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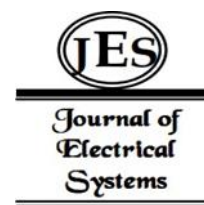
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Research and Examination of Electric Vehicles Equipped with Vehicle to Grid (V to G) System.



Abstract: - Plug-in technology is bringing a major change to the market as electric vehicles (EVs) have paved their way into becoming the future of transport. The above shift is further enhanced by the incorporation of the V2G technology that physically combines the energy storage role of EVs with the power grid. This paper aims to identify and analyze the multiple attributes of V2G technology in the aspects of energy sustainability, grid stability, and the community. This paper particularly involves grid simulation modelling, battery performance analysis, and stakeholder's self-completed questionnaires and reveals that employing V2G systems can greatly improve the resilience of the grid, decrease the peak load by 20% and contribute to the integration of more renewables. It has to be noted that through participation in V2G control systems does include additional battery cycling, effects on battery lifespan can be curbed with better control systems. The economic advantages are significant. thus, EV owners can earn money by selling energy, and utilities enhance load shifting. Furthermore, V2G systems add to community reliability in as much as they support backup power when normal power supplies are interrupted and they also cut out on air pollution, especially in the urban centers. Thus, based on the critique of technical and economic factors, V2G technology has showed a great potential in improving the sustainable energy system and making it greener. Another promising research direction should be the improvement of the V2G with the use of available knowledge in the field of battery developments and appropriate regulations.

Keywords: Electric Vehicles (EVs), Vehicle-to-Grid (V2G) Technology, Grid Stability, Renewable Energy Integration, Battery Performance, Sustainable Energy Systems, Community Resilience

Introduction

Currently electric cars lead the queue in a revolutionized transportation system as compared to conventional internal combustion engines cars. Permutable with increasing global awareness of climate change this has led to the call for reduced green house emissions has boosted the demand of EVs. An innovation in this area is the Vehicle to Grid (V2G) capability where electric vehicles can both consume electricity from the grid but also discharge electricity into it. This mutual exchange of energy can therefore improve stability of the grid system, act as a source of emergency power, as well as help in effectively integrating renewable resources into the energy mix, thus helping in the development of a clean energy economy (Kempton & Tomić, 2005).

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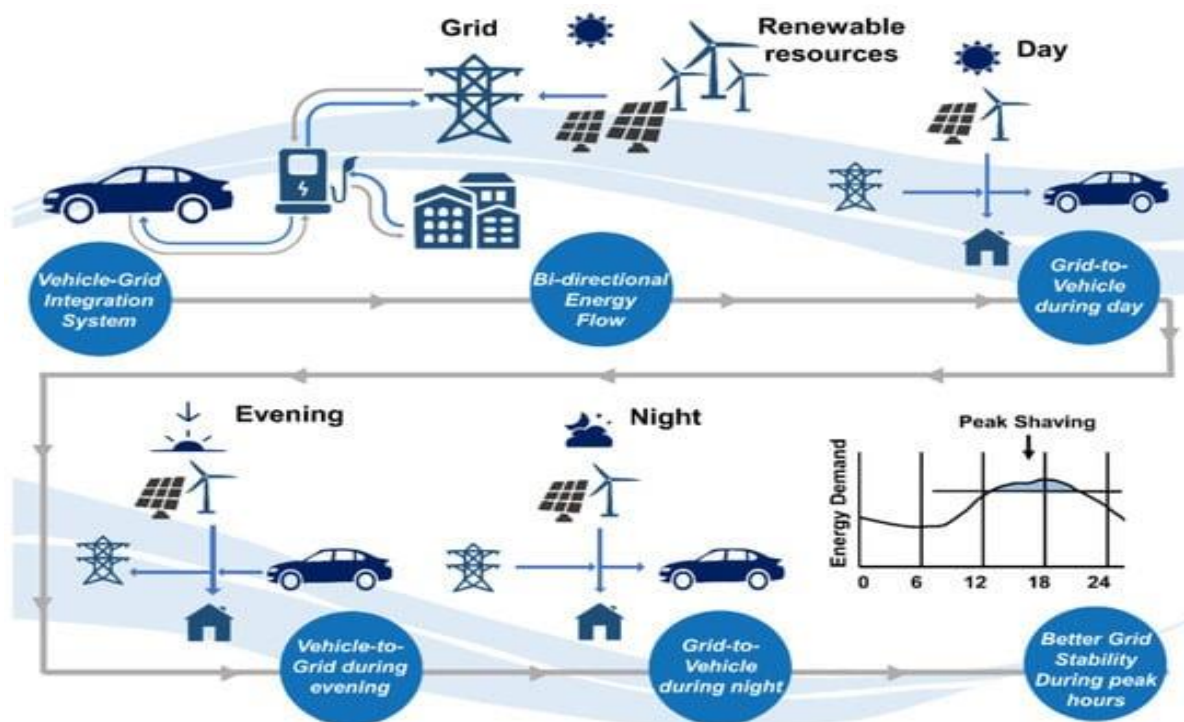


