Suitability of Electric Vehicle Charging Infrastructure and Impact on Power Grid Due to Electrification of Roadway Transportation with Electric Vehicles

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Abstract: ***Understanding the types of electrical vehicle charging infrastructure for automobiles, buses, trucks, and motorcycles is key where electrification is concerned. Starting from slow to fast and ultra-fast charging equipment commercially available, the grid is often exposed to intermittent loading and the addition of elements that impact stability. This study is focused on documenting the challenges associated with the addition of EV charging infrastructure to current power systems. By studying available charging options for each type of vehicle, a planned selection of sites and capacity of chargers will allow customers to learn when, ideally, to be plugged in. Previous studies documented a typical capacity of charging infrastructure required based on the anticipated number of electric vehicles in the next thirty years. However, there is a need for the establishment of impacts due to connected EV loads. Unlike known demand curves for loads such as lighting, power, process equipment, and so on, the prediction of EV demand curves is significantly limited due to a lack of past data. By utilizing publicly available data on existing charging infrastructure, a detailed layout of additional chargers for a typical city in the United States is a subject of study in this paper. Some of the concepts in accurately predicting suitable types of infrastructure (such as slow vs fast and ultra-fast) for each vehicle type become a subject of importance in electrification and become key to this transition. Some limitations of this study include a lack of accurate forecasting and shifting user preference to other technologies.***

Keywords: electric vehicles, smart grid

1. Introduction

The electric vehicle (EV) charging infrastructure is developing at a pace to cope with the rising number of electric vehicles and their technological improvements [1] [2]. The known challenges with low consumer uptake were due to charging logistics, and range [3]. Given EVs are a practical solution to mitigate climate change and decrease reliance of depleting fossil fuels [4], their profile in the next thirty years was forecasted [5], and the capacity of charging infrastructure required initiated the need to sketch a layout of chargers for a typical city in terms of their optimal location and type. The types of EV chargers commercially available include level 1, 2, and DC fast chargers [6]. The rise in the EV is strongly dependent on the market supply chain, customer behavior, availability of funding, and commercially available charging infrastructure. Some may argue both EVs and their charging infrastructure go hand in hand. Planning strategies have been devised for electrification in the transportation systems to optimize the costs of construction and operation of electric vehicle supply equipment (EVSE) or electric vehicle charging stations (EVCS) [1]. Since voltage stability and its profile are heavily impacted based on the location of EVCS on an IEEE 33 bus radial system [7], a focus must be on a suitable location in the electrical system. Outlined impacts of EVs on the power grid were harmonics [8], increase in power demand and loss, voltage fluctuations, overloading, V2G impacts, Distributed Generation (DG) impacts [9] [10] [11] [12] [13], and implications on smart grid infrastructure [14] [4]. Similarly, for the environment, EVs reduced GHG emissions and ensured the least noise pollution. However, economically added an increased cost of ownership with reduced operational costs. Due to increased EV adoption, there will be 66% increase in energy consumption by 2050, thereby increasing the grid challenges [15]. Controlled charging by shifting the EV loads at a particular time of the day is going to play a crucial role, as uncontrolled charging can increase peak load demands [16]. DG requires an appropriate connection point [17] [18] [19]. Some power stability concerns with DG are similar to EV charger integration, such as voltage stability issues with interconnection to the grid.

To improve the manufacturer's contribution in reducing the undue burden on the grid due to added demand, an EVSE typically be configured to reduce current consumption when the frequency goes below 59.7 Hz due to EVSE in operation [20]. Since electric grids continue to evolve with some predictable EV transition based on uptake by public and private owners, it is crucial to sketch the shape of the EV demand curve. So, service disruptions from large-scale EV charging infrastructure are less likely as long as utility companies start to model and integrate both EVs and DGs into the system. When the benefits of EVs are weighed against undue disturbances added to the grid, there must be growth in increased government support for utility companies, especially when government support is available for customers in terms of tax credits and subsidized charging station deployment [21] [22]. The labor market gets a huge advantage in increasing green jobs [23] from EV charging for both consumers and utilities. Engineering standards development and detailed design of EVCS and equivalent generation infrastructure increase demand for skilled manpower.

Electric power generation companies have a blend of power generation either from renewables, nuclear, gas, or coal. The generation companies are capable of supplying peak loads without compromising the reserve capacity. Although the operation of power plants to supply peak loads increases the cost, a demand response tells the customers to either limit the power consumption or shift to a different time of the day. The TOD (time of day) tariff ensures that generation companies are compensated for the increased loads. The power grids operate to ensure the loads are distributed to the cheapest generation source available at any point. Mainly frequency and voltage drop from substations are indicators for the generators to supply rising loads. Electricity demands grow from rising population, economic growth, and transportation electrification [24]. Variable renewable energy resources raise the need of determining the shape of demand curves [24] by using known models in analyzing the energy and electricity systems [25].

Biden Administration announced in Feb 2023 on the addition of 100,000 public chargers with major contributors Tesla with at least 7,500 chargers for non-Tesla customers, Hertz and bp with investments of more than $1 billion by 2030; Pilot Company, General Motors, and EVgo with 2,000 high power rated at 350kW; TravelCenters of America and Electrify America with addition of 75MW solar PV for powering EV; Mercedes-Benz, Charge Point, and MN8 Energy with 400 charging hubs comprising more than 2,500 stations; ChargePoint, Volvo Cars, and Starbucks with 60 DC fast chargers; Francis Energy with 50,000 EV ports by 2030; Forum Mobility with $400 M to translate into 1,000 DC fast chargers; and Ford with DC fast chargers at 1.920 dealerships by 2024 [26].

