Empowering microgrids: harnessing electric vehicle potential through vehicle-to-grid integration

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ABSTRACT

Electric vehicles (EVs) can potentially be integrated into microgrids via vehicle-to-grid (V2G) technology, which enhances the energy system's stability and durability. This paper provides an in-depth examination and evaluation of V2G integration in microgrid systems. It analyses the present state of research as well as possible uses, challenges, and directions for V2G technology in the future. This paper addresses the technological, economic, and regulatory aspects of implementing V2G and provides case studies and pilot projects to shed light on potential benefits and barriers associated with its adoption. The research highlights how V2G contributes to more efficient integration of renewable energy sources, grid stabilization, and cost savings for EV owners. It also addresses the latest developments in technology and proposed laws aimed at encouraging growing applications of V2G.

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1. INTRODUCTION

As the century progresses, growing pollution and climate change are the two primary causes of concern. Excessive emissions of greenhouse gasses are the cause of both global warming and environmental damage. The generation of electricity, transportation, and other industrial and commercial applications are among the essential human necessities that account for a large portion of these emissions [1]. Alternative vehicle technologies, including electric vehicles (EVs), are being developed and improved in response to the expanding need for environmentally friendly transportation. EVs have the potential to lower the reliance on fossil fuels, minimize gas emissions, and save transportation expenses [2]. In recent years, there has been a noticeable seismic change in the global energy landscape toward greener, more sustainable solutions. The rise of microgrids and EVs stands out among these changes as a disruptive force affecting the path of energy systems [3]. Microgrids—localized energy distribution networks that may operate both independently and in conjunction with the main grid—offer benefits over traditional centralized power systems in terms of resilience, stability, and efficiency. Driven by power pricing, the bidirectional energy transfer between EV batteries and the grid via the vehicle-to-grid (V2G) technology offers businesses increased flexibility and cost-effectiveness [4]. Conversely, electric automobiles, which run on electricity rather than fossil fuels, are becoming more and more popular as environmentally friendly modes of transportation. The purpose of this research study is to present a thorough investigation of the incorporation of electric cars via V2G technology into microgrids [5]. It will explore the state of research, technical developments, possibilities, problems, and prospects for V2G deployment in the future. To facilitate bidirectional power exchange between the EV battery and the grid, V2G technology requires a certain type of EV charger [6]. Peak shaving characteristics in the power system are made attainable by V2G technology, which makes way for an enormous decrease in energy costs. Moreover, peak-shaving strategies may be used to boost the potential of the microgrid that integrates renewable energy [7]. Additionally, level 1 and level 2 AC charging for V2G technology is used in almost all of the reported works [8]. A further challenge is that the distribution infrastructure was not designed for two-way energy transfer. There is a need for research to develop technically feasible charging station topologies to accommodate V2G technology in microgrids [9]. A dc is shown in the piece. Depending on the condition of the vehicle's battery, V2G technology permits bidirectional energy transmission between electric cars (EVs) and the grid. This allows energy exchange in both ways. Energy is moved from the grid to the automobile and the same happens when the battery is low [10].

The V2G structure's fundamental elements and functions are shown in the block diagram in Figure 1. Power electronics circuits are used to perform conversion operations to match the kind of power during the energy flow [11]. Bi-directional energy flow and conversion procedures are used by V2G to change the power type as needed. First, an AC/DC converter system is used to set the grid voltage to the appropriate level. The voltage is subsequently reduced by a declining converter to the proper level for grid or car storage or consumption. Conversely, though, energy from the vehicle's battery is sent to the grid via an increasing converter, which adjusts the voltage [12]. A DC/AC conversion process that makes grid interconnection easier comes next. To effectively regulate energy demand, these conversion processes are carried out dynamically based on the battery's energy level. The primary objective is to optimize energy utilization by leveraging the energy stored in the battery or available from the grid to meet varying energy demands [13]. To put it simply, V2G technology is critical to maintaining grid stability, optimizing the use of renewable energy sources in microgrid settings, and balancing supply and demand for energy. Using effective energy management and reciprocal energy exchange, V2G advances robust and sustainable energy systems [14]. V2G technology is introduced by integrating electric cars into a microgrid. EVs are generally regarded as electricity users that may be charged using renewable energy sources or the grid [15]. But because of their V2G capabilities, EVs may also serve as portable energy banks and even replenish the grid with electricity when needed. EV batteries may store excess energy from renewable sources during times of low demand and release it during times of high demand or grid emergencies thanks to this bidirectional energy flow [16].

