A Review on the Impact of Electric Vehicle Deployment on Smart Grid Infrastructure

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Abstract: The global energy demand is increasing, and in parallel also the depletion of non-renewable energy sources and ecological damage. Electric vehicles are revolutionary for both the automotive and energy industry as they point towards a sustainable solution to move people around. Smart Grid supports four basic electricity operations, and with the increase demand of EVs Smart grid is expected to be challenged. This increasing number of charging stations can create huge demand on the electricity grid, following rising popularity for EVs. Several charging strategies and smart grid connection techniques have been used to minimize the adverse effects of EVs on Charging. Vehicle-to-Grid (V2G) technology would address these issues in part by making it possible for excess energy to get back into the grid from EVs. V2G technology has many benefits such as frequency regulation, harmonic filtering, peak load shaving or shifting, grid stabilization and reliability improvement, energy backup storage capacity both at home in the vehicle enjoys cost savings for rate optimization purposes as well revenue earning options to consumers participating. Load Pattern Optimization for Smart Grid presents a problem in the smart grid as it is designed to integrate various components of power systems, utilizing state-of-the-art technologies that ensure seamless coupling between all interconnected operations providing effective and resilient energy management. The Smart Grid is a complex integration of multitude autonomous parts into the power system that pays attention to increasing energy efficiency and adaptability.

1 INTRODUCTION

The world's energy demand has been increasing everyday which is leading to the depletion of non-renewable energy sources like fossil fuels, coal, nuclear energy, while also contributing to ecological deterioration and energy crisis. Electrification has emerged as one of the most effective measures to solve the problems of energy crisis, coinciding with a rise in CO_2 emission due to increasing energy demand. The conventional vehicles, industries also add up to the Carbon emissions. The application of non-conventional vehicles has enticed significant attention in the recent times. The emergence of Electric Vehicles represents a significant shift in automotive and energy sector, indicating a transition towards sustainable transportation solution. Electric vehicles use batteries, fuel cells, PTC heaters, DC/Dc convertors to meet the energy demands of the vehicle. The power demands of the same are self-reliant and abstain from pollution. The Fig1 shows the growing demand of Electric vehicles from 2010 to 2030. The Smart Grid is expected to endure a flux and ambiguity due to the augmented demand in Electric vehicles (Tavokoli et al., 2020).

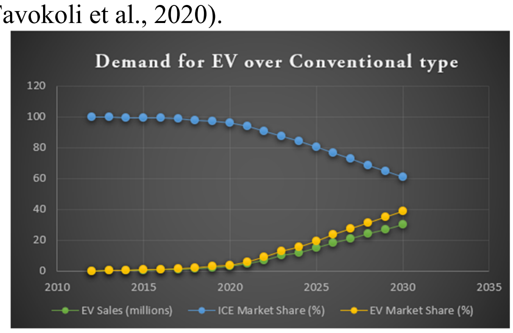

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Fig 1: Demand for EV vs Convention type vehicles

The grid the term grid denotes an infrastructure that supports four fundamental electricity operations, including electricity generation systems, long-distance electricity transmission, electricity distribution networks, and electricity consumption by end users.

2 ELECTRIC VEHICLE STANDARDS AND CHARGING

The demand for EVs is growing prodigiously compared to conventional vehicles as shown in fig1. The burgeoning popularity of EVs has resulted in a surging number of charging stations, significantly impacting the electricity grid. Diverse A variety of charging methodologies alongside intelligent grid integration techniques are employed to ameliorate the detrimental impacts of electric vehicle charging. EV was first invented in the 19th century, however after myriad fluctuations Electric vehicles had captured only a modest share of the automotive market landscape (Das et al., 2020).

Present-day EV technologies when compared to old EV are garnering widespread acclaim due to multitude of benefits, including reduce carbon footprint, zero exhaust gases, silent operation, utilization of renewable energy source, enhanced efficiency, lower operating cost. The convergence of the transportation sector with the power grid poses several formidable challenges for the power system. For instance, the widespread adoption of electric vehicles will exacerbate grid demand during the charging phase.