Battery energy storage systems (BESSs) undergo multiple cycles of charge and discharge; hence, their health diminishes with time [27] [28] [29]. This paper limits the assessment of the BESS application by disregarding diminishing battery performance from aging, charging, and discharging cycles, temperature, environmental stresses from installation, and public and private uptake. Lithium-ion batteries are primarily being used in BESS. Alternate battery chemistries include sodium, nickel, and metal air [30] [31]. Supercapacitor as a storage is an option explored in [32]. A total of 20.7 GW installed capacity of BESS in the United States [33] diversifies the generation profile. BESS is promising in increasing the penetration of renewable energy as it allows the storage of excess energy and redistributes it to the grid. Recent plans by the Energy Information Administration (EIA) and the US Department of Energy (DOE) are to add about 30 GW of utility-scale BESS to be installed in Texas [34]. Safety design standards NFPA 855 and IEC TS62933-5 are applicable safety design standards that govern hazards around BESS [35]. Lithium-ion batteries pose many hazards when exposed to some conditions, such as overcharging, high and low-temperature variations, shock impacts from seismic activities, poor thermal management systems, aging equipment, and explosions [36]. Cost becomes a key driving factor [37] when the installation of large BESS is evaluated against the return on investment.

Demand Response

Typically, utility companies see peak demands through the daytime hours, but during mid-night to early morning hours, there is significantly less demand. To ensure the utility companies do not incur any revenue loss due to the low operation of generators during the off-peak hours, a time-of-the-day tariff ensures users draw power when it's cheaper for generation companies to produce. From a general understanding, shifting all the EV loads during off-peak hours requires a method similar to how gasoline and diesel are being planned and distributed to customers. An analogous system to gasoline stations may be seen as an energy storage system for fuel storage tanks, charging stations from dispensers, and transmission & distribution lines for shipment of power for tank trucks with fuels. However, the re-fueling time from a gasoline dispenser and charging time from a charging stations limits this analogy. It is evident that more charging stations are required given they require longer to charge, and thus adds burden on additional space requirements at existing gasoline stations. Additionally, BESS addition requires additional space as gasoline tanks are underground. Demand Response (DR) allows consumers to adapt their energy consumption to reach the set amount of energy that utility companies are capable of serving at a given time globally. This lets customers gauge their demands and categorize them into fixed, shiftable, and curtailable loads [38]. EV charging loads fit into the shiftable category. Controlling the user demand based on signals from utility companies in a smart grid [39] enables customers to alter their shiftable and curtailable loads.

Typical Load Curves

The typical load curves of electric trains are shown in Fig. 1 [40]. For residential, commercial, and industrial, they are shown in Fig. 2. As seen from Fig. 2, residential demands peak during the evening time, whereas the commercial demand is during the morning to afternoon times. However, all of them are significantly low during the midnight to early morning hours. The demand curves tend to show some trends based on usage by varying customer types. Moreover, per [24], similar trends were predicted for electricity demands. However, with the addition of distributed energy generation from renewables, it has become a subject of interest for researchers [25].

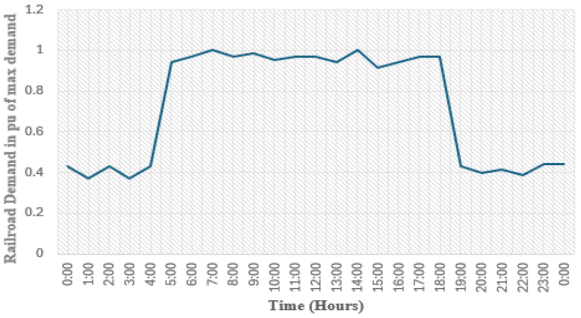

Figure 1: Railroad Demand Curve [41]

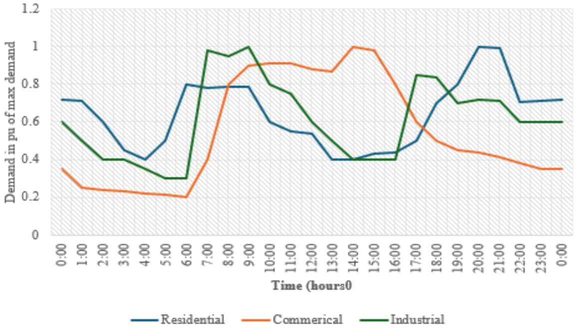

Figure 2: Residential, Commercial, and Industrial Demand Curve [41]

Load Curves in Maryland

The major utility companies in the Maryland area include Potomac Edison, BGE, Delmarva Power, and Pepco. Location of EV chargers for utility companies is key for assessing the load flow studies. For example, the authors utilized an IEEE 30 bus network with EV chargers at 100kW and incorporated OSPI and QRPI to determine voltage and oscillatory stability status for planning purposes [1].

