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Review On V2g (Vehicle to Grid) Stability and Power Quality

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Abstract
Currently, Electric Vehicles are being widely adopted worldwide due to the gradual depletion of conventional sources of energy, environmental pollution, and global climate changes. Integration of Electric Vehicles in power system networks is gradually adopted. The integration is being accompanied by power stability, reliability, and quality issues. Intelligent incorporation of electric vehicles to the grid is required to address these challenges. The expected expansion in the quantity of Electric Vehicles will effectively affect the power framework. Albeit the transmission framework may be affected, most of the effects will be seen at the appropriation framework level. These effects incorporate both the framework stacking conditions and power quality issues. The electric vehicle (EV) Vehicle to Grid (V2G) framework alludes to that as an appropriated energy stockpiling unit, EV partakes in the guideline of force Grid through charging and releasing and leads two-way power change with the power Grid to keep up with the solidness of the Grid.
Keywords: Ancillary Services, Challenges, Distributed Energy, Dynamic Load, Electric Vehicles (Evs), Energy Storage, Plug-In Electric Vehicles, Power Grid, Reliability, Stability, Storage, Vehicle to Grid (V2g)

I. INTRODUCTION

The increase in global concern over depletion of fossil fuel reserves and their adverse effect on environment have resulted in fast development in technologies like renewable energy generation and EVs. “Conductive charging has been long introduced but is still not preferred due to tripping hazards, leakage from old cracked cables (particularly in cold zones), risk of electrical shocks etc. It is desired to reduce our dependency on fossil fuels and resulting environmental impacts in individual transportation has led to significant increase in the number of electric vehicles (EV) in recent years” [1]. “According to the international Energy Agency, the Global EV fleet grew by 2 million, exceeding 5.1 million in 2018 alone. The global automotive industry is investing heavily in EV technology to increase market penetration. This includes industry heavy-weights such as Ford, Toyota, Volkswagen, Nissan and Porsche. While generally regarded as a positive development, this electrification creates major challenges for power grids world-wide” [2]. Electrical appropriation networks are a particular sort of enormous scope frameworks that are intended to give the necessary capacity to the heaps while guaranteeing the dependability of hub voltages, for example the nature of administration. The new patterns towards the double-dealing of environmentally friendly power sources and incorporation of new administrations, for example the charging of the electrical vehicles, are presenting striking inconstancy of the powers that are conveyed or potentially ingested at terminal burdens. Such a fluctuation can risk the strength of the

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organization and the nature of the assistance. "Electrical vehicles are one of the important technologies which have been developed rapidly and make the transportation vehicles fuel by electric power rather than the fossil fuels. On the whole the electric power is obtain from renewable energy sources, so the emission from the transportation are reduced. The rapid introduction of EV in the transportation market I the coming years and the development of new technologies like V2G show the importance of this research. There are lot of benefits from the transport using electrical power where electrical energy is derived from clean resources like sun using PV cells or from the wind using wind turbines or any other renewable energy resources"[3].

II. ELECTRIC VEHICLE-TO-GRID TECHNOLOGY

EVs are driven by electric motors powered by energy stored in energy storage devices (batteries, supercapacitors, fuel cells). Electric Vehicle-to-grid (V2G) technology can be described as a system capable of controlling bi-directional power flow between PEVs and the power grid [3]. V2G system refers to PEVs communication with the power grid to avail grid support services by either discharging to the grid or throttling their charging rate.V2G technology can avail flexible, cheap, and quick-responding energy storage unit of the EVs battery pack. The incorporation of electric vehicles into the power grid is referred to as a V2G integral system. In [4], V2G can provide ancillary services like load leveling, frequency regulation, energy storage, and the spinning reserve. Electric vehicles have in the combined energy storage and power converter systems capable of driving power control strategies. It has been determined that 92% of the total EVs remain parked even during peak time. When EVs are not being operated, the on-board battery energy storage system can be connected to a nearby power grid node through appropriate communication devices to provide grid support services. Types of V2G systems include unidirectional and bi-directional systems. V2G application's substantial benefits can be achieved through a unidirectional V2G system, also referred to as smart charging. Smart charging entails EVs charging time variation for ancillary services provision to the grid. Possible applications of this system of V2G include absorption excess renewable generation, EVs charge rate variation to avail frequency regulation, or load management services.