The inception of smart grid has streamlined the power system with an extraordinary communication facet. Vehicle to Grid encompasses the afore mentioned smart grid technology. V2G (Vehicle-to-Grid) technology aims to alleviate such challenges. By enabling bi-directional energy flow between electric vehicles and the power grid, V2G technology can potentially mitigate the increased load on the grid caused by EV charging (Tan et al., 2020). V2G notion empowers bidirectional charging allowing batteries to charge during low demands and expel excess energy back to the grid when it is not needed. The power capacity of V2G EV is constrained by three factors (Kempton and Tomić, 2020):

- The ability of the wires and other connections in the building to carry current
- The amount of stored energy in the vehicle relative to its usage time
- The maximum rated power of the vehicle's electronic systems

V2G technology presents a multitude of advantages, encompassing frequency regulation, harmonics filtering, peak load shaving, grid stability, reliability enhancement, resilience during blackouts, uninterrupted power supply for homes, backup energy storage, cost savings, and revenue opportunities for vehicle owners (Tan et al., 2020).

3 CONCEPTS OF SMART GRID

Smart Grid represents the sophisticated amalgamation of the multifaceted operations within the power system encompassing the intricate processes of electricity generation, distribution, and bidirectional functionalities. This advanced infrastructure leverages cutting-edge technologies to optimize the seamless coordination of these interconnected activities, ensuring efficient and resilient energy management (Tuballa and Abundo, 2016).

Smart grids are autarkic systems capable of autonomously diagnosing and rectifying their deficiencies within the network, significantly reducing the need for human intervention. Smart grids offer a multitude of benefits, including autarkic reliability, heightened operational efficiency, seamless integration of renewable energy sources, robust cybersecurity, consumer empowerment via real-time data analytics, significant environmental advantages, economic savings, and scalable flexibility, representing the zenith of contemporary energy infrastructure sophistication (Bayindir et al., 2016).

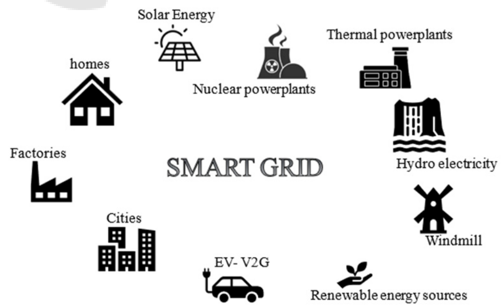

Fig2: Components connected to the smart grid

4 IMPLEMENTATIONS TO THE GRID

Smart Grid an integrated network encompasses several areas like AMI, WAMS, Power quality, distributed automation, customer technology etc (Soykan et al., 2021). Prerogatives of Grid manager and the EV Driver are considered in designing the V2G. The driver requires sufficient stored energy and grid manager is responsible for activating and deactivating the grid at specific intervals. These schemes of vehicle to grid can address the impending disagreements:

- Augmenting additional energy storage (electrical brawn)
- Utilizing V2G from fleets with predetermined usage pattern
- Implementing sophisticated controls for supplementary requirements (Kempton and Tomić, 2020)

Advanced metering infrastructure (AMI) is deployed to evaluate comprehensive load variation at each customer interface and furnish feedback, also facilitating the enhancement of power quality (PQ) levels. Wide area monitoring systems (WAMS) leverage phasor measurement technology to surviel transmission system conditions across vast regions, identifying and mitigating grid instabilities. Distribution automation (DA) technologies grant operators sophisticated capabilities to detect, locate, and diagnose faults, with real-time data on primary feeders provided by remote fault indicators, relays, and re-closers.

Customer technology (CT) and information and communication technology (ICT) manage customer communications and align customer needs with grid operations. Distributed generation (DG) involves electricity production from renewable sources like rooftop photovoltaic (PV) systems, small-scale hydro, and wind plants. Energy storage systems (ESS) allow engineers to optimize the power system, primarily addressing uncertainties in renewable distributed generation. Finally, electric vehicle (EV) charging infrastructures, a burgeoning global market, necessitate access to electric vehicle supply equipment (EVSE).

Along with these facets there are some imperatives to be chosen they are:

- Fault current restrictions
- Power flow regulation
- Adaptive Protection Measures
- Enhanced safety against faults
- Instantaneous electricity load transfer
- Ascertainment equipment status
- Expeditious electric loads transfer

Concomitantly other steps involved are diagnosis of traits of smart grid, synchronizing each role, Data Compilation, determining the benefit, Valorise the benefit, expense evaluation (Sospiro et al., 2021). EV charging characteristics should also be considered for implementing. EV charging entities include charging point, charging point operator, charging station, distribution system operator, smart meter. The charging connector types include Type1, Type2, Combined Charging systems, CHAdeMO and GB/T. These connectors vary in plug and socket designs and are standardized differently across countries and vehicle models. Main factors to be considered along with other characters are Battery State of Charge and Charging Duration.