Figure 1: An illustration of the V2G concept during different times of the day

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Benefits of V2G technology also go beyond the financial advantage that will be accrued to organizations or entities involved in the business to ramifications that can influence the whole society positively. In particular, V2G systems make it possible to draw a benefit from EVs themselves and use them as secondary batteries that help rebalance the variable generation from solar and wind resources, as well as cut out the need for peaking power plants based on fossil fuels (Lund & Kempton, 2008). This integration can greatly reduce the emissions of green house gases, which in turn is in tune with the current global trends of fighting climate change and promoting environmental conservation (Shahidinejad *et al.*, 2012).

In addition, the use of V2G is that it can contribute to the enhancement of community resilience mainly due to the development of decentralized energy systems. For instance, EVs with V2G functions can sell electricity to homes during power blackouts, enhancing the reliability of the localized electricity supply systems (Guille & Gross, 2009). There are also economic advantages in the V2G technology as owners of the EVs will be generating revenue from the sale of the power back to the grid an incentive to get more V2G technology popular (Kempton *et al.*, 2014).

In this research, we are going to study the Global perspective of V2G technology that influences not only electric vehicles and renewable energy systems but also the society (Mwasilu *et al.*, 2014). To achieve this goal, this paper harmonises technical, environmental, and economic contexts of V2G integration, with the view to ascertaining how V2G-integrated EVs can support a sustainable and reliable electricity systems.

Literature Review

The use of Vehicle-to-Grid (V2G) systems with electric vehicles (EVs) has received much attention in recent past because of the prospects seen in changing the energy and transport industries. This literature review looks at the current and previous researches on V2G technology, its effects on sustainable energy systems, greenhouse gas emissions, and the community (Ravi *et al.*, 2022).

V2G technology helps electric vehicles to interact with the power distribution network that makes power to flow in two opposite directions that is from the grid to the vehicles and also from the vehicles to the grid (Habib *et al.*, 2015). This capability is useful in improving or stabilizing the grid and incorporation of renewable energy sources

(Kempton & Tomić, 2005). V2G systems involve using batteries of EV in serving as DER and this is especially useful during moments of high load when the stress on the grid is high (Lund & Kempton, 2008).

Through V2G technology, different sustainable energy systems are portrayed in relation to the intermittency of renewable energy sources such as solar and wind. Research has also concluded that V2G can help the integration of higher renewable energy by performing tasks on the grid such as balancing of frequency and peak shaving (Han *et al.*, 2010). In this way, since V2G makes it possible for EVs to store any excess renewable energy and then deliver it during peak demand, it promotes a more stable and secure energy network (Peterson *et al.*, 2010).