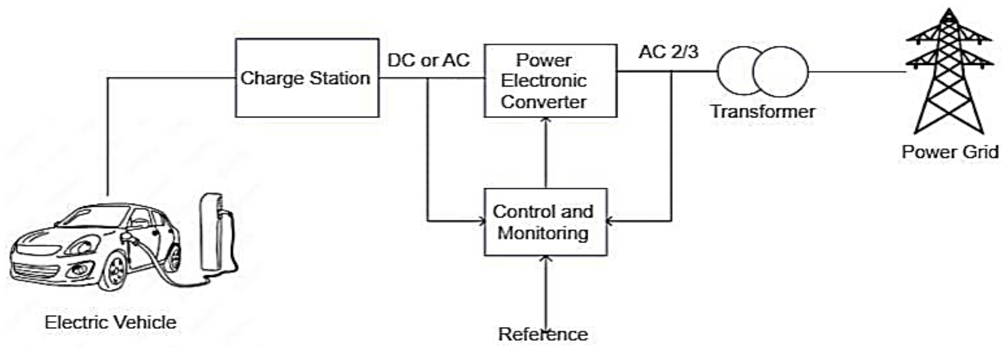

Figure 1. Block diagram of V2G structure

2. PROPOSED METHOD

The microgrid is composed of one synchronous generator and two sets of batteries from electric cars, as shown in Figure 2. Battery (V2G) block models are used to represent EVs with a state of charge (SOC) higher than 90%. These models provide V2G support during grid peak demand [17]. Two batteries are taken off of the grid and charged first. Their SOCs increase from their initial values of 70% and 98%, respectively. A 1 MW load connected to the grid causes the grid frequency to drop below 0.999 per unit at time 10 s. When the battery starts to run low, the battery (V2G) block supplies power to the grid [18]. Not only does the grid frequency drop to the predefined range, but the battery (V2G) block also goes back to being charged. Battery (G2V) block during the charging procedure [19]. Under this scheme, extra energy from renewable sources is stored in EVs by a microgrid, which then extracts it when needed [20]. After 30 seconds, when a 2 MW load disconnects from the grid, the battery (V2G) block resumes its charge state. This collects excess power and preserves the frequency below the predetermined upper limit [21], [22].

