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Impact of Electric Vehicle (EV) Adoption on Power Transmission System

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Abstract - *Governments across the globe are increasingly adopting policies to encourage the adoption of electric vehicles. While this move has numerous benefits for the climate, it raises new concerns about its ramifications on the grid. This piece of writing discusses the impact of EV charging on the grid and explores some of the upgrades that can be implemented on the grid to reinforce it for EV charging.*

***Key Words*: Grid, Power supply, Electric vehicles, EV chargers, Voltage, Systems.**

1. INTRODUCTION

Climate change is emerging as one of the major problems in the 21st century. The deteriorating weather patterns across the globe are not only affecting food security and undermining the quality of ecosystems but also displacing populations and leading to the loss of species. According to the United Nations, weather conditions such as frequent severe storms, increased drought, floods, and heat waves, which stem from climate change, are not only hindering food production but also impeding other economic activities [1]. Extreme weather events combined with air pollution aggravate diseases and mental health. Although climate change can be attributed to a myriad of factors, evidence suggests that fossil fuels are the main drivers of climate change.

According to a UN report, fossil fuels are by far the largest contributors to global climate change, accounting for over 75 percent of global greenhouse gas emissions and nearly 90 percent of all carbon dioxide emissions [1]. According to the United States Department of Energy, highway vehicles release about 1.5 billion tons of greenhouse gases into the atmosphere each year [2]. The report further notes that each gallon of gasoline produces 20 pounds of greenhouse gas, translating to 5 to 9 tons each year for a standard vehicle. As the global economy and population continue to grow, the number of highway vehicles will also continue to surge. This implies that the quantity of greenhouse gas emissions will worsen in the future, causing more implications for the climate.

To combat the impact of automobiles on the climate, world governments have launched initiatives to promote the adoption of vehicles with low carbon footprints on the environment. Such vehicles are electric vehicles, commonly abbreviated as EVs. With no exhaust pipe, pure electric vehicles reduce carbon emissions considerably. In fact, according to the United States Department of Energy, electric vehicles produce zero direct emissions [3]. Unlike conventional vehicles, whose combustion engines require more parts to manufacture and assemble, electric vehicle engines are simple and hence do not require more parts, further reducing the carbon footprint of electric vehicle manufacturing. Overall, multiple studies agree that electric vehicles can reduce carbon emissions by 50 to 70 percent.

Although the proliferation of electric vehicles is good for the environment, the widespread adoption of the technology has various impacts to the global power transmission infrastructure. Pure electric vehicles are solely powered by electricity. This implies that as masses adopt the technology, the pressure on power transmission systems will significantly increase. Widespread adoption of the technology will mandate grid upgrades and the development of new infrastructure to support the new demand. These upgrades may involve increasing power supply to meet the surging demand, developing charging points, and securing the grid from downtimes such as those caused by cyber threats. This piece of writing discusses the projected assimilation of electric vehicles and the impact of the adoption to power systems, and explores some of the strategies that can be exploited to enhance the efficacy of power systems to meet the increased demand.

2. ELECTRIC VEHICLES ADOPTION

The presence of electric vehicles in the global market has significantly grown over the past decade. According to Gomez-Ramirez et al, only 120,000 electric vehicles were sold globally in 2012 [4]. In 2021, this number had surged to 6.6 million, denoting a growth of over 5400 percent in just 10 years. They further note that by 2021, electric cars accounted for 10 percent of global car sales, and more than 16.5 million users were driving electric cars. In 2022, electric car sales were 75 percent higher compared to 2021 sales. The International Energy Agency (IEA) asserts that electric car sales have been growing at an annual rate of 60 percent and projects that over 130 million electric vehicles will be in use by 2030. According to Automotive Dive, electric vehicles will account for 62 percent to 86 percent of global car sales by 2030 [5]. Goldman Sachs report projects that by 2040, electric vehicles' annual sales will reach 73 million [6]. The report further notes that developed markets, such as the European Union, may completely get rid of tailpipe cars by