Charger Infrastructure

The US Environmental Protection Agency (EPA), Federal Highway Administration (FHWA), and Census Beaueau classifies vehicles based on the weight rating (in pounds or lbs). Some classifications from FHWA are categorized as vehicle class starting from Class 1 to Class 8 from weight until 33,001 lbs and more. However, for this study, the classification by EPA for light-duty and heavy-duty trucks was considered. As seen in Table 1, the EPA classifications were based on weights up to 60,000 lbs and more. Refer to Appendix for Table 1.

Power System Stability and Harmonics

EV charging stations add frequency variations, disturbance with inconsistent power flows, and harm the stability. The additional demand for EV charging adds a drop in frequencies at generating stations. Due to intermittent demand for charging EVs, there are inconsistencies in power flow, and the large-scale addition of charging stations harms the system stability from undue demands added to the point of common coupling (PCC). Power harmonics is the result from the multiple frequencies of operation to serve non-linear loads. Major power electronic equipment such as variable frequency drives, rectifiers, LED drivers, and EV chargers all add harmonics to the power system. Depending on the non-linear load the type of harmonics varies. For example, six-pulse drive or rectifier adds 5th, 7th, 11th, 13th, and so on.

The major components of electric vehicle supply equipment (EVSE) include housing, power electronic components (AC to DC converters), network connectivity, connectors, and ports. The rectification processes in the chargers thus add varying harmonics. For example, when a secondary wave of seven times the fundamental frequency is added to a sinusoidal source operating at 60 Hz, then the resultant harmonics is 7th. A schematic of the EV charger is shown in Fig. 3.

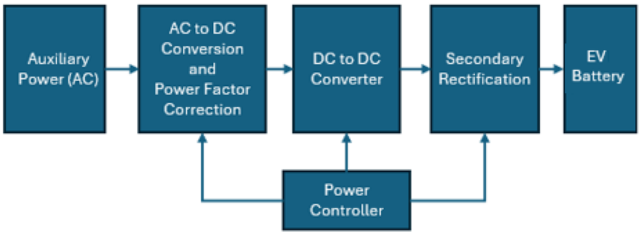

Figure 3: EV Charger Schematic [42]

Problem of Intermittent Loading

There is an imbalance due to the addition of single-phase loading, altered peak demand, and harmonic distortions from power electronic components. A power system suitable to meet the rising EV demand requires a more accurate demand curve to ensure the system is resilient to intermittent charging needs. Although this paper suggests encouraging charging during nighttime for homeowners and device BESS at gasoline stations, a more resilient model may be developed to support charging needs without significantly adding infrastructures at homes and BESS.

V-2-G and BESS

The vehicle-to-grid (V2G) concept is very promising when a system allows a bi-directional power flow [43] and provides the EV owners with the supply back to the grid when the grid has a power shortage. When evaluating this concept by ignoring the cost implications, BESS deployment for commercial charging needs appears promising. The cost implications due to lost energy during conversion from AC to DC and DC to AC, along with lost energies due to inverters and rectifiers, transmission, and distribution costs, require a further assessment to validate the argument that both V2G and BESS are successful candidates for resourcing grids with additional distributed generation.

Load Profiles

The fossil fuels are diminishing, and so are their dependent technologies. Internal Combustion Engine (ICE) revolutionized the industry ever since it was invented. There is a strong indicator of a shift from ICE to a technology that is less reliant on fossil fuels not only to eliminate GHG emissions but also to become sustainable when meeting the energy demand. Electric vehicle (EV) technology with varying types of electric motors and battery packs has become a safe and acceptable alternative to ICE vehicles, thereby influencing policymakers to start a strong move towards EV adoption on a large scale. Major components that differ from traditional ICE vehicles are the electric motor, battery, and controller. Each of these components added to EV brings challenges to utility companies when large-scale adoption is considered. For example, the power electronic components add harmonics to the system, and the battery requires a charging infrastructure, which adds a burden on the existing grid to power generation. Customers freely drive up to any gasoline station for refueling at any time. However, with limited infrastructure for charging EVs there, customers' choices for recharging are limited. To solve the major problems around the burden added to utility companies and charging hub stations for supplying intermittent charging needs, this paper proposed research around deciphering known methods in redistributing the demands to off-peak periods. Whereas harmonic issues with power electronic components of an EV charger may be eradicated by the use of harmonic filters, better design aspects of harmonic reduction were presented as well.

This paper is framed in the following manner: introduction, methods, results, conclusion, and discussion. Introduction describes literature review. Methods describes the methods for obtaining the suitable chargers, smooth transition quantification, and charging demand distribution. Methods also touch base on the application of BESS for smoothening the demand curves, typical charging hub design, and payback period. Results obtain a layout of charging hub for a customer base of 1000 per day and perform cost and payback analysis.