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Fig. 1. Electric Vehicle-to-grid (V2G) technology

III. POWER QUALITY CHALLENGES IN MICROGRIDS

The study emphasizes the importance of maintaining PQ in the electrical power system to provide end customers with an effective and dependable energy supply. The ideal role of the electrical grid is to provide consumers with an ideal voltage supply. The ultimate goal of the power supplier is to produce and supply the perfect voltage and current, which are both single-frequency sine waves at nominal levels with constant amplitude and frequency. The voltage and current must also be in synchronization [4]. This includes equipment manufacturers, facility designers, standards bodies, and suppliers of generation, transmission, and distribution in addition to end users. The equipment linked to the electrical grid is one of the many elements that influence PQ. Due to the substantial use of power electronic equipment in microgrids and RES-based power systems, their PQ is especially sensitive. PQ disturbances can result from transitions, voltage dips, swells, harmonics, imbalances, and oscillations. Voltage Fluctuations: Voltage fluctuation is "a sequence of random voltage changes with magnitudes ranging from 0.95 to 1.05 p.u." or "systematic variations of the voltage waveform envelope." The word describes variations in the voltage amplitude that can happen once, repeatedly, arbitrarily, or regularly [5]. Figure 2 illustrates an example of voltage fluctuation in an arc furnace operating. Variable loads or generation could be the source of voltage fluctuation [6-8]. Moreover, abrupt grid disruptions that result in notable voltage swings might be caused by short circuits, transmission line problems, or equipment failures; depending on how serious and what kind of fault these disturbances are, voltage dips or spikes may result [9]. Variations in voltage inside the microgrid may result from sudden shifts in the demand for EV charging. High loads may impact the stability and functionality of linked equipment during concurrent EV charging sessions, resulting in voltage sags or swells.

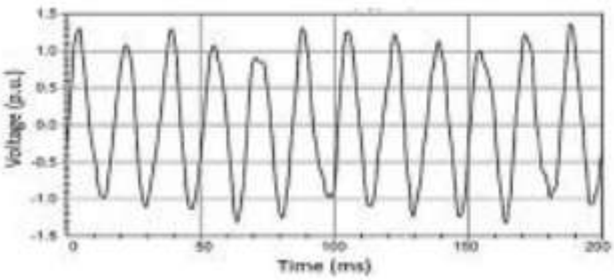

Fig.2. Voltage fluctuation

Harmonic Distortions: Harmonics are waveform distortions that occur as integer multiples of the fundamental frequency. Non-linear loads and devices bring on these distortions in normal operation, which are frequently made worse by power electronics. [8]. Regular operation of nonlinear devices and loads typically results in the injection of current harmonics. DGs frequently use devices like pulse-width modulation (PWM) inverters, which are major generators of voltage harmonics because of their series connection with internal device impedances [7]. The Total Harmonic Distortion (THD) index commonly measures the severity of harmonic disturbance. The THD index is the ratio of the root-square of harmonic content to the nominal fundamental voltage (or current), expressed in percentage. This is shown in below equation, where Vh is the RMS value of the nth harmonic component of voltage (or current), and Vn is the RMS value of the nominal fundamental voltage (or current). Nonlinear loads associated with EV chargers can introduce harmonics into the grid. These harmonics, typically in the form of distorted currents or voltages, can degrade power quality, causing overheating in equipment and affecting the efficiency of power distribution.

IV. LOAD PROFILE

The smart grid Load profile dominated by EVs is determined by the number of connected EVs, Charging period, and charging characteristics. Research on the effects of massive employment of PEVs on the consumer side has been extensively covered. In, EVs load with dump charging contribute to an upsurge in load profile leading to grid instability [4]. This phenomenon can also be addressed by the use of efficient and intelligent charging schemes that balances EVs load demand and power supply. In conclusion, the Intensive deployment of EVs has a ripple effect on the grid's peak demand since the charging of substantial EVs will raise the maximum demand of the power grid.