2040. The graph below summarizes the shift to electric cars in the world's leading economies.

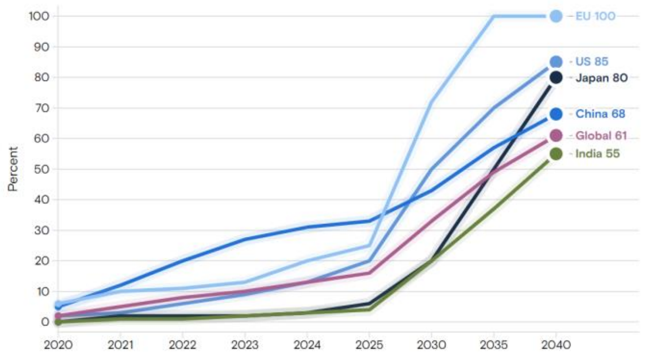

Figure 1: Shift to EVs in leading markets

Increased adoption of electric vehicles is driven primarily by two factors: environmental concerns and government policy. As aforementioned, electric vehicles are largely appreciated for their eco-friendly nature. They not only produce zero emissions, but also emissions related to their production and running are significantly low. Besides, these vehicles offer other eco-friendly benefits such as low noise pollution and recyclability of their components. Lithium batteries used in electric vehicles can be easily recycled, hence reducing the environmental impact of EVs.

Government policies tailored to promote the acceptability of electric vehicles are also playing a key role in pushing EV sales higher. Some countries are incentivizing the production and purchase of electric vehicles by offering subsidies and tax benefits on key production materials. For example, China has ratified carmaker exemptions from consumption tax and vehicle and vessel tax for production. All electric plug-in cars with a range of over 400 km are eligible for subsidies of about $2000, and those with a range of 300-400 km are eligible for $1400 subsidies per car. The United States offers credits of up to $7,500 per car for buyers. These credits are claimable when filing tax returns. Other countries, such as Canada, India, and the European Union, have similar arrangements. These mechanisms not only make the production of electric cars cheaper and profitable for manufacturers but also make the cars affordable on the buyer's side. Charger intensity and reduction in EV battery costs are other factors that will push for the adoption of electric vehicles.

From the insights above, it is evident that the adoption of electric vehicles is unstoppable. In the coming years, fossil fuel cars will subtly phase out as electric cars become mainstream. While this shift is commendable, it raises questions about the ability of power supply systems to support the increased load from a large number of electric vehicles charging simultaneously.

3. IMPACT OF ELECTRIC VEHICLES ON POWER

According to a report by the University of Navarra, in 2020, electric cars consumed just 80 TWh of global electricity [7]. This figure rose to 110 TWh and is forecasted to grow to a range of 525 TWh and 860 TWh by 2030. As people assimilate EV technology, the power demands will proportionally surge. The increased demand for electric power will have various impacts on the power supply systems across the globe. These impacts will include;

3.1 System overloads

Even though there are arguments that the power supply systems of some countries, such as the United States, are well equipped to handle the power demands of the widespread adoption of electric vehicles without significant system updates, simulations indicate that some countries' power systems are not ready to meet the needs of electric vehicles. For example, according to simulations by Gomez-Ramirez et al., Costa Rica's high-voltage power supply systems may support the short-term electricity demand induced by electric vehicles but may not be sufficient to guarantee meeting long-term needs [4]. They note that Costa Rica's power supply system has enough capacity to meet the power needs until 2040. However, beyond this time, the country's power systems will experience overload problems, and voltage profiles will become unstable. They further observe that the country's medium voltage systems will only meet EV power supply demand until 2030. Beyond 2030 the systems will become vulnerable to overload issues, and voltage profiles will be unhealthy.

A similar simulation study by Szablowski & Bralewski on Poland yielded almost similar results [8]. According to the study, the demand for power resulting from electric vehicles was relatively high during weekdays as compared to non-working days. Besides power demand varying between days, the study found that the demand fluctuated during the day as well. During weekdays, the demand peak fell in the evening hours, coinciding with the greatest daily demands. Morning hours also registered significant power demand as compared to afternoon hours. During non-working days, the demand for power from electric cars was higher during afternoons. The simulation also found that power demand for summer was significantly lower than winter demand. The report asserts that high energy demands during the winter may be a result of more people using cars to commute to work. The report estimated that on weekday evenings and weekend afternoons, the demand would increase by 11 to 12 percent and would drop sharply during the night. In a nutshell, the report concluded that widespread assimilation of electric cars in Poland would result in frequent power demand fluctuations. Irregular load distribution on the power supply would prove problematic for the system to handle. High load unevenness would adversely affect the use of installed power in the system. Overdemand during peak periods would risk issues such as load shedding, and power oversupply during off-peak would risk exploding transformers. The figure below demonstrates the simulated power demand fluctuations in Poland.