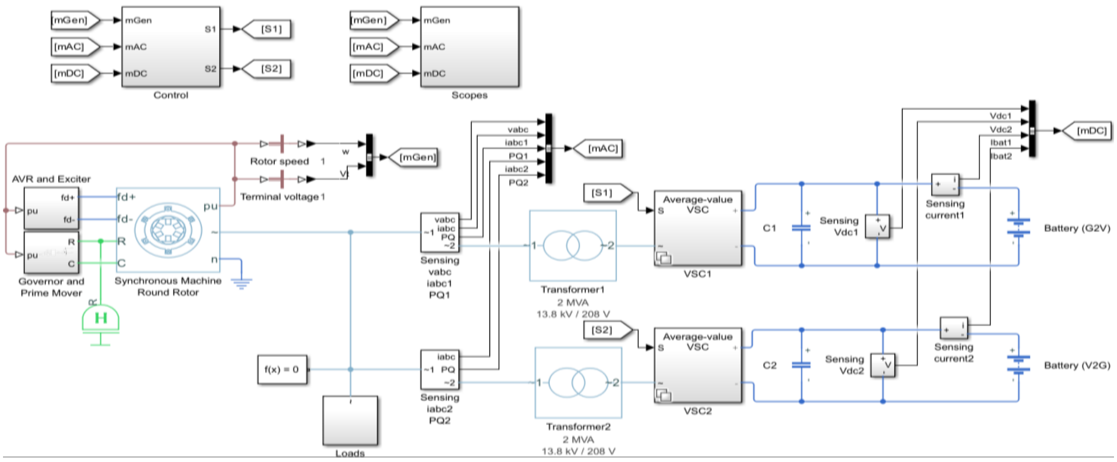

Figure 2. Microgrid with electric vehicle (V2G) architecture

Power regulation is an essential part of the converter controller and power regulator that ensures the stability and reliability of the microgrid [23]. The circuit manages electricity using a range of components and management strategies, especially when the load fluctuates and the EV batteries are in varying SOC. The battery powers the charging mechanism primarily while it is in V2G mode [24]. Due to this, it is very difficult for interruptions to spread and impact battery current by interfering with the system's energy flow [25]. Power regulation and converter management are essential to the effective operation of microgrids with V2G capability because they provide resource efficiency, grid stability, and reliability while permitting two-way power exchange with EVs. To make full use of V2G technology in microgrid situations, cutting-edge integration and control approaches must be employed [26]. A microgrid is essentially a small, localized group of sources and needs for electricity that may be connected to or operated separately from the traditional, centralized grid [27]. It enables the production, storage, and distribution of power inside a constrained area, such as a commercial complex, university, or neighborhood. When there is a high energy demand or unstable grid circumstances, the energy management system has the ability to initiate V2G operations. Overcharging EV batteries can release energy into the grid, increasing output and controlling frequency [28]. On the other side, when renewable energy output surpasses regional needs, it may be sent into the main grid or stored in EV batteries for later use. A creative approach to energy management that encourages sustainability, reliability, and efficiency in power distribution is the microgrid with electric vehicle (V2G) design [29]. As renewable energy sources become more widely used, V2G technology will have a significant impact on future global energy systems. Decentralized microgrids reduce dependency on centralized power sources and decrease the impact of grid disruptions or outages, hence enhancing system resilience [30].

3. RESULTS AND DISCUSSION

The research study's conclusions provide important details regarding the feasibility, benefits, and challenges of integrating EVs into microgrids using V2G technology. These findings contribute to our understanding of V2G's role in increasing the energy system's resilience, sustainability, and efficiency and help guide policy and decision-making processes as we move toward a more sustainable energy future. Microgrids with EV-V2G connectivity have enormous potential to increase grid resilience and give EV owners access to new revenue streams [31], [32]. An EV to grid frequency vs. time graph is presented in Figure 3. Usually, it shows how the electrical frequency varies over time as EVs recharge the grid with energy. Due to their different power requirements, EVs might have an influence on the overall frequency of the electrical system when they are linked to the grid and charging or discharging. The graph would demonstrate how the frequency varies over time depending on whether EVs are charging or discharging and are plugged in or not. Grid operators use this information to maintain the stability of the electrical grid.

The power vs. time curve for EV to the grid is presented in Figure 4. Usually, it depicts the power flow over time from EVs back to the grid. Since the EVs are either not actively producing electricity or are not connected to the grid, there may be little to no power flow at the start of the plot. As time goes on, the power flow may rise, a sign that EVs are beginning to release energy into the grid. This typically happens at times of high demand when electricity costs are higher.