V. SYSTEM OVERLOAD

Electric power flows from generating plants and energy storage systems to distribution systems for EVs charging. Power system distribution components like transformers and conductors have technical limits. Present elements are not able to handle the additional unpredictable load for charging a huge number of EVs fleet. This constraint is one of the biggest challenges in the mass adoption of EVs at the commercial level. Any future grid with the substantial connection of EVs must adopt different configurations to cater to EVs charging while checking its parameter limits and component loadings. EVs are dynamic and stochastic loads that magnify the overall burden of network components and directly affect the entire grid system (transformers, lines, and protective gears) [5]. Component overloading can be checked by intelligent EVs charging and discharging and maintaining the desired level's system parameters.

VI. RESEARCH MOTIVATION

Environmental pollution is a result of increasing levels of pollutants including the emission of greenhouse gasses(carbon dioxide, carbon monoxide, and nitrogen oxides) and unburnt hydrocarbons. To cope with this we are now switching over to electric vehicles. They are sustainable, yet economical in comparison to gasoline-powered vehicles. Batteries are known to serve as the primary source of energy to power electric vehicles, while they do not emit carbon on the road, the generation of electricity which is done from nonrenewable generates carbon and increases the strain on electric power grids that are already struggling with reliability and seasonal outages. Hence, V2G (Vehicle to Grid integration) which involves bi-directional charging, involves EVs to not only draw power from the grid but also return excess energy back to the grid is necessary. This offers great potential to improve grid stability, increase energy utilization, and support the integration of renewable energy sources. The main concern as we shift from gasoline-powered vehicles to electric vehicles, is the electricity required for the millions of cars that would need to be recharged. Hence, these vehicles are required to coordinate and minimize the impact on the grid as well as the generation of power. This even brings up a question on the life-cycle assessment of the EV, we do believe that EVs generate net zero carbon emissions when we are driving them, but the impact on the environment is much more as it comprises of the extraction of Lithium from the soil, and the electricity that is generated from new-renewable sources of energy amidst the shift to renewable sources of energy. Concept and Mechanism of V2G Integration: Bidirectional flow of electricity between EV's and the Grid, a DC/DC power transformer allows for the control of power when needed, and utilizes them for energy storage and distribution during 'peak' demand. Electric batteries that are fully charged during low demand hours and when the vehicle is not being operated , the onboard battery is connected to the grid to supply electricity. This can be done using a 'smart grid' , an electricity network that uses digital instruments that manages the transport of electricity from various sources to meet the varying demands of end users. To fulfill the growing demand for energy and successful transition to renewable sources of energy, we cannot solely rely on wind and solar power. To ensure reliable, yet sustainable use of renewable sources of energy we must integrate new aspects to combat the climate change that we witness today.

VII. LITERATURE REVIEW

Xuan Xie et al. [1] As fossil fuels continue to deplete, renewable energy's application in electric vehicles has garnered significant attention. Simultaneously, the proliferation of Vehicle-to-Grid (V2G) technology has promoted deep integration between electric vehicles and the grid. However, current research on integrating photovoltaic (PV) systems into vehicle energy systems and combining V2G technology remains insufficient. Therefore, this paper proposes a Photovoltaic Battery-Fuel Cell-Power Battery hybrid energy storage bus (PEB) based on the platform of buses, exploring its interactive application with the grid (PEB-V2G). The study employs a Power Following Strategy (PFS) to control the three-electric system, ensuring precise regulation of the DC bus and effective tracking of power currents. Additionally, a general framework is proposed to optimize the V2G energy model, including strategy adjustment for V2G events and flexibility assessment. Research results indicate that under urban conditions, the power battery SOC of PEB increases by 1.24 % compared to Fuel Cell Electric Vehicles (FCEV), providing support for subsequent vehicle grid connection. The PEB-V2G system can supply over 100 MW of power during peak periods and can rapidly recover from V2G events within 3 h through the PV system. These innovations, bridged by new energy vehicles, promote deep interaction between renewable energy and the grid, contributing to reduced greenhouse gas emissions and enhanced grid stability.