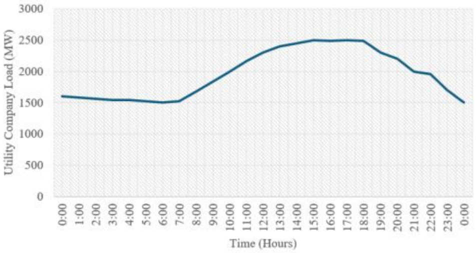

Figure 4: Load Profile for Summer [44]

2. Methods

Fig. 5 shows a model for first obtaining an accurate forecasting tool for predicting the EV profile of the next years and documenting the existing EV profiles. Accordingly, the EV charging infrastructure is predicted based on demand, and new infrastructure is added to the system. This known EV infrastructure becomes the benchmark of the total demand required at the generation station and predicts a demand curve. This demand curve acts as a tool for utility power grids to prepare for generation and supply the intermittent loading from the EVs that have consistency when demand curves are forecasted. Equation 1 gives total required wattage for EV charging needs for a given year. Fig. 6 shows the power flow of the connected BESS system to the grid.

$$W_T = u_a \sum_{k=1}^{n} \binom{n}{k} n_{a_i} w_{a_i} + u_b \sum_{k=1}^{n} \binom{n}{k} n_{b_i} w_{b_i} + u_t \sum_{k=1}^{n} \binom{n}{k} n_{t_i} w_{t_i} + u_m \sum_{k=1}^{n} \binom{n}{k} n_{m_i} w_{m_i} \quad (1)$$

Where W_T is the total energy required to charge vehicles in a given year. n_{a_i} is the number of automobiles of a given type and w_{b_i} is energy required to charge to 100% SOC for an average number of miles driven by each in a given year for the given automobile. u_a is the utilization factor of automobiles. Similarly, subscripts of b, t, and m represent buses, trucks, and motorcycles.

The demand will be formed based on equation 2.

$$D = \frac{f_1 W_T + f_2 W_T + f_3 W_T}{8.760} \quad (2)$$

Where D is total demand in kW. f_1 is the fraction of level 1 chargers use, f_2 and f_3 respectively for levels 2 and 3. The summation of the f_1, f_2, and f_3 is 1 or 100%.

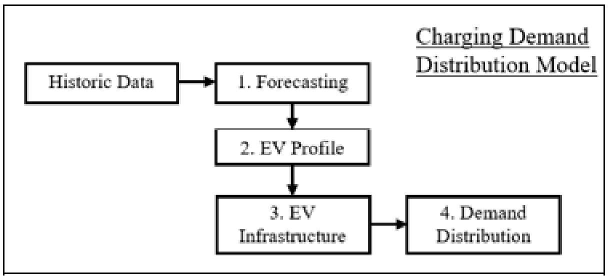

Figure 5: Model

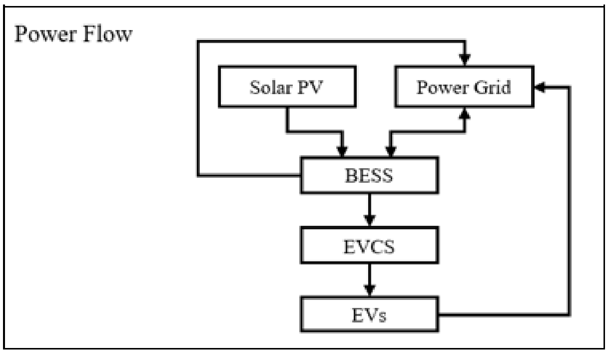

Figure 6: Power Flow

Table 1: Steps

Steps	Description	Source/ Intent
Step 1	Forecasting EVs for subsequent years based on historic data	Based on Published Research [1]
Step 2	Projection of EV for given year	Based on Published Research [1]
Step 3	Total EV Charging Infrastructure	Based on equation 1 and chosen f value in equation 2
Step 4	Charging Demand Distribution	Based on analysis in Step 3

Step 1 and 2: EV profile in next 30 years

The researchers have projected the electric vehicles count for Maryland by the end of 2052. Based on these numbers an assumption on transition by each year be taken as at 10% every year at steady growth. However, the transition is limited by many factors, such as the availability of EV cars in the market, government support, availability of charging infrastructure, substitute products, and customer ideology.

For Maryland the total count of vehicles by each type were shown in Fig. 7-10.

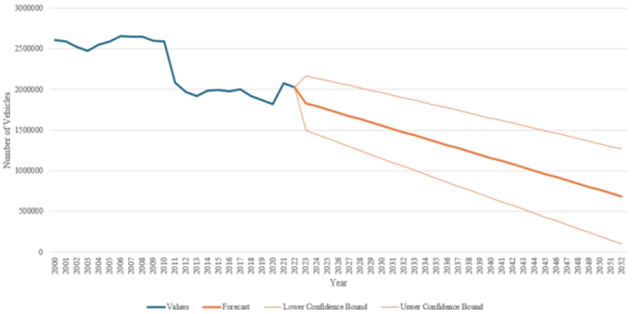

Figure 7: Vehicle Projections for MD – Automobiles [1]

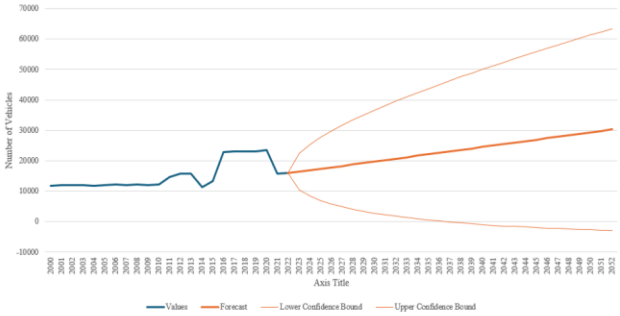

Figure 8: Vehicle Projections for MD – Buses [1]