Battery State of Charge represents the amount of remaining charge stored in the battery of an electric vehicle. The initial SoC is the battery's energy level at the start of charging process, while the target SoC denotes the desired charge level upon completion.

The EV charging curve shown in fig 3 initially rises rapidly and then slows down as it approaches full capacity due to the battery management system reducing the current to prevent overcharging. Conversely, the discharging curve shows a steady decline initially, followed by a more rapid decrease as the battery depletes, which reflects increased energy demands and voltage drops. This behaviour is typical for lithium-ion batteries, where efficient charging occurs at lower states of charge and protective measures kick in as the battery nears full capacity.

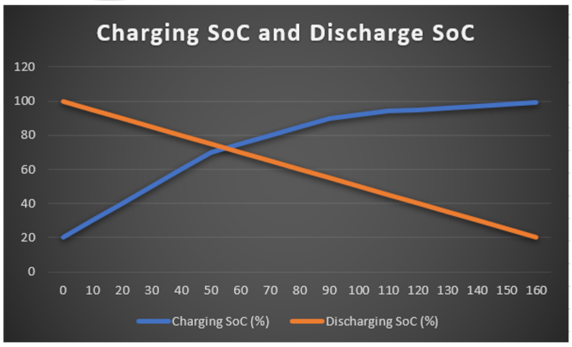

Fig 3: Charging State of Charge and Discharging State of charge

5 IMPACTS OF EV ON SMART GRID

Electric Vehicle (EVs) integration into the grid presents significant possibilities and obstacles. It requires strategic planning and technological advancements to manage increase electricity demand, peak load challenges and infrastructure upgrades, while also leveraging smart grid and V2G technologies to enhance renewable energy utilization and demand response capabilities.

5.1 Peak Load

This section must be in one column. The Electric Vehicles (EVs) are being promoted has a primary mode of transportation that increases the load in work areas as well as residential area due to their plug in charge mode. This causes' peak plus peak' and increase of peak valley difference leading to regional imbalance (Chun-lin et al., 2011). Significant voltage deviation and overloads in local distribution transformer might result from Plug-in Electric Vehicle (PEV) charging during peak hours. The system load curve is influenced by the rate and time of PEV charging. Concentrated charging during peak periods can result in greater total system peaks, but spreading charging during off-peak hours can reduce these peaks (Masoum et al., 2010).

5.2 Economic Demand

Setting up vehicle (EV) infrastructure requires an amount of investment, in charging facilities, which includes both public and private charging stations. This investment plays a role in guaranteeing access to charging points and accommodating the increasing EV population. Implementing metering infrastructure (AMI) and incorporating grid upgrades are essential for enabling communication, between EVs and the grid. This optimization helps streamline the charging procedures while minimizing expenses (Jiang et al., 2016).

5.3 Vehicle to Grid Integration

Electric vehicles enabled with V2G technology in parking lots or residential buildings can serve as energy storage units by supplying electricity to the grid or recharging during low demand periods providing advantages, for both grid operators and EV users (Kumar et al., 2019). V2G also enables electricity to flow both ways, thus enabling electric vehicles (EVs) to draw power from the grid for charging (G2V) and send it back during peak periods of demand (vehicle-to-grid, or V2G), which helps in load balancing and grid stability. But integrating this requires significant investments in grid infrastructure and equipment upgrades for managing two-way power flows and increased EV demands (Inala et al., 2021). While Plug-in Electric Vehicles (PEVs) grow in market share, the power grid can have higher energy losses which requires reinforcing of already existing infrastructure to decrease these losses.

Therefore, the EV charging/discharging should be managed properly with proper control mechanisms to prevent challenges such as transformer overloads, system efficiency degradation and harmonic distortion in generation and transmission lines. However, the V2G system necessitates sophisticated communication technologies so that secure and efficient interaction among the EV owners, grid operators and aggregators is possible (Kumar et al., 2019).

5.4 Grid Infrastructure

One big concern as EVs proliferate is the added demand on grid infrastructure when it comes to charging all of them, and that can lead to a lot of stress on an already-stressed grid.
As EVs are integrated into the grid, this increased electricity demand, particularly during peak charging times, can stress the distribution networks and transformers by causing constant overheating cycles of equipment (Beaude et al., 2016).

Excessive use of electric vehicle charging stations can result in voltage imbalances and fluctuations in areas where the power grid infrastructure may not be equipped to handle changes, in electricity demand resulting in either overvoltage or undervoltage situations (Chun-lin et al., 2011).