Shehzad Alamgir et al. [2] In recent years, the significance of electric vehicles (EVs) in smart grids has become crucial because of their eco–friendly attributes and capacity to curtail emissions, in contrast to vehicles with internal combustion engines. In vehicle–to–grid (V2G) technology, plug–in electric vehicles (PEVs) function as both loads and sources in charging and discharging mode, respectively. The increasing penetration of renewable energy sources (RESs) creates some challenges for stable grid operation like voltage and frequency fluctuation. V2G can enhance the efficiency, stability, and reliability of the power grid by injecting power back into the grid and offer various ancillary services, such as voltage and frequency regulation, peak load shaving, spinning reserves, and backup for intermittent RESs. This paper presents a comprehensive review of all possible ancillary services facilitated by V2G. The conventional and recent technological developments, control techniques, and novel approaches are reviewed in this article. Additionally, this research comprehensively and objectively investigates how these services can be achieved from other sources and compares them using V2G. Furthermore, the worldwide distribution of V2G demonstration projects and the services they offer are highlighted. Finally, potential recommendations are presented based on future prospects.

Mahmoud Elnady et al. [3] The increasing adoption of electric vehicles (EVs) has positioned Vehicle-to-Grid (V2G) systems as a cornerstone for the integration of renewable energy into the power grid. By enabling bidirectional energy flow, V2G systems contribute to grid stability, load balancing, and peak shaving. However, the complexity of real-time energy management in V2G requires advanced solutions. Artificial Intelligence (AI) techniques have emerged as powerful tools for optimizing various aspects of V2G, including demand prediction, scheduling, battery health monitoring, and grid stabilization. This paper reviews state-of-the-art AI methods applied to V2G systems, categorizing them into machine learning, deep learning, and optimization algorithms. A comprehensive literature review highlights the development trajectory, challenges, and achievements in applying AI to V2G systems. A comparative study evaluates these models based on accuracy, efficiency, scalability, and adaptability. Additionally, a case study on implementing an LSTM-ILP hybrid model for V2G optimization in a residential community demonstrates practical application and performance benefits. Insights into future research directions are also provided.

Sugunakar Mamidala et al. [4] Battery-operated electric vehicles store energy during charging from the grid. This stored battery energy is extensively used for driving the vehicle, known as the grid-to-vehicle (G2V) technology. However, the battery storage energy is not utilized when the vehicles are parked in the parking lot. To utilize this energy, vehicle-to-grid (V2G) technology is introduced, where the stored battery energy will supply the grid when the vehicles are not in use. This can reduce the burden on the utility grid. During the power transition from G2V and V2G, transient and switching losses are present in the system, thereby leading to power quality issues. This can affect the grid-side parameters (namely frequency, real power, reactive power, and inverter current) and converter-side parameters (namely output voltage, switching losses, battery SOC, and efficiency). To overcome this problem and to improve the power quality of the system, this paper proposes the integration of a DC/DC zeta converter. The effectiveness of this integration is verified under various test conditions and is compared with the results of the conventional buck-boost converter. From the simulation results, it is observed that when the system is operating in G2V mode, the output voltage and frequency are settled very quickly at 0.035 s and 0.12 s, respectively, the ripple voltage is reduced by 120 V, and the efficiency is increased to 98.82 % with the proposed converter. Similarly, in V2G mode, the output ripple voltage is reduced by 10 V, efficiency is increased to 97.63 % and the response quickly settles compared to the conventional converter. In the overall operation, the converter switching losses are minimized, thereby improving the entire system's performance. From all these findings, it is recommended that the DC/DC zeta converter integration in V2G and G2V systems leads to superior power quality and fast charging/discharging of the energy.