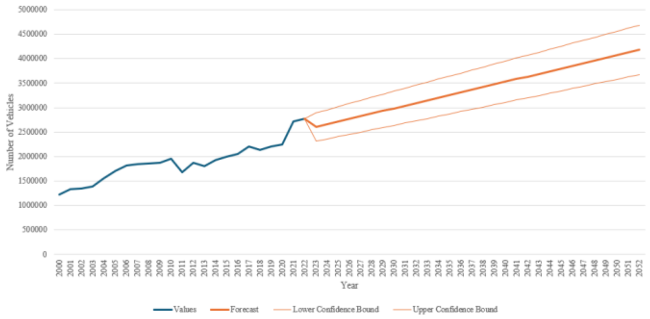

Figure 9: Vehicle Projections for MD – Trucks [1]

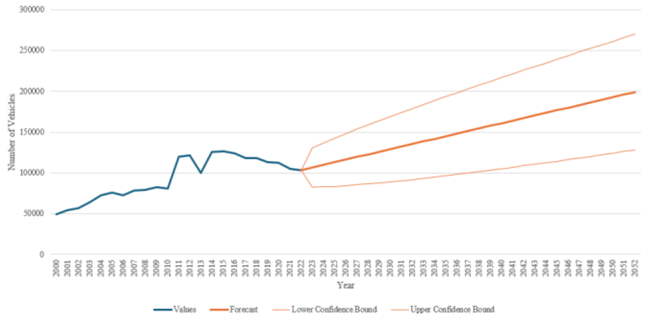

Figure 10: Vehicle Projections for MD – Motorcycles [1]

EV Infrastructure Smooth Transition

Based on a smooth transition modeling to electrification of all the categories (automobiles, buses, trucks, and motorcycles), the percentage of total EVs against current year total were shown in Fig. 11-14. The number of EVs during a certain year were a percentage of the cumulative vehicles in the past years. The chosen percentage for automobiles, buses, trucks, and motorcycles was 0.4%, 0.25%, 4.13%, and 4.21% of the cumulative number of vehicles in the previous years starting 2022 until 2052, respectively. The equivalent percentage of EVs against total vehicles during a given year is shown in Fig. 15. This becomes the basis of the transition model for policymakers and manufacturers.

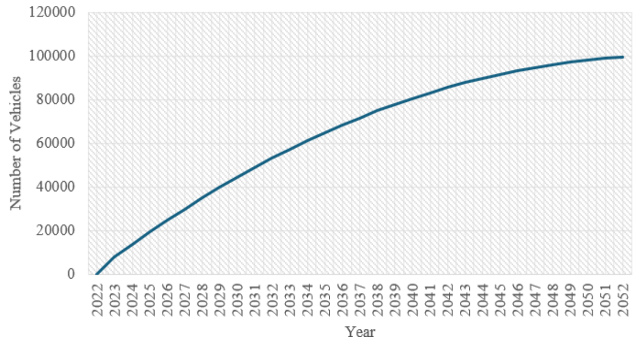

Figure 11: EV - Automobiles

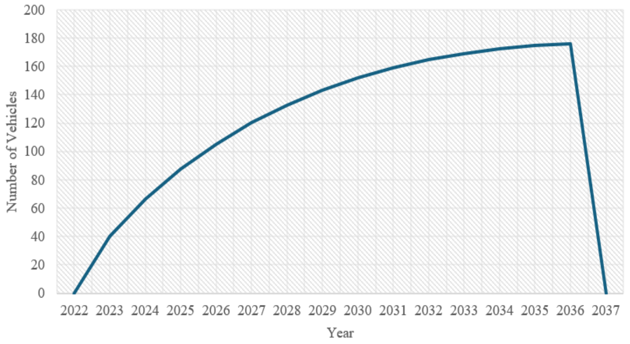

Figure 12: EV - Buses

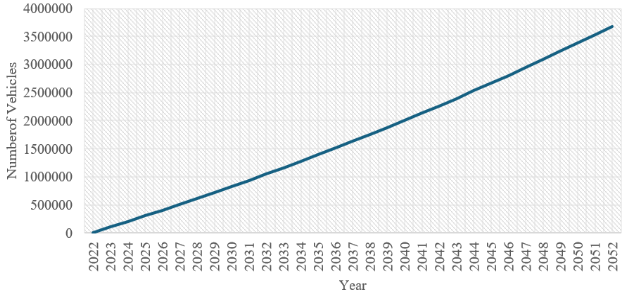

Figure 13: EV – Trucks

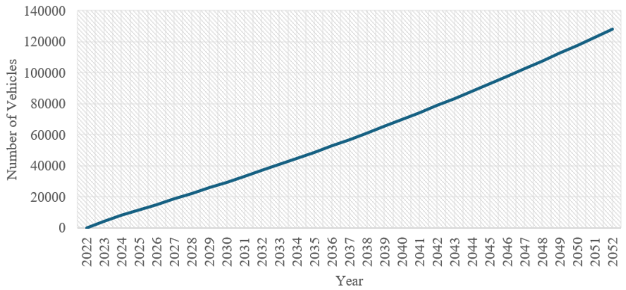

Figure 14: EV - Motorcycles

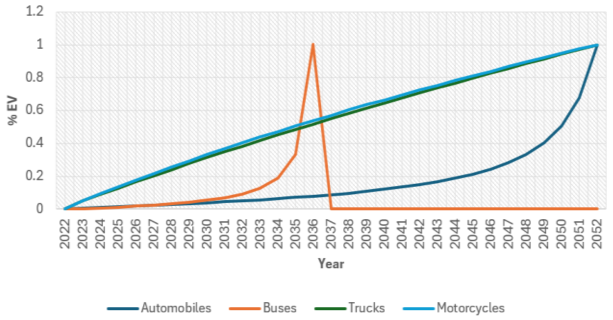

Figure 15: %EV by year

Step 3: EV Infrastructure

The researchers have projected the electric vehicles by the end of 2052 for Maryland. Based on these numbers an assumption on transition by each