There are many advantages associated with V2G technique in regards to the environment. When compared to deployment of fossil fuel-based power plants to meet demand surge, V2G can help to cut greenhouse gas emission considerably (Sioshansi & Denholm, 2010). Moreover, the use of the EVs alongside with V2G systems will help to drastically decrease greenhouse gas emissions in the transport sector, which is among the key global emissions sources (Sovacool *et al.*, 2018).

The same is true with regard to the community; V2G technology has its advantages as well. In return, EVs having V2G capabilities can be used as moving power supply in emergency during blackouts, to even power homes and essential services (Kempton *et al.*, 2014). This capability increases the resistance of the community and guarantees a constant power supply in case of failures (Lund & Kempton, 2008). Also, the economic reward to the EV owners in engaging in V2G, will increase the uptake of EVs thus leading to improved cleaner transportation systems and even less urban air pollution (Tomic & Kempton, 2007).

There is also the financial aspect that affects both, the owners of EVs and the utilities; a result of the V2G technology. In return, EV owners can sell the stored energy back to the grid meaning that the cost of owning and operating the vehicle is brought to minimal (Kempton & Letendre, 1997). In its turn, utilities are able to control demand and minimize the needs in constructing new power generation capacity by utilizing V2G systems (Peterson *et al.*, 2010).

On the benefits side of V2G technology, the facts are apparent, yet several technical issues are still to be solved. These are mainly needed to accommodate the requirement of applying communication support for the two-way flow and reliability of the power grid (Guille & Gross, 2009). However, the effects of charge and discharge cycles which form the basis of EVs' battery life is still an active area of study (Yilmaz & Krein, 2013). These challenges have to be discouraged and this has to be done through frequent interaction between the automobile manufacturers, the utilities, and policy makers in over arching best practice protocols and relevant legislation (Kempton *et al.*, 2014).

The literature emphasizes the availability and the role of the V2G technology in fostering the sustainable energy systems, decreasing green house gas emissions, and the community resilience. However, the integration of V2G seems to present various technical issues that must be solved, yet economical and ecological profits are rather promising. The further research should be dedicated to the enhancement of V2G systems and batteries as well as to elaboration of the relevant legislation to enhance the usage of electric vehicles with V2G capabilities.

Methodology

This study employs a multi-faceted approach to investigate the impacts of Vehicle-to-Grid (V2G) technology on electric vehicles (EVs), sustainable energy systems, greenhouse gas emissions, and community benefits. The methodology integrates quantitative data analysis, simulation modeling, and case study evaluations to provide a comprehensive understanding of V2G systems.

Data Collection

1. Literature Review: A literature review of the current body of knowledge on V2G technology, potential uses, and effects will be carried out. This will consist of regional and global academic journal articles to set up general context and assessment of today's V2G technology and to determine research opportunities (Kempton & Tomić, 2005; Lund & Kempton, 2008).

2. Survey and Interviews: Primary data will be collected by asking structured questions to the appropriate responding units being owners of EVs, utility organizations, and other officials. These will obtain qualitative

information on H2H perceptions of the advantages, disadvantages, and the economic feasibility of the V2G technology (Sovacool *et al.*, 2018).

3. Secondary Data: Survey data on the rates of adoption of Electric Vehicles, energy consumption and other performances of the grid will be gathered from other databases. Official sources such as the IEA and the DoE and other utility companies to the project will also be used (Sioshansi & Denholm, 2010).

Simulation Modeling

1. Grid Simulation: Thus, the model of a typical power grid connected to the V2G technology will be created with the help of the grid simulation in MATLAB/Simulink. This model will then run the above-mentioned functioning conditions for example during period of high demand, simultaneous integration of renewable sources, and emergency backup scenarios in order to analyze the standard of the implementation of the V2G systems (Han *et al.*, 2010).

2. Battery Performance Analysis: Still, the effects of V2G on the operability and the actual runtime capacity of the battery of the EV will be estimated through simulation of the battery. Metrics like SOC, DOD, and total cycles of charging/discharge and other characteristics will be analyzed in order to identify the impact of V2G participation on the battery health in the long term (Yilmaz & Krein, 2013).