Emrullah Aslankaya et al. [5] Fuel cell electric vehicles (FCEVs) are estimated as the future's mobile distributed generators with vehicle-to-grid (V2G) functions. Besides, V2G topologies are required to be designed with an appropriate analog filter by accurately measuring the reference current and voltage values of inverters and converters. Thus, the highest accuracy is required in control structures for charging and grid connection of FCEVs to improve the power quality (PQ). In this study, PQ improvement of V2G operation of FCEVs is proposed by considering the developed real-time digital infinite impulse response (IIR) filters in generating reference signals in the power calculation stage. A band-pass digital IIR filter design is realized with the inverter using LabVIEW infrastructure, and reference signals are smoothed by using IIR filters. The performances of developed different IIR filters' results are examined in the study. Developed filters are designed using the order estimation method. Elliptic, Chebyshev, and Butterworth filters are applied to the voltage and current signals, and the best results are obtained in reference power signals with the Butterworth filter. The Butterworth filter maintains stability in current RMS, induces a 0.09 % decrease in voltage RMS, and shows a slight 0.30 % increase in active power. The proposed approach removes distortions in reference power signals by using a designed filter for a reliable V2G operation of FCEVs.

Jiajun Fu et al. [6] The rapid proliferation of electric vehicles (EVs) faces challenges due to diversified battery voltage levels and power quality degradation in vehicle-to-grid (V2G) chargers under distorted grid conditions. This paper proposes a hybrid hierarchical control scheme for two-stage V2G converters, offering two primary advantages: the front-stage dual-active-bridge (DAB) converter could stabilize the DC-link voltage and accommodate wide-ranging battery voltages; meanwhile, a unified linear matrix inequality (LMI) framework is established for the rear-stage DC–AC converter to systematically synthesize all control gains, which integrates a resonant-suppressing state feedback controller to reduce parameter sensitivity, repetitive learning to attenuate multi-order harmonics in the charger current, and previewable reference current feedforward to enhance tracking precision. Experimental results demonstrate superior performance over conventional methods: total harmonic distortion is reduced by 55% (from 8.72% to 3.97% in V2L mode), zero steady-state error is achieved under distorted grid voltages (V2G mode), and tracking accuracy improves by over 86% under exceeding 30% parameter deviations (V2L/V2G mode), alongside enhanced grid harmonic suppression.

Ismail A. Soliman et al. [7] Adopting electric vehicles is pivotal for mitigating environmental impacts and enhancing energy sustainability by reducing emissions and fossil fuel reliance in transportation systems. The integration of electric vehicles significantly impacts power grids and increases complexity but offers opportunities for grid stabilization through vehicle-to-grid (V2G) technology. Grid performance can be improved by integrating renewable energy sources (RESs) and reactive power compensation devices. This paper presents a proposed multi-objective function solved using parallel search real-coded genetic algorithm (PSRCGA) for obtaining the optimal placement of electric vehicle charging stations (EVCSs), V2G sharing points, photovoltaic systems (PV), wind farms, and capacitor banks. The multi-objective function aims to minimize the cost function and total energy and maximize power quality indices. The power quality indices are improved within constraints including the voltage stability and voltage deviation index. The constraints are merged with the multi-objective function within a fitness function, implemented considering fault repairing periods (FRP). Load flow analysis is applied on the IEEE 33-bus radial test system and the algorithm is verified on a real system. The system is divided into various zones to depict streets/regions/population distribution. The results affirm the algorithm's reliability across different scenarios and system configurations. Integrating RESs of 40 % in the IEEE 33-bus system decreases the annual active energy loss to 575.40 MWh with simultaneously inserting capacitor banks of 43.24 % reduces the reactive energy loss to 415.10 Mvarh. The system minimum voltage is maintained at 0.903 pu during system reconfiguration in FRP, which is within the allowable voltage limits

Yudi Qin et al. [8] The construction and development of the new power system with new energy sources as the main component will face significant challenges in terms of scarcity of flexible resources. User-side adjustable loads and energy storage, particularly electric vehicles (EVs), will serve as substantial reservoirs of flexibility, providing stability to the new power system. The rapid deployment of renewable energy and the surpassing of expectations in the penetration rate of EVs in China present opportunities for the significant growth of virtual power plants (VPPs) and vehicle-to-grid (V2G) interactions. The enormous potential and advantages of V2G as a primary user-side resource are further revealed. Under China's current electricity market policies, the pilot projects of user-side interactions are being analyzed. Furthermore, the prospects for the future development of VPPs and V2G, along with relevant recommendations and perspectives regarding business models, technologies, and policies, are highlighted. The development of VPPs and V2G interactions in China holds immense potential for leveraging adjustable resources, especially EVs and energy storages with lithium-ion batteries, to enhance grid flexibility and stability.