Moreover, EV chargers that often involve power electronics can also bring harmonics into the grid.

Along with damaging the already damaged power grid, this non-linear loading can also degrade the quality of power moving through utility lines, exciting other reactive elements on a transmission line that might have been idle for a long time and leading to overheating and efficiency degradation in transformers and other components.

In fact, the non-linear charging loads of EVs can lead to harmonic currents that distort the voltage waveform and endanger sensitive electronic equipment (Garwa and Niazi, 2019).

6 ADVANTAGES OF IMPLEMENTING EV TO GRID

The uses of electric vehicles in the grid infrastructure have a lot of advantages that can help complement both energy management and sustainability. Some of the advantages are listed below:

- Smart charging techniques such as off-peak hours or high renewable energy generation can help reduce the peak demand on the grid by flattening load duration curve and should allow for a greater level of balance and efficiency in transporting.
- V2G also has the potential to stabilize grid needs by allowing an EV to draw from storage but then give back, helping provide ancillary services like frequency regulation and spinning reserves at peak times of demand (Garwa and Niazi, 2019).
- Adopting smart charging strategies can help lower energy costs for EV owners. By adjusting charging times according to grid demand and electricity prices, users can benefit from reduced rates during off-peak hours (Kumar et al., 2019).
- Encouraging the adoption of EVs can lead to a decrease in greenhouse gas emissions and air pollutants, particularly when the electricity used for charging is sourced from renewables. This shift supports overall environmental sustainability (Beaude et al., 2016).

EV owners can make money by selling energy stored to the grid or mitigating their demands through demand response programs, effectively bringing down cost of ownership and operation of EV as well hence making financial proposition stronger. Moreover, EV use can eventually lead to savings for consumers and utilities. When power is abundant, EVs and chargers can take advantage of dramatically lower rates compared to peak loading which avoids the costly infrastructure upgrades necessitated by demand (Garwa and Niazi, 2019).

7 FUTURE SCOPE

The future possibilities for integrating Electric Vehicles (EVs) to the grid system are vast and wide with many vital areas of innovation as well as research being poised. As the EV's integration into the grid is increasing, V2G plays an essential role in enhancing the grid stability by providing ancillary services such as frequency regulation which is essential for managing volatile renewable energy sources (Kumar et al., 2019). EVs will also be vital in flexibly absorbing the variability of supply and demand as renewable deployment is expected to escalate their share in power mix. It designates future work to advance schemes that would let EVs uptake when renewable generation peak and yield during its trough, hence benefiting grid constancy while supporting fossil-fuel reliance (Garwa and Niazi, 2019). The fig 4 shows the market strategy for Electric Vehicles (EVs) by 2030 and growth EV production volumes with increasing integration of bidirectional converters allowing transferring power from the grid to vehicles (Kaufmann, 2017).

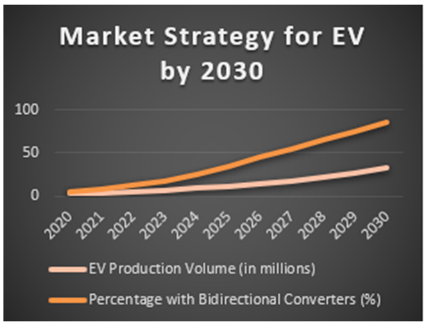

Fig 4 Market Strategy for Electric Vehicles

It is important to conduct longitudinal studies that measure how EV adoption affects grid impact cumulatively over years. This will allow EV penetration to be mapped, and for future challenges to be anticipated.

8 CONCLUSIONS

The growing penetration of Electric Vehicles (EVs) in the power grid help transform them from fossil fuel-based to a cleaner and more efficient mode of transportation. However, there are big challenges with this shift — increased grid stress and potential overloads due to the demand as well infrastructure upgrades. Smart grid technologies like Vehicle-to Grid (V2G) can help as they make the energy flow bi-directional so we may have a demand response at peak periods in which vehicles give back some of their stored electricity to stabilize the system. To truly capitalize on the advantages electric vehicles can offer, smart charging as well as other state-of-the-art grid management technologies are essential to curb peak loads and boost resiliency whilst also providing further resources for renewable energy sources at large. With the maturing of EV technology and its broader integration with traditional energy infrastructure will come new opportunities in innovation, planning and implementation to support a healthy (not unsustainable) transformation to cleaner forms of power.

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