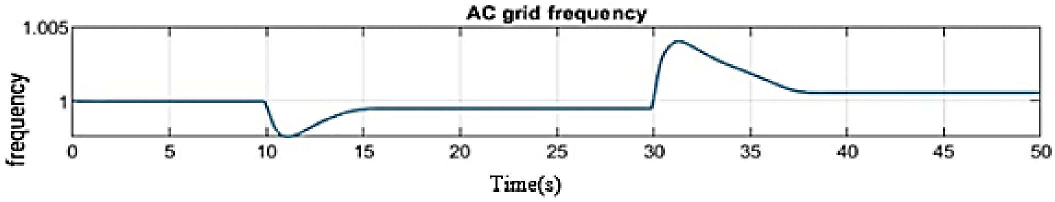

Figure 3. Frequency vs time graph for EV to grid

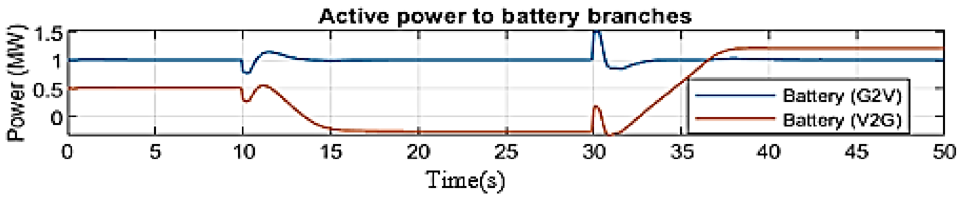

Figure 4. Power vs time graph for EV to grid

A state of charge vs. time graph for grid-to-EV charging is displayed in Figure 5. It shows the gradual variations in the battery charge level of the electric vehicle when it is being charged from the grid. The SOC initially indicates that the EV's battery is partially depleted since it is at a lower level. The SOC steadily rises as charging progresses, signifying a fully charged battery that is prepared for use. Users can anticipate when their EV will be fully charged and understand the status of the charging process with the help of this graph. Indicating a growing battery charge level. The charging rate, battery capacity, and infrastructure for charging all affect how quickly the SOC rises. The SOC stabilizes at a point after the battery achieves its maximum capacity or the charging process is terminated.

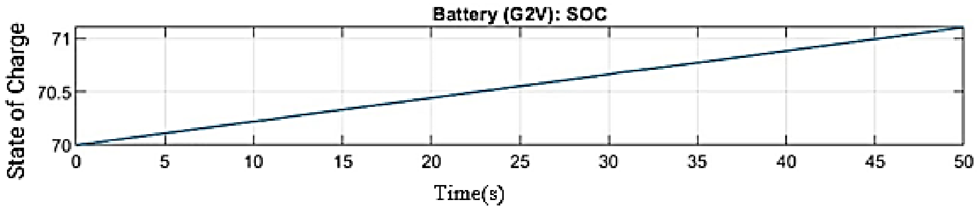

Figure 5. State of charge (G2V) vs time graph for the grid to EV

A state of charge vs. time graph for EV-to-grid (V2G) is displayed in Figure 6. It shows how the charge level of the battery varies over time when the vehicle transfers energy to the grid. As soon as the EV is fully charged, the SOC may be high. As energy is released from the battery and onto the grid over time, the SOC falls. The EV owner may be able to resell any extra energy to the grid at times of high electricity costs, or during periods of peak demand. User preferences, charging infrastructure, and grid demand are some of the variables that affect the rate of discharge. The user may be prompted to discontinue V2G and recharge the car when the SOC eventually reaches a lower threshold.

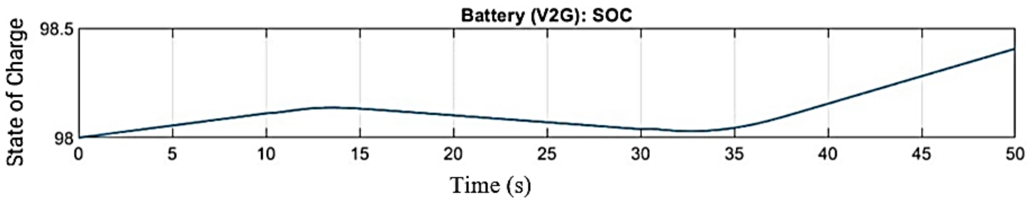

Figure 6. State of charge (V2G) vs. time graph for EV to grid

The grid-to-vehicle charging voltage vs. time graph is plotted in Figure 7. Usually, it shows how the voltage applied to the car's battery varies over the course of charging. When charging commences, the voltage typically starts off relatively low, rises progressively to reach a peak charging voltage, and then falls as the battery gets closer to its maximum capacity or as the charging process slows down to avoid overcharging. This graph aids in the visualization of the charging profile and can be helpful in determining the charging process's effectiveness and speed. Figure 8 plots the charging current versus the time of a G2V block. Usually, it shows the battery charging process for an electric car over time. The current may be strong at first because the car's battery is taking up charge quickly. When the battery approaches its full charge capacity or when charging protocols change to avoid overcharging or overheating, the current may eventually drop. The charging process as a whole, rate of charge, and charging efficiency may all be understood from the graph.