Selection of Level 1, 2, or DC Fast Charger

All the available charging infrastructures are suitable for the light-duty and heavy-duty segments. However, given the size of batteries for heavy-duty, the application of level 1 and level 2 is less feasible as there is the likelihood of the majority of the vehicles on the road. However, a fleet of vehicle trucks that return overnight may utilize the level 2 charging option. Table 1 shows available chargers for EVs. Selection is based on evenly distributing charging demand to the utility grid. Levels 1 and 2, when directly connected to the grid, will evenly distribute the charging demand for an elongated time, thereby not overburdening the grid. Additionally, BESS for charging applications may further redistribute the demand for EV charging evenly to the grid. Criteria for suitable selection of chargers per type of infrastructure vs charging speeds and ease in accessibility was covered in [45] [46] [47] [48].

Step 4: Charging Demand Distribution with Varying f

The Let us consider year 2052 and use the number of vehicles by each category in equation 1, all battery wattages were based on a typical commercially electric vehicle for given category. It is assumed that all registered vehicles were operational and used daily for scenario 1, 2 and 3. They add an average demand D during a given time (hour of the day). After utilizing equation 1 and 2, D is 52,233 MW.

For scenario 1, D is distributed amongst level 1, 2, and DCFCs based on f_1, f_2, and f_3. Assuming f_1 and f_2 at 0.25 25% each and f_3 at 50%. The D can be distributed between mid-night to 6 am at 13,058 kW each for level 1, and 2; and throughout 24 hours at 26,116 MW for DC fast chargers.

For scenario 2, assuming f_1, f_2, and f_3 at 33.3%. The D can be distributed between mid-night to 6 am at 17,411 MW each for level 1, and 2; and throughout 24 hours at 17,411 MW for DC fast chargers.

For scenario 3, assuming $f_1$is zero; and both f_2 and f_3 at 50% each. The D can be distributed between mid-night to 6 am at 26,116.5 MW for level 2; and throughout 24 hours at 26,116 MW for DC fast chargers.

For scenario 4, assuming $f_1$and f_2 are zero; and f_3 is at 100%. The D can be distributed throughout 24 hours at 52,233 MW for DC fast chargers.

BESS Model for Charging Hub Stations

A regular gasoline station occupies about 30,000 to 40,000 gallons of gasoline and diesel in underground storage tanks. On average, the stock lasts for about a week or longer, depending upon the throughput of the gasoline station. To reduce intermittent loading to the grid it is possible to deploy a battery energy storage system (BESS) at the fueling stations of a capacity enough to supply the customer's charging demand. The advantage of BESS of being capable of supplying power even during a grid power loss, together with the capability of drawing power for charging the battery bank when it's cheaper from the grid, ensures resilience. For example, the BESS recharges only during off-peak periods or nighttime when it is cheaper to run generators at the power stations. Additionally, the integration of solar PV systems mounted on rooftop or ground mounts closer to these charging stations ensures further reduction of energy demand on the grid. Based on scenario 1-4, a suitable size of BESS must be planned. Ideally for charging hubs at gasoline stations (with widespread DC fast chargers) to keep customer behavior in returning to charging hubs just like traditional gas station visit, scenario 4 may be utilized to size BESS.

Demand Shift during Night-time

From methods section., the total demand for electricity was determined for each of the categories of the vehicles. For a local utility in the Baltimore, Maryland area, the majority of the peak demand is during the daytime. The time between 12 am to 4 am are typically underutilized, and many generators may be stalled due to low grid loading. The BESS storage charging curve for a total BESS capacity per scenario 4 when overlapped with the utility company demand curve a best fit for the BESS charging is possible.

Losses from BESS from charging and discharging equals to 10-20% thus total cost lost due to the same is $0.02-0.04/kWh. However, cost of intermittent loading the grid with EV charging need at any point in the day is $0.33 (peak load tariff by BGE was considered [49]). This cost is based on the assumption that, on average, more than 50% of the vehicles would go for charging during peak loading times. So, BESS becomes a solution even without factoring in the local integration of solar or wind energy system.

Existing EV Chargers

The total number of EV charging stations in Maryland for public use comprises of more than 1500, out of which 13 are level 1, 1,454 are level 2, and 313 are level 3 [50]. This equates to around 26 MW of charging infrastructure.