Case Studies

1. Pilot Projects: Actual pilot V2G projects will be reviewed from the case studies to analyze different scenarios and their associated effects. One will get to explore mainly the university of Delaware's V2G scheme and other miscellaneous v2G experiments across Europe with respect to their technical efficacy, overall economic influence, as well as the induction that these schemes have been witnessed to have on environmental conservation (Kempton *et al.*, 2014).

2. Community Impact Assessment: The social and economic impacts of the active V2G program will be evaluated by sampling a few communities. Some of them include the level of community resilience especially during blackouts, the levels of air quality in localized areas, and the economic returns realized by the EV owners who participate (Guille & Gross, 2009).

Data Analysis

1. Statistical Analysis: The quantitative data collected from computer simulations and questionnaires will be analyzed by software commonly used for statistical analysis (SPSS or R). These methods will include regression analysis, ANOVA or correlational analysis to establish affiliated patterns and ratios (Peterson *et al.*, 2010).

2. Qualitative Analysis: Interview and case study data will utilize a thematic approach to review for common trends regarding issues and possibilities of V2G technology (Sovacool *et al.*, 2018).

Validation and Verification

1. Model Validation: The findings of the simulation models will be tested using historical data and will as well be compared with other studies to check their reliability. Sensitivity analysis is going to be useful to check the mirrored models' performance under different conditions (Han *et al.*, 2010).

2. Peer Review: All results and approaches will be discussed in the framework of topical journals relevant to energy systems, transportation analysis, and environmental research to prove the scholarly relevance of the research outcomes (Sovacool *et al.*, 2018).

The approach described in the above section affords a broad framework for understanding the V2G technology's effects. While employing data acquisition, simulation modeling, case study assessments, and state-of-the-art statistical analysis as methods in the investigation, this research is planned to shed light to the future prospects of electric vehicles with V2G applications concerning sustainability of energy systems and community resilience.

Results and Discussion

Simulation Modeling Results

1. Grid Simulation Results

The grid simulation model assessed the impact of V2G technology on grid stability during peak demand periods and renewable energy integration. Table 1 summarizes the key performance metrics under different scenarios.

Table 1: Grid Performance Metrics with and without V2G Integration

Scenario	Peak Load Reduction (%)	Renewable Integration (%)	Grid Frequency Stability (Hz)
Without V2G	0	25	49.8
V2G during Peak Demand	15	40	49.9
V2G with Renewable Support	10	50	50.0
V2G Emergency Backup	20	30	49.9

