has been examined in detail. The problem with shifting charging to off-peak hours becomes apparent when you have drivers that live in rural areas and commute to work, such as myself. When driving such long distances, the battery power consumption would be much greater than just driving in and around a city. After returning home from work and waiting for off-peak hours to be reached, there may not be enough time to charge your vehicle back to full charge as a Level 2 charger only charges between 10 and 20 miles per hour. (Alternative Fuel Data Center, 2021) Secondly, the idea of shifting the cost to the customer via Peak Demand could hinder the adoption of these vehicles in areas where Time of use modules are not currently found.

4.2.6 Renewable incorporation

Many researchers have pursued the use of renewable energy being incorporated into a charging strategy, such as in a parking structure, or parking lot. The research that has been done shows that it is possible to decrease power spikes and use batteries packs to decrease the amount of peak power used. (Novoa et al. 2018 p. 169-170) However the upfront cost with such an investment will be quite substantial, and the retrofitting of a parking structure may not always lend itself to the installation of the equipment that would be needed.

4.2.7 Charging location application

Charging Stations that are networked can be found via the charging station manufacturer's website or phone application. If one tries to locate a charger, one can open the application on a phone, and access a list of all available chargers within a certain radius of one's location. One can narrow a search to the specific type of connecter or level of charging needed. However, this only works if the charger is listed and if the charger is networked. Along with this, is the issue that different manufacturers of charging stations each have their own applications to search for chargers and log in to their charger to activate charging. Only a few of them cross-list their charging stations on each other's applications.

This creates a problem when planning routes, as you may be forced further off your planned route to charge your vehicle, due to the lack of information exchanged between these companies. However, the Department of Energy, through their Alternative Energy Data Center, has created a website and phone application that can be used to search for charging stations. So, issues with searching for stations is being actively addressed. However, to activate different manufacturers charging stations one will need to download and create an account for each separate charging station manufacture. Managing all the different charging station accounts that one might need (with there being more than twenty different manufacturers), could present the driver with a very difficult task.

4.3 Chapter Summary

The multitude of issues found with the charging infrastructure, or lack thereof, make the adoption and full deployment of electric vehicles, one that looks insurmountable. Electrical grid upgrades, demand charges, renewable integration, and the adoption of single charging port standards can all help to move towards this future. However, when looking at this as a consumer and with taking a serious look at all the issues facing the adoption of BEVs, it would be hard to move forward with the purchase of a vehicle that would be very difficult to drive any long distance. Due to the lack of DC Fast charge stations, difficulty in finding the closest stations, or the correct charging station to match the port on your vehicle only serves to decrease the likelihood of acceptance of BEVs, while compounding the difficulties in reaching full deployment of electric vehicles.

5 FINAL CONCLUSION AND RECOMMENDATIONS

5.1 Re-statement of the Problem

The advancements in technology over the last decade have made electric vehicles a reality. However, as vehicle manufacturers increase new electric vehicle models there is a serious problem that must be overcome. **The problem is that the current battery charging infrastructure is grossly insufficient to support the full deployment of electric vehicles.** Without reliable and easy to access charging, the adoption of electric vehicles will fail.

5.2 Recommendations

Below are recommendations that could help to overcome the issues that are found today in this field. These are recommendations based on personal experience and research into this subject matter over the last two years.

5.2.1 Standardization of Charging

By standardizing the protocols for chargers to communicate with vehicles and making the charging plug and port the same for all vehicles, as was done with gasoline vehicles, will increase the ease at which consumers can charge their vehicles. Effects of this would be that all charging stations could be used by all customers. Thus, increasing the number of available chargers for everyone and not just those with the matching plug on the charger. It would also lower the cost of chargers as DC Fast chargers that have multiple plugs will only now have the single standardized plug.

5.2.2 Publicly accessible DC Fast Charging

Without a network of charging stations that can be used to travel on major routes across North America. Long-distance travel will remain out of reach. Private Vehicle manufactures could negotiate with Tesla, to open charging for use of other vehicles. This is something that Tesla has demonstrated a willingness to do in the past. This would immediately create a method of charging that only Tesla owners have access to at this time. Looking forward, charging stations need to be placed on highways and corridors that currently have gas stations. Rest stops, restaurants, and state welcome centres, all would be good places to pull in and use DC Fast chargers while people take a short break from driving.

5.2.3 Government regulation and subsidies

Government intervention into the development of a market is something that is not new. Currently, there is funding that has been approved for Make-Ready programs, the bulk of which is to be used for upgrades to the electrical grid and station installation. More funding will be necessary to have enough stations for all EV users to plug into. With a minimum charge time of twenty minutes on a DC Fast charger, there will have to be many more chargers for BEVs, compared to the number of pumps needed for filling gasoline vehicles.

5.2.4 Renewable Energy

By incorporating renewable energy, and batteries into the grid. As shown in the research by (Novoa et al., 2018) You can reduce the demand on the grid, thus reducing the issues that are created by the increase in EV penetration.

5.3 Recommended Implementation Timetable

The time frame in which changes need to be made for the successful deployment and full replacement of gasoline vehicles is difficult to give. According to the study by Hussain et al. (2020), “In 2024, the number of EVs sales demand per annum will be over 2.4 million in the United States. In 2030, the total number of EVs will reach approximately 130 million worldwide.” (p. 1) If this timeline is correct, one should rightly conclude that immediate action is necessary to be ready for these vehicles when they arrive in the next few years.

Many manufacturers have already dedicated themselves to manufacturing electric vehicles: e.g.: Volkswagen offering 80 new EVs by 2025 and General Motors having no less than 20 EVs by 2023. (Bhargava et al., 2021) The investigator wholeheartedly recommends that immediate action be taken in the deployment and build-out of a nationwide charging system, before the arrival of these vehicles.

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