3. Results

The size of a Battery Energy Storage System for the charging hub around the city is based on the kWh output required to supply the customers. This was obtained in scenario 4. A layout of chargers at charging hub (converted from an existing gasoline station) is shown in Fig. 18. Let us consider 1000 customers visited in each per day and each customer utilized around 100 kWh during an ultra or hyper charging session. By addition of five ultra-fast chargers and six hyper fast chargers, an installed capacity of ~3kW requires BESS of ~15.6kW to supply three days of energy for 1000 customers. An additional 2 days storage may be supplied back to grid when BESS acts as a DG source.

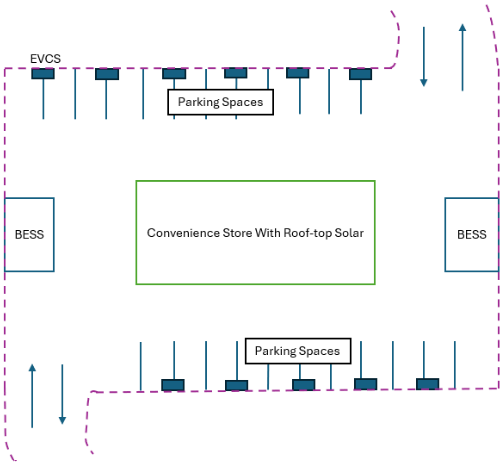

Figure 16: Layout for Charging Hub Stations [51]

Assuming the existing customer base remains constant throughout the year. For a new charging station with a convenience store, dual port ultra and hyper-fast chargers were proposed. The number of parking spaces was dependent on the maximum number of customers visited at any given hour during the year. The total wattage of the chargers was the basis of the design for a battery energy storage system. The roof-top space for the convenience store was a tentative location for a solar PV system to power the convenience store and charge the battery energy storage system. BESS chargers during the off-peak periods (mainly night hours) and feed the grid when required. The size of a typical BESS is based on the total capacity required to meet the demand for the next or until it takes the BESS at SOC 10%.

Energy Lost at Storage

The energy conversion takes place at multiple stages in scenario 1, as shown in Fig 17. vs Scenario 2, as shown in

Fig 18. With BESS there is an energy lost in process as shown. Without BESS there is lesser energy loss.

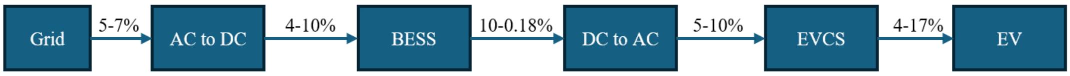

Figure 17: BESS

Figure 18: Without BESS

Energy Savings from Charging at off-peak times

In Maryland the time of the day tariff during normal and peak periods is usually between the range of $0.16 to $0.33 per kWh [49]. So, shifting the demand during nighttime or off-peak periods results in a savings of $0.05 to $0.22 per kWh.

Cost of BESS infrastructure

Table 2 shows cost breakdown of a 15,625W BESS for a charging hub. The unit cost per kWh of installation is $7.8. All the costs used here were based on fair market price in local Baltimore, Maryland area for materials only.

Table 2: Cost of BESS

Component	Cost
Battery Bank (15,625W, 300,000kWh)	$1,562,500
Rectifier (AC to DC)	$25,000
DC to DC converter	$26,500
EVSE	$6,50,000
Enclosures	$50,000
Miscellaneous Materials	$25,000
Total	$2,339,000

Payback Period

The payback period is shown in Table 3.

Table 3: Cost of BESS

BESS Cost	$2,339,000
Sales per year (20% profit)	$2,409,000
Operational Costs	$80,000
Payback Period (in years)	~2 years

Thus, the payback period is around 2 years. For typical gasoline stations, a similar return on investments is expected.

Revised Demand Curve

Charger demand distribution from scenario 1-4 when overlapped with utility demand curve as shown in Fig. 4, demand curve may be reshaped.

4. Conclusion

A simplistic model for projecting charging demand distribution was presented by documenting the methods in obtaining the forecasted profile of vehicles in the nearing future (2052). The selection of the chargers (level 1, 2, or DC fast chargers) was based on selection of f value. A smooth transition model of electric vehicles presented the need to focus on the truck category. Key aspects around transition model were useful from a policy making and manufacturing standpoint. BESSs application in smoothening the demand curve for utility companies was based on scenario 4. A charging hub with ultra and hyper fast chargers was developed for customers base of 1000 per day to any regular gasoline station. The BESS system costs, and payback period were calculated based on available market prices. A typical of 2 years of payback was achievable without factoring in the labor and other costs.

5. Discussion, Limitations, and Future Scope

The shape of the demand curve going forward may look simplistic when distributing the EV demands to off-peak periods is concerned. However, whether large-scale BESS's adoption poses any environmental threats is a subject of study as large-scale battery bank poses risks in terms of fire safety, heat, and hazardous wastes from manufacturing and operation. The evolution of grids with DGs and EVs may seem seamless, but the shape of the demand curves would address demand response. The capabilities of unoccupied urban spaces with solar PV installations or wind power installations are subject to study, as is the case with increasing DGs for EV charging needs. Documentation of the initiatives by the government agencies for encouraging utility companies to add renewables for meeting EV charging demands is a subject of research. The impact of existing policies may give a path forward for policymakers to regulate the EV market supply chain and moderate the EV transition to allow utilities to have enough timelines and government support to increase generation.