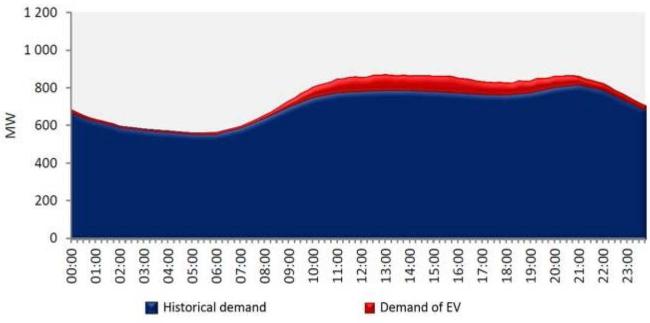

Figure 2: EV power demand throughout the day in Poland

A similar study by Suski et al in Maldives indicates that the growing number of electric vehicles would stress the power supply systems at specific times of the day [9]. The projection indicates that electric power demand in Maldives' capital, Malé, will grow from 71 MW in 2021 to 105 MW in 2030, representing EV power demand growth of 4.4 percent annually. The report notes that despite the increased pressure, the capital’s power systems would still be able to meet the demand for the period before 2030. However, in 2030, the evening peak would increase power demand by over 31 percent. The unprecedented power demand could result in load shedding. For Malé to sustainably assimilate electric vehicles, it must have plans to upgrade its power supply infrastructure in the future.

A simulation done by Fokui et al. to measure the impact of electric vehicle adoption on Kenya's power supply systems showed that the country's systems were more suitable for level 1 charging systems as opposed to level 2 chargers. The simulation projects that while both level 1 and level 2 chargers increase the load to the supply, the load imposed by level 2 chargers is significantly higher than level 1 chargers [10]. Level 2 chargers are capable of charging batteries faster (5 hours), but they lead to an increase in the network's total power losses. On the contrary, level 1 chargers are relatively slower (9 hours), but power losses are relatively low. The simulation also found that level 2 chargers would be installed in commercial parking areas and would be mainly active during the day, coinciding with normal power demand during the day. The normal power demand coupled with the high demand imposed by level 2 chargers on the system would destabilize power supply. In comparison, level 1 chargers would be installed at home and would be primarily used during the night when normal power demand is low. The study concluded that while Kenya's power supply system could support the widespread adoption of electric cars, the system was only suitable for level 1 chargers. For the country to install both level 1 and level 2 chargers, the power system would require upgrades.

In summary, increased adoption of electric vehicles will result in increased demand for electric power. While many countries' power supply will be able to cater to this increased demand in the short term, projections indicate that many will struggle in the future. Simulations indicate that many countries' current power supply systems will not be able to support electric vehicle power needs from 2030. Some studies indicate that power demand fluctuations throughout the day may be challenging for systems to handle. During peak hours, typically morning and evening hours, power supply systems may experience unprecedented stress. This may risk systems responding with cautionary measures such as load shedding. During off-peak hours, power supply systems may experience power surges in the transmission. This can trigger transformers to explode. Some studies have also found that some countries' power supply systems are not well-developed to handle all types of electric vehicle chargers. Countries in developing regions are not well prepared to support fast-charging EV chargers.

3.2 Premature aging of components

Contemporary power supply transformers and components were designed to handle normal commercial and household demand. The designers of the infrastructure did not envisage the systems handling extra fluctuating loads similar to EV charging loads. Charging electric vehicles will cause excessive and undesirable peaks in energy demand that may risk damaging transformers and other components of the system. Barros et al. assert that when transformers are exposed to high ambient temperatures and loads above what they were designed to handle transformer windings may overheat, reducing their performance and even rendering them dysfunctional [11]. The lifespan of transformers is affected by factors such as temperature, moisture levels, and oxygen content in core components. Electric vehicle charging may not have a significant impact on factors such as moisture level and oxygen content. However, overloads on transformers can significantly raise temperatures in critical components.

According to simulations by Barros et al., generally, high adoption of electric vehicles will push the temperatures in transformers high. However, the study found that some factors would accelerate the rise of temperatures beyond rated capacity. These factors are seasons and the battery capacities of electric vehicles. The simulations indicate that despite the increased power demands during winter, transformer temperature levels were relatively low, hence less damage to components. In contrast, transformer temperatures remained relatively high even in off-peak hours in summer. This implies that electric vehicle charging was more likely to accelerate damage to power supply systems during the summer. The figure below demonstrates transformer temperature changes throughout the day in summer and winter.

