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Analysis of Vehicle-to-Grid (V2G) Technology for Grid Support and peak Load Management

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Abstract The increasing use of electric vehicles (EVs) is changing the transportation system and also affecting the electrical power system. As the number of EVs increases, more electricity is required for charging their batteries. If many EVs are charged at the same time, especially during peak hours, it can increase the load on the grid and may cause problems such as higher power losses and voltage variations. Vehicle-to-grid (V2G) technology provides a way to use EV batteries not only for transportation but also for supporting the power grid.
In V2G technology, power can flow in both directions between the EV battery and the grid. The EV can take power from the grid during low-demand periods and can supply stores power back to the grid during high-demand periods. This can help in reducing peak load and improving the overall operation of the grid. V2G can also be useful for renewable energy sources such as solar power because EV batteries can store extra renewable energy and use it when required.

This paper studies the role of V2G technology in peak-load management and grid support. The effect of controlled EV charging and discharging on grid demand is analyzed. The study also considers the use of EV batteries for storing solar energy. The performance of the V2g system can be evaluated using parameters such as peal load, battery state of charge, power exchanged with grid and renewable-energy utilization. The study shows that proper control of EV charging and discharging can help reduce peak demand and provide useful support to the power grid. However, battery degradation, EV availability, charging infrastructure and user requirements are important factors that need to be considers while implementing V2G technology.

Keywords – Vehical-to-grid (V2G), Electric Vehicles (EVs), Peak Load Management, Bidrectional Power Flow, Smart Grid, Load Blancing, Battery State of Charge (SOC), Renewable Energy Integration, Solar Photovoltaic (PV), Energy Management.

INTRODUCTION

An Electric vehicles (EVs) are becoming increasingly popular because they can reduce the use of conventional fuels and help in reducing air pollution. The development of better batteries, charging infrastructure and EV technology has also made electric vehicles more suitable for daily transportation. However, the increasing number of EVs creates a new Challenge for the electric power system because all EVs need electricity for charging. If a large number of vehicles are charged at the same time, the demand on the power grid can increase significantly.
In a conventional EV charging system, electricity flows from the power grid to the EV battery. This type of operation is known as Grid-to-Vehicle (G2V). Although G2V is necessary for charging can increase the load during already high-demand periods. For example, if a many EV owners start charging their vehicles after returning home in the evening, the additional charging demand can occur at the same time as the normal residential peak load. This can increase the total peak demand and put additional stress on distribution transformers, transmission lines and other power-system equipment.

Vehicle-to-Grid (V2G) technology provides a different approach to this problem. V2G allows electrical power to flow in both directions between the EV battery and the power grid. During periods of low electricity demand, EVs can be charged from the grid. When electricity demand becomes high, some EVs can supply a part of their stored energy back to the grid. In this way, EV batteries can work not only as energy sources for transportation but also as small energy-storage units connected to the power system.

V2G technology can provide several types of support to the power grid. One important application is peak-load management. During peak-demand periods, EVs can discharge their stored energy and reduce the amount of power required from the grid. During low-demand periods, EVs can be charged when sufficient power is available. This type of controlled charging can help to make the daily load profile more balanced.

Another important application of V2G is the integration of renewable energy sources. Solae and wind power generation is variable and does not always match the electricity demand. For example, solar power generation is generally high during the daytime, while electricity demand may become higher during the evening. EV batteries can be charged using excess solar energy during the daytime and can later supply some of this stores energy to the grid when demand increases. Therefore, V2G can help in making better use of renewable energy.

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However, V2G also has some challenges. Frequent charging and discharging can affect battery life and may increase battery degradation. The availability of EVs is also important because vehicles may be required by their owners for transportation. In addition, bidirectional charges, communication systems, control strategies and suitable charging infrastructure are requires for practical V2G operation. Therefore, proper coordination between EV owners, charging stations and the power grid is necessary.

Because of these advantages and challenges, it is important to study how V2G technology can be used effectively for grid support. This paper focus on the use of V2G for peak-load management and renewable-energy utilization. The study considers controlled charging and discharging of EV batteries and evaluates their effect on grid power demand, battery state of charge and renewable-energy utilization. The main aim is to understand how EVs can be used as flexible energy-storage resources while still meting the transportation requirements of EV users.

1. LITERATURE REVIEW

Many researchers have studied Vehicle-to-Grid (V2G) technology because electric vehicles can be used not only for transportation but also for supporting the electrical grid. Different studies have focused on V2G operation, peak-load management, and renewable-energy integration, charging strategies, battery degradation and grid stability.