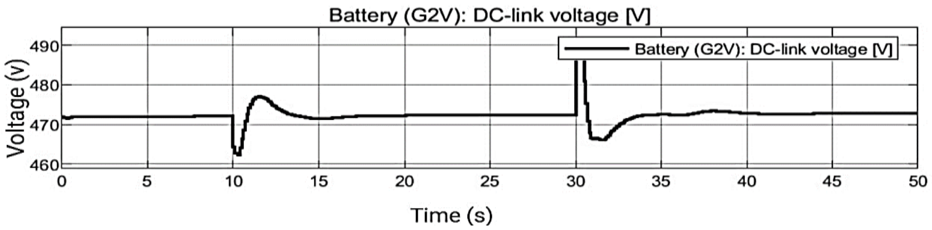

Figure 7. Voltage vs. time graph for scope 1

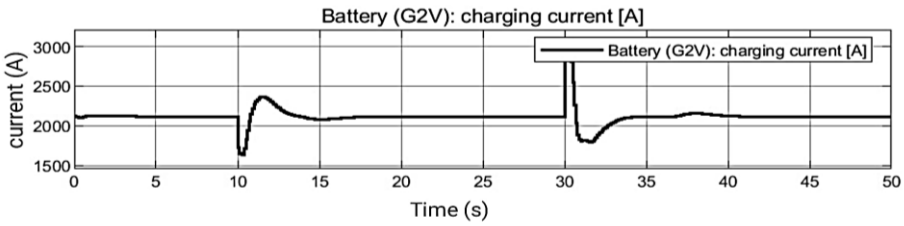

Figure 8. Charging current vs. time graph for scope 1

A G2V block with a state of charge vs. time graph is depicted in Figure 9. It describes how, as the battery is charged from the grid, its charge level varies over time. A partially discharged battery will be indicated by a low SOC at first. When charging starts, the SOC rises steadily until, under continuous charging, it obtains a full charge. Depending on variables like battery capacity, charging efficiency, and charging pace, the rate of growth in SOC may differ. The SOC stabilizes when the battery reaches full charge and continues to do so until the charging process is interrupted or stopped. This graph can be helpful for tracking and streamlining the charging procedure in G2V systems since it gives a clear picture of the battery's charging status.

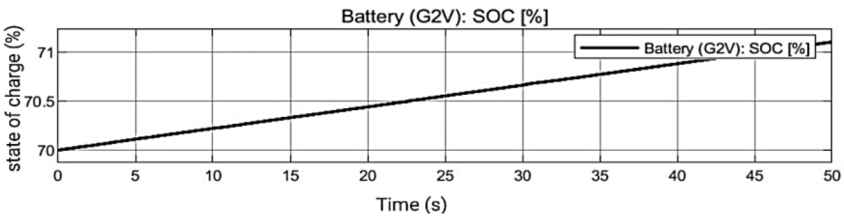

Figure 9. State of charge vs. time graph for scope 1

A V2G block that depicts the voltage output's behavior over time is seen in Figure 10. Cars with electric batteries operating in a V2G system can take power from the grid and return it when necessary. EVs may release stored energy back into the grid when needed thanks to V2G technology. One would probably notice variations in voltage over time in a voltage vs. time graph for V2G as the vehicle's battery charges and empties in response to grid demand. The voltage may steadily rise when the car is plugged in and not in use as the battery charges. The car can release its stored energy when the system needs more power, which would result in a decrease in voltage.

A V2G current vs. time graph is displayed in Figure 11. Usually, it shows how electrical current flows over time when cars that can charge in both directions communicate with the grid. When cars are first plugged in, there may be a spike in current when the charging process begins. This current may eventually drop when the cars get to the appropriate charge level. The graph may display a reverse flow of current from cars back to the grid at times of high electricity demand as they release stored energy to support the grid. On the graph, this reverse flow might be shown as a negative current. All things considered, the graph shows how cars can both use and supply electricity to the grid, depending on demand and the vehicles' charging status. A V2G block, which depicts a state of charge vs. time graph, is plotted in Figure 12. It shows how the battery's charge level varies with time while bidirectional energy flow is occurring.