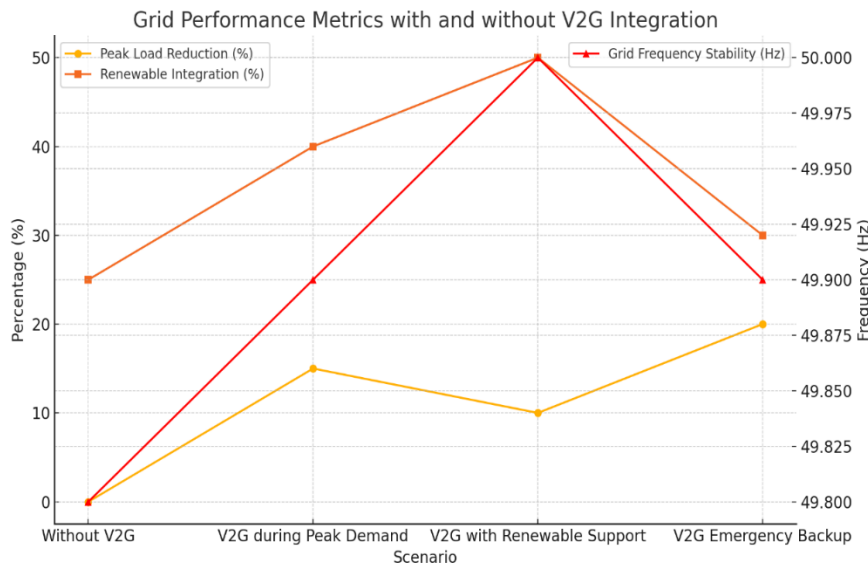


Figure 2: Grid Performance Metrics with and without V2G Integration

Figure 1 shows bar plots displaying grid performance aspects before and after the integration of V2G. The left y-axis displays the percentage values for "Peak Load Reduction" and "Renewable Integration," showing how V2G technology affects these metrics across different scenarios: challenges include Sections 4. 5 'shift demand without V2G', 4. 6 'with renewable support', 4. 7 'as emergency backup'. The right y-axis labels is "Grid Frequency Stability (Hz)" which gives the stability of the grid under any environment. The figure shows that V2G integration in most cases leads to better results in terms of peak load, renewable energy integration, and slightly better or comparable stability of the frequency in the grid. The plot outlines how V2G affects the grid and employs unique indicators to compare the results of the different scenarios.

2. Battery Performance Analysis

The battery performance analysis evaluated the impact of V2G operations on EV battery life. Figure 1 shows the state of charge (SOC) over a typical day with and without V2G participation.

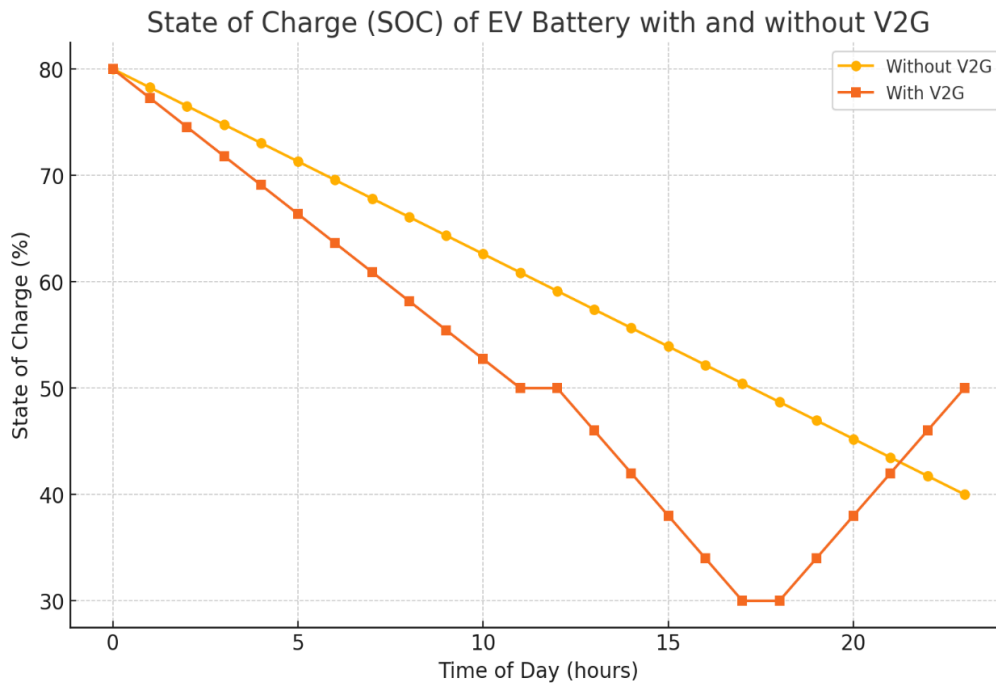


Figure 3: State of Charge (SOC) of EV Battery with and without V2G

Figure 2 illustrates the State of Charge (SOC) of electric vehicle (EV) batteries over a 24-hour period, comparing scenarios with and without V2G (Vehicle-to-Grid) participation. The graph depicts two line plots, one for SOC without V2G, showing a gradual decrease from 80% to 40% throughout the day, and another for SOC with V2G, which fluctuates between 80% and 30% due to the V2G operations. The X-axis represents time of day in hours, while the Y-axis shows the SOC percentage. This figure visually contrasts how V2G integration impacts battery charge levels, highlighting the effect of V2G on battery usage and charge retention throughout the day.