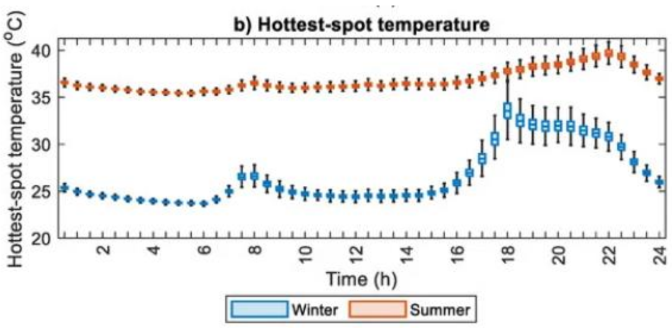

Figure 3: transformer temperature throughout the day in summer and winter

Electric vehicles with 75 kWh batteries charge at high power levels, increasing peak demand. The simulations indicated that with a penetration rate of only 20 percent, peak time transformer temperatures would exceed the transformer rate capacity for both winter and summer seasons. On the contrary, for electric vehicles with 24 kWh batteries, peak time transformer temperatures remain within manageable ranges until the penetration rate reaches 50 percent. The figure below illustrates the impact of EV battery size on transformer temperature.

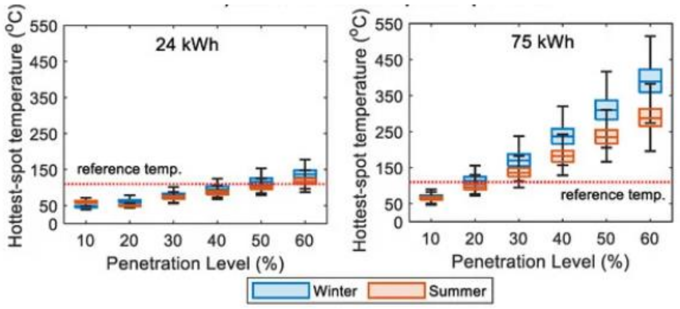

Figure 4: Impact of battery size on transformer size in relation to penetration rate

Transformers are one of the most critical and expensive components of a power supply system. For the power supply system to function optimally, transformers must be in perfect working conditions. Premature aging of transformers due to electric vehicle charging will necessitate frequent replacement of transformers and overall system maintenance. This implies that the increased adoption of electric vehicles will translate to additional power supply system maintenance costs.

In a nutshell, the widespread adoption of electric vehicles will accelerate the aging of key power supply system components such as transformers, increasing the maintenance costs of the systems. The rate of aging will likely be more pronounced in summer due to high transformer temperatures during the season. Increased adoption of electric vehicles with more powerful batteries will also hasten the aging of power supply components.

3.3 Increased Vulnerability to cyberattacks

The grid is one of the critical infrastructures commonly targeted by cybercriminals, especially state-sponsored hackers. Typically, cyber attacks on the grid are meant to disrupt the power supply in a region and, as a result, hinder economic activities, deny households access to power, and cause deaths in healthcare facilities. These types of attacks may also be intended to sabotage target governments by making them appear unable to provide critical services to their citizens. Increased reliance of vehicles on the grid makes power supply systems even more critical than before, making them more ideal targets for cyberattacks. For example, in case of a successful cyberattack on the grid, a country's transport sector is likely to suffer severely if its EV adoption rate is 100 percent. As the importance of power supply systems increases, they become favorite targets for state-sponsored attacks [12].

Besides electric vehicles increasing the relevancy of grid attacks to state-sponsored hackers, charging ports act as new avenues for cybercriminals to launch attacks on the grid. Modern cars are connected to the internet and are part of the IoT. EV charging ports are computerized and communicate with electric vehicles' computerized systems. Consequently, EV charging ports connect the grid to the IoT. Linking the grid to the IoT opens it up to conventional internet-based hackers. Sayed et al. note that electric vehicles are cyber-physical attack vectors against the power grid. Hackers targeting power supply systems can easily use electric vehicles as agents to spread attacks to the grid [12].

It is not just electric vehicles that pose danger to the grid; the grid also poses danger to electric cars. According to Route Fifty, computerized EV charging systems can be used by attackers to spread attacks on electric vehicles [13]. According to the agency, attacks spread through charging systems can be used to lock car owners out of their vehicles, overcharge car batteries to destroy them, and steal car owners' payment information. The reliance of electric vehicles on the grid gives cyber attackers a chance to leverage power supply systems to harm car owners.