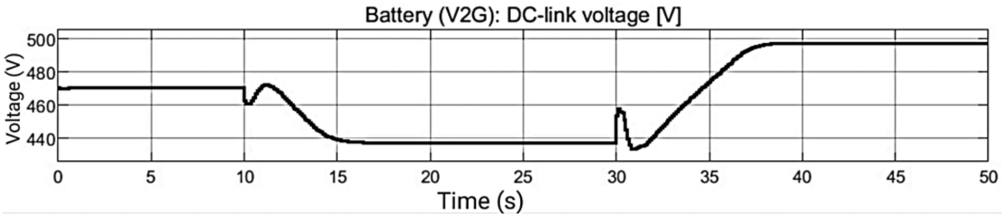

Figure 10. Voltage vs. time graph for scope 2

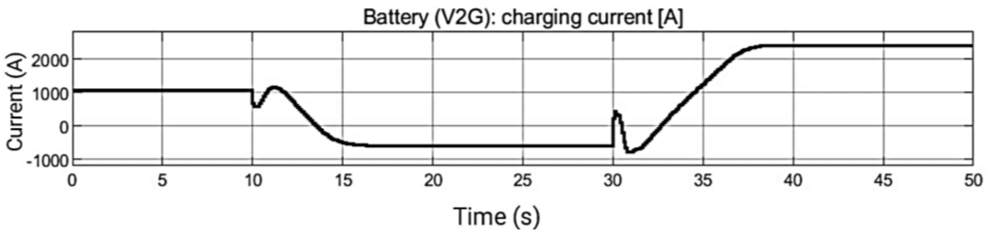

Figure 11. Current vs. time graph for scope 2

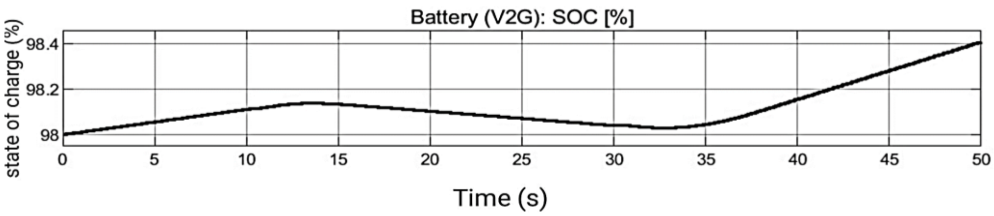

Figure 12. State of charge vs. time graph for scope 2

Depending on whether the car is idling, charging, or discharging at first, the SOC may change. The SOC usually increases when charging, showing that the battery is storing energy. On the other hand, as the battery discharges stored energy to the grid or other connected devices during draining, the SOC lowers. The graph's fluctuations could correspond to several operational situations.

4. CONCLUSION

V2G has a wide range of applications and offers a plethora of options for dependable power generation and storage. Additionally, V2G offers a more persistent strategy. Another important issue is the environment. It still receives a lot of criticism, though. The primary causes of this criticism are the high initial cost, the absence of government subsidies, and the producers' and people's unwillingness to change. Most individuals have a limited and careless perspective since they only evaluate the current circumstances and ignore the potential benefits of V2G in the future. Promising outcomes from the most recent V2G deployment projects have prompted more studies in the area. V2G will spread widely as and when more robust batteries and reasonably priced grid lines become standard. The opinions of individuals and manufacturers need to be watched until then. Finally, the path to V2G implementation will be made considerably easier by the governments of wealthy and developing nations widely disseminating the concept, as well as its possibilities and opportunities. Furthermore, V2G will be supported by smart grid technologies, which can meet future power demands.

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AUTHOR CONTRIBUTIONS STATEMENT

All authors read and approved the final version of the manuscript.

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Surender Reddy Salkuti				✓		✓	✓			✓		✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

ETHICAL APPROVAL

This article does not contain any studies with human participants or animals performed by any of the authors.

DATA AVAILABILITY

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable requests.

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