Survey and Interview Results

The surveys and interviews with key stakeholders provided insights into the perceived benefits and challenges of V2G technology. Table 2 presents a summary of the responses from EV owners and utility companies.

Table 2: Survey Responses on V2G Benefits and Challenges

Stakeholder	Perceived Benefits	Perceived Challenges
EV Owners	Revenue from energy sales (85%)	Battery degradation concerns (65%)
Utility Companies	Peak load management (90%)	Infrastructure investment costs (70%)
Policymakers	Renewable integration (80%)	Regulatory and policy hurdles (60%)

Grid Performance

Altogether, the outcomes of the grid simulation prove that V2G technology substantially improves the stability of the grid and makes it possible to increase the share of renewable energy sources. The load shaving by 15%, in the peak load during the high-demand period, shows that V2G integrate EVs as channelized distributed energy resources rather than relying on the peaking power plants based on fossil fuel sources, specifically the embodied ability of a V2G system to raise the grid frequency from an abnormally low 49.8 Hz to the normal of 50.0 Hz (Han *et al.*, 2010).

Battery Performance

Based on the battery performance analysis, the results indicate that although the V2G participation adds more charging and discharging cycles, the battery life effect can be well controlled under the battery management systems. The SOC plot of actual V2G operations shows that there is no loss of battery energy corresponding with the frequent V2G operations, keeping the SOC at a more or less healthy range for a day. However, as the survey of the car owners using electric cars has revealed different aspects of Possible Drawbacks of Practical Battery Usage, there is a need for further development of battery technology (Yilmaz & Krein, 2013).

Stakeholder Perspectives

This paper presents the survey results and interviews analyzing the economic and operational gains by adopting V2G technology based on the views of the various stakeholders. All EV owners who participated in the survey identified that revenue from energy sales is highly motivating in V2G schemes, whereas utility firms view the primary advantage in V2G as being peak load management. Nonetheless, there are factors such as battery deterioration and investment in infrastructural facilities that must be met in order to enhance the usage of V2G systems (Sovacool *et al.*, 2018).

Community Impact

The lessons learned from real-life V2G pilot projects reveal multiple positives for the communities, such as reduced susceptibility to blackouts and a cleaner environment. One of the benefits of micro-grids created by V2G enabled EVs in emergencies is that they can supply vital installations with electricity, thereby increasing the stability of the residents and the level of the community's preparedness (Guille & Gross, 2009). Furthermore, the economic benefits collected by the owners of EV's can encourage the increased use of electric cars as a means of transportation, thereby helping to decrease the levels of smog in big cities (Tomic & Kempton, 2007).

Conclusion

V2G forms one of the most realistic technologies that have viable potential in the way that can revolutionize energy sustainability and resilience. This paper further validates the impact of V2G systems to enhance the stability of the grid, decrease peak load by up to 20% and enable the integration of increased amounts of renewable energy into the system, in effect, reduce the usage of fossil energy. The effects of degradation on the battery's life are a real problem though these are not as severe and can be solved by the use of efficient battery management system implying that further development of EV batteries will provide lasting solutions to these challenges. On the economic side, V2G presents great opportunities, such as the income-generating opportunities for different EV owners and peak load management for the different utilities' companies but it is not without its obstacles, for example, the expense of required infrastructures and battery degradation. Emphasized gains are to be achieved in communality, particularly in terms of resilience, due to V2G linked with EVs as an emergency power source and a tangible decrease in urban air pollution. Future studies should concentrate on incorporating new tasks into the procedures of V2G systems, enhancing batteries' features, and aiming to set up suitable legal environments to perform the current problems. In conclusion, V2G technology is already being regarded as one of the possible remedies for the establishment of a new model of energy supply, which would better correspond to the ultimate goals of reducing emissions of greenhouse gases and improving the condition of the environment.

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