In a nutshell, electric vehicle charging impacts the cybersecurity safety of power supply systems in three ways. First, it increases the role of power systems in society, making them ideal targets for politically motivated cyberattacks. Two, electric vehicles and charging stations provide an additional interface for cyber attackers to reach power supply systems. Access to these systems via IoT gives almost every hacker a chance to harm the grid. Lastly, electric vehicles and charging systems hold vital customer details such as financial information. This makes power supply systems a lucrative channel for trying to steal customer information.

Overall, the introduction of EV charging on the grid has various ramifications. One of the major concerns with the introduction of EV charging on the grid relates to system overloads, especially during peak hours. Fluctuations in power demands throughout the day induced by EV charging can cause instability in the system. Also, while many countries' power supply systems can support EV charging today, these systems may need upgrades in the future, particularly from 2030 and beyond. Failure to upgrade power supply systems risks exposing the systems to frequent blackouts due to load shedding or power oversupply. Premature aging of systems components such as transformers is another major EV charging concern. System overloads will raise transformer temperatures beyond acceptable levels, destroying them. Premature aging of components will increase the maintenance costs of systems. Lastly, EV charging will ease hackers' access to power supply systems and will also make them attractive to attackers. It is paramount relevant parties take necessary steps to proactively safeguard the grid from these impacts.

4. UPGRADING POWER SUPPLY SYSTEMS FOR EV CHARGING

The negative impacts of EV charging on the grid have the potential to slow down the assimilation of the technology. Consequently, the capacity of power supply systems must be reinforced in advance to mitigate the anticipated challenges. These upgrades should focus on managing loads on the system, increasing the power supply, enhancing the resilience of power supply systems, and protecting them from cyber threats. Some of the key upgrades to power supply systems are;

4.1 Active regulation of power supply

One of the key impacts of EV charging on the grid is the high demand for power during peak hours and low demand during off-peak hours. Extreme power demands during peak hours can cause load shedding, hence blackouts. Similarly, power oversupply during off-peak hours can cause transformers to explode, causing power failure. The impact of fluctuating power demand can only be mitigated by actively regulating voltage levels in supply systems. The voltage levels should be ramped up when demand grows and lowered when demand diminishes. Power Company states that the secret to effective regulation of power supply is knowing when power demand increases and decreases [14].

Regulation of power supply can be implemented manually or automated. Manual implementation can entail grid operators increasing and reducing power supply manually throughout the day based on the historical data of their grid. Using historical data, operators can develop a model that shows times of the day to increase power supply and when to reduce it. For example, according to ETAP simulations, the EV charging power demand surges in the early morning and evening and drops from 10 PM. Based on these simulations, voltage levels in the grid should be lowered from 10 PM and increased from 5 AM. Automated power supply control can leverage computerized systems that can track power demand in real-time and make power supply adjustments accordingly. Automated systems are the most effective but can be complex to implement, especially for sophisticated grids.

4.2 Advanced transformer installation

Contemporary transformers used in power supply systems were not designed for electric vehicle charging. Barros et al. asserts that while studies show that current transformers can support EV charging up to a certain electric vehicle penetration rate, these transformers are still exposed to overloads beyond their limit and will eventually fail [11]. Because of the vulnerability of current transformers to EV charging, experts recommend upgrading of power supply systems with modern transformers capable of withstanding peak time power demands. According to Hammond Power Solutions publication, conventional transformers should be replaced with k-factor rated transformers [15]. K-factor rated transformers are more resistant to heat that stems from overloading and harmonic currents. Besides, k-factor-rated transformers are designed to handle high neutral currents produced by multiple level 1 and 2 EV chargers. The agency further notes that the grid can be divided to handle different types of EV chargers. Transformers with a k-factor of 4 can be designated to support EV chargers with low loads, like level 1 chargers. Transformers with k-factor 9 can be designated for high-power chargers like level 2 chargers. The agency also directs the installation of low-temperature rise transformers in regions with daily average temperatures above 30°C or maximum of above 40°C. Low-temperature rise transformers usually have 220°C insulation systems and can handle temperatures up to 130°C. Upgrading power supply systems with advanced transformers will reduce long-term maintenance costs and stabilize the performance of the grid.