The limitation of the study was the exact pattern of customer inflow for charging stations was less predictable. Customers, both local and long-distance travelers, may end up at charging stations at almost unpredictable times during day or night times. Their choice of charging station is almost driven by many factors such as availability of amenities, ease of charging, safety, brand, and so on. A research on customer behavior leads to input for this study in estimating potential locations for BESS. Availability of substitute products in the meantime due to technological revolution is unpredictable and thus was not considered in this study. BESS and other infrastructure at existing gasoline stations or new charging stations are less traditional. BESS is a growing concept for utility companies when utilizing renewable energy, and thus, its application for EV charging needs at a secondary point is subject to debate amongst policymakers and industry experts. Utility companies' flexibility in adopting BESS for charging during off-peak periods is subject to criticism as there may be a loss of revenue for them when the storage is seen as a distributed generation and thus gives back power to the grid and gets paid for.

Evolving charging infrastructures with wireless charging capabilities, such as Robo Taxi by Tesla, are subject to further study as their impacts in adding harmonics and other power system stability issues may vary from present types of chargers. On a large scale, opponents of EV adoption may raise concerns about BESS and its safety issues. Some government policies may be slow in incentivizing grids to prepare them for EV charging needs in comparison to subsidizing the EV market for consumers. Additional support from engineering standards governing agencies would require collaboration with major utility companies so that there are no undue costs due to standards compliance. For example, some SAE and IEEE standards require the provision of safety features for the BESS and EV chargers. Utility company transmission and distribution systems with integrated DGs and BESSs require extensive standards review to ensure cost-effective safety measures are in place. Smart grid preparedness to integrate V-2-G and BESS as DG is the subject of studies both from power system stability and cost impacts. DGs have been proven to have been widespread for a long time. Detailed power system studies with PQ load flow become a driving factor in the selection of sites and scale of battery systems. For example, manufactured products with low power quality issues may significantly limit the burden on the power grids to mitigate grid stability issues in frequency and voltage dip controls.

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Definitions/Abbreviations

BESS	Battery Energy Storage System
DG	Distributed Generation
EV	Electric Vehicles
Charging Hub Station	Area where there are multiple charging stations with or without amenities

Appendix

Table 1 is enclosed as an appendix.

Table 1: EPC Classification and Charging Infrastructure

Category	EPA Classification	Vehicle Battery kWh	Commercially available Vehicle (Example)	Suitable Charging Infrastructure	Charging System	Time for Full Charge (SOC 100%)
Light Duty Vehicles (Passenger Vehicles)						
	Light Duty Vehicles (< 8,500 lbs)	15-100kWh	Tesla Model X	Level 1 (2kW), Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type	Level 1: 40-50 hours Level 2: 4-8 hours DCFC: 20-40 minutes
	Medium Duty Passenger Vehicle (8,501 to 10,000 lbs)	120-150kWh	Tesla Cybertruck, Chevrolet BrightDrop 600	Level 1 (2kW), Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type	Level 1: 40-50 hours Level 2: 4-8 hours DCFC: 20-40 minutes
Heavy Duty Trucks						
	Light Duty Truck 1 & 2 < 6,000 lbs	80-100kWh	Tesla Cybertruck	Level 1 (2kW), Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type	Level 1: 40-50 hours Level 2: 4-8 hours DCFC: 20-40 minutes
	Light Duty Truck 3 & 4 < 8,500 lbs	120-150kWh	Tesla Truck, Ford F-150 Lightning	Level 1 (2kW), Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type	Level 1: 40-50 hours Level 2: 4-8 hours DCFC: 20-40 minutes
	Heavy Duty Vehicle 2b (8,501 to 10,000 lbs)	150-400 kWh	Typical Volvo Trucks	Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type, Pantographs	Level 2: 5-8 hours DCFC: 1-2 hours
	Heavy Duty Vehicle 3 (10,001 to 14,000 lbs)	250-400 kWh	Chevrolet BrightDrop 400	Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type, Pantographs	Level 2: 5-8 hours DCFC: 1-2 hours
	Heavy Duty Vehicle 4 (14,001 - 16,000 lbs)	250-400 kWh	Typical Volvo Trucks	Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type, Pantographs	Level 2: 6-8 hours DCFC: 1-4 hours
	Heavy Duty Vehicle 5 (16,001 to 19,500 lbs)	250-400 kWh	Typical Volvo Trucks	Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type, Pantographs	Level 2: 6-8 hours DCFC: 1-4 hours
	Heavy Duty Vehicle 6 (19,501 to 26,000 lbs)	250-400 kWh	Typical Volvo Trucks	Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type, Pantographs	Level 2: 6-8 hours DCFC: 1-4 hours
	Heavy Duty Vehicle 7 (26,001 to 33,000 lbs)	155-400 kWh	Blue Bird Vision Electric Bus	Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type, Pantographs	Level 2: 6-8 hours DCFC: 1-4 hours
	Heavy Duty Vehicle 8a (33,001 to 60,000 lbs)	280-565 kWh	Volvo FL Electric, IC Electric Bus CE Series	Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type, Pantographs	Level 2: 6-8 hours DCFC: 1-4 hours
	Heavy Duty Vehicle 8b (>60,001 lbs)	360-540 kWh	Volvo FH Electric	Level 2 (7 to 12 kW), Level 3 (DC fast charger, 50 to 350kW)	Plugin type, Pantographs	Level 2: 6-8 hours DCFC: 1-4 hours