Fuzhong Yu et al. [9] This study presents an optimization framework for integrating electric vehicles (EVs) into microgrids using Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) functionalities. The framework coordinates the charging and discharging of EVs, renewable energy sources, and energy storage systems to minimize operational costs while ensuring grid reliability. The model incorporates real-world operational constraints, such as State of Charge (SOC) limits, charging/discharging rates, and state transition restrictions, ensuring that V2G and G2V scheduling aligns with practical conditions. Numerical results demonstrate the 98 % reliability of the system under ±20 % variability in renewable energy generation, and the system achieves 0 % energy unavailability in specific scenarios. While the study assumes a low-latency communication framework for real-time coordination of aggregated EVs, the practical implementation requires addressing issues of communication latency, reliability, and control architecture, all of which are essential for real-time demand-side resource management. The optimization framework currently relies on a centralized control architecture, with future work aimed at exploring distributed control strategies for scalability and better system performance in large-scale deployments. This study provides a scalable and robust approach for integrating EVs into microgrids, laying the groundwork for efficient real-time energy management in future energy systems.

Mohammad A. Razzaque et al. [10] Integrating electric vehicles (EVs) into the smart grid networks through vehicle-to-grid (V2G) systems offers transformative potential for energy optimisation and grid stability. However, this bidirectional energy exchange introduces significant cybersecurity challenges, including vulnerabilities to spoofing, denial-of-service attacks, and data manipulation, which threaten the integrity and reliability of the V2G system. Despite the growing body of research on V2G cybersecurity, existing studies often adopt fragmented approaches, leaving gaps in addressing the entire ecosystem, including users, EVs, charging stations, and energy market and trading platforms. This paper presents a systematic review of recent advancements in V2G cybersecurity, employing the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework for detailed searches across three journal databases and includes only peer-reviewed studies published between 2020 and 2024 (June). We identified and reviewed 134 V2G cybersecurity studies and found five important insights into existing V2G cybersecurity research. *First*, most studies (104 of 134) focused on protecting V2G systems against cyber threats, while only seven studies addressed the recovery aspect of the CRML (Cybersecurity Risk Management Lifecycle) function. *Second*, existing studies have adequately addressed the security of EVs and EVCS (EV charging stations) in V2G systems (113 and 81 of 134 studies, respectively). However, none have focused on the linkage between the behaviour of EV users and the cybersecurity of V2G systems. *Third*, physical access, control-related vulnerabilities, and user behaviour-related attacks in V2G systems are not addressed significantly. Furthermore, existing studies overlook vulnerabilities and attacks specific to AI (artificial intelligence) and blockchain technologies. *Fourth*, blockchain, AI, encryption, control theory, and optimisation are the main technologies used, and *finally*, the inclusion of quantum safety within encryption and AI models and AI assurance (AIA) is in a very early stage; only two and one of 134 studies explicitly addressed quantum safety and AIA through explainability. By providing a holistic perspective, this study identifies critical research gaps and outlines future directions for developing robust end-to-end cybersecurity solutions to safeguard V2G systems and support global sustainability goals.

VIII. CONCLUSION

In conclusion, V2G integration offers a viable solution to the current as well as future challenges of energy management and grid stability in the transition to renewable energy sources. By harnessing the bidirectional flow of electricity between EVs and the grid, V2G can significantly enhance energy efficiency, support grid stability, and contribute to a sustainable energy future. Continued research, investment, and collaboration among stakeholders are important to witness the full potential of V2G technology.

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