4.3 Incorporating energy storage

The problem of power supply systems overload can also be mitigated by incorporating energy storage batteries in the grid. Batteries can charge during off-peak hours and be deployed to supplement the grid during peak hours when demand for EV charging exceeds the network's capacity. According to Power-Sonic Corp , a company that specializes in energy storage systems, the use of energy storage systems can help reduce the extent of upgrades to power infrastructure [16]. For example, incorporating batteries on the grid reduces system overload, hence minimal damage to the transformers. Other benefits of incorporating energy storage batteries in the grid include improved reliability and resilience of power supply networks, enhanced EV charging capacity, and the use of renewable energy sources. The graph below demonstrates the impact of batteries on the grid.

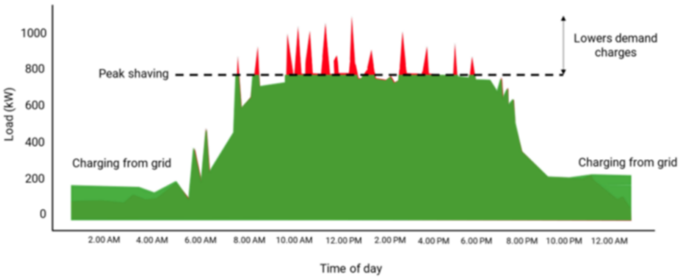

Figure 5: Batteries supplement the grid during peak, reducing stress on the network.

4.4 Incorporating renewable energy sources

According to the Center for Climate and Energy Solutions, renewables account for only 29 percent of electricity generation globally, with hydropower accounting for 16 percent of this figure [17]. This implies that other renewables such as solar, wind, and geothermal contribute 13 percent only to the grid. Wind and solar energy are the most underexploited sources of energy globally despite their potential to power half of the globe by 2050. To cover the power deficit created by EV charging, power supply entities can exploit the potential of renewable energy. The number and size of wind firms can be enhanced. Solar farms can also be developed to harness solar energy. According to Utilities One, photovoltaic cells can also be installed directly on vehicles for solar charging [18]. This will not only reduce the reliance of electric vehicles on the grid but will also facilitate vehicle-to-grid (V2G) technology, enabling vehicles to feed extra power into the grid, providing more power to the grid. Nearly all countries across the globe have the potential to enhance their power production by installing solar and wind energy.

4.5 Cybersecurity monitoring

Integration of EV charging to the grid makes it among the favorite targets for hackers. Besides, EV charging acts as an easy interface for hackers to compromise the grid. The increased susceptibility of power supply systems to cyber threats necessitates measures to protect the grid from malicious actors. One of the cybersecurity measures that can be adopted into the grid is installing an artificial intelligent monitoring system. An AI monitoring system can detect suspicious activities in a network in real-time and block them instantly. This system can also raise alarms for administrators to act. Other strategies, such as penetration testing, can be used to proactively detect cyber vulnerabilities and mitigate them before hackers can exploit them.

4.6 Coordinated charging

These are methods that aim to manage grid load by controlling the number of electric vehicles charging at a particular time. These methods are controlled charging and time of use (TOU) tariffs. Controlled charging refers to a smart grid approach that schedules the charging of electric vehicles in a way that lowers aggregate impact on the grid. Controlled charging can be implemented by installing an algorithm that controls EV chargers [19]. Time-of-use tariffs are incentives that are designed to encourage users to charge their electric vehicles at off-peak hours. Time-of-use tariffs include strategies such as reducing charging costs during off-peak hours. Suski et al. notes that time-of-use tariffs are an effective strategy for peak shaving and reducing EV-related capacity investments in distribution [9].

5. CONCLUSION

Electric vehicles are subtly replacing fossil fuel automobiles. While this shift is good for the environment, it has various ramifications for the power supply systems. Increased adoption of electric vehicles will add more load to the grid. This might render some systems unable to meet the power demands, especially during peak hours, causing blackouts. EV load also tends to fluctuate throughout the day. These extreme fluctuations are dangerous to the stability of power supply systems. Increased EV load will also cause premature ageing of critical components, increasing the system maintenance costs. This writing has also indicated that the reliance of vehicles on the grid makes power supply systems ideal targets for cyber criminals. The grid can be cushioned from the adverse impacts of EV charging through upgrades such as the installation of power regulation systems, increased integration of renewables into the grid, assimilation of energy storage batteries in the grid, adoption of more powerful transformers, and integration of advanced cybersecurity technologies in the grid. This writing also recommends the use of coordinated charging strategies to manage EV loads on the grid.

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BIOGRAPHIES

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