1.1 Kempton and Tomic-Basic V2G Concept

Kempton and Tomic [1] were among the early researchers who presented the concept and practical use of Vehicle-to-Grid power. They studied how electric-vehicles could provide power to the electrical grid when they were connected to the grid. Their work discussed the available power from vehicle batteries, suitable grid services and the possible economic benefits of V2G. They also explained that V2G is more useful for fast-response grid services rather than continuous base-load supply.
In another study, Kempton and Tomic discussed the implementation of V2G for grid stabilization and large-scale renewable-energy support. Their work showed that EVs could provide power to the grid when required. They also discussed the technical requirements and control of V2G systems.

1.2 Mahmud et al., - Peak-Load Management

Mahmud, Hossain and Ravishankar studies peak-load management using electric vehicles, battery energy storage and photovoltaic generation. They proposed a method in which EVs available in a parking area could be used through V2G operation during high-demand periods. Their study considered realistic load and weather conditions and also investigated the economic benefits of the proposed system. The results showed that EV-based management could reduce the peak load and energy cost in the studies system.
This study is important for the present work because it shows how EV batteries can be used during peak hours instead of considering EVs only as additional loads.

1.3 Zheng et al. – EV-Grid Integration and scheduling

Zheng, Niu, Shang, Shao and Jian presented a comprehensive review of integrating plug-in electric vehicles with power grids. They discussed different power-interaction modes between EVs and the grid and reviewed various charging and scheduling methods. They also considered important issues such as grid impacts and battery degradation. Their study showed that suitable scheduling is important for obtaining the benefits of V2G, especially when a large number of EVs are connected to the grid.
The authors also pointed out that many existing studies use mathematical optimization models, while the practical implementation and optimization of charging strategies for a large number of EVs still require further investigation.

1.4 Ota- Integration of EVs with Power Systems

Ota studied the integration of electric vehicles with power systems and discussed the increasing importance of vehicle-grid integration. The study considered the effect of EV charging on distribution feeders, renewable-energy-based charging and V2G services. The author also highlighted the importance of electrical interfaces, integration of multiple grid services and practical demonstration of EV-grid integration.
This work shows that the use of EVs in power systems is not limited to charging. With proper control, EVs can also provide different support services to the grid.

1.5 E Joseph et al. – V2G with Renewable Energy

Joseph and co-authors studied the combination of renewable energy, electric-vehicle charging and V2G technology. Their work discussed bidirectional power flow between EVs and the grid and considered renewable-energy-based charging. They also examined charging and V2G configuration using power-electronic systems and simulations.

The study shows that EV batteries can be useful for storing renewable energy and supplying it when required. This is particularly useful because renewable-energy generation and electricity demand do not always occur at the same time.

1.6 Arfeen et al., -V2G in Distribution Networks

Arfeen and co-authors reviewed the development of EVs with V2G technology in distribution networks. Their study discussed the applications of V2G, technical challenges, renewable-energy integration and issues related to the implementation of V2G in distribution systems.

The study indicates that V2G can provide useful support to distribution networks, but practical issues such as charging infrastructure, control, communication and battery-related problems need to be considered.

1.7 Tavakoli et al., -Solar PV and EV Integration

Tavakoli and co-authors studied the combined integration of solar photovoltaic systems and electric vehicles. Their review considered the effects of PV-EV integration on grid stability,

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power quality and energy economics. The authors highlighted that the increasing use of both PV systems and EVs can have combined effects on the power grid.

This work is relevant to V2G because EV batteries can be used to store excess solar energy and can be used to store excess solar energy and can later supply energy when demand is higher.

1.8 Huda et al. –Power Electronic in V2G

Huda and co-authors reviewed the role of power electronic in V2G systems. Their work discussed bidirectional AC/DC and DC/DC converters used to exchange power between the electrical grid and EV batteries. The study also discussed different charging and discharging configurations and highlighted the importance of smart charging and discharging in renewable-energy-based grids.

This research shows that bidirectional power converters are an important part of V2G because they control the direction and amount of power exchanged between the EV battery and the grid.

1.9 Shrivastava et al., - V2G for Peal Shaving Frequency Regulation

Shrivastava, Khalid and Nishad recently studied the use of EVs for peak-load reduction and frequency regulation in a micro grid containing solar, wind and diesel generation. Their work investigated how EV-grid integration can support both load management and frequency control.

This study is useful for understanding the combined role of EVs and renewable energy in modern power systems. It also shows that V2G can be studied not only for peak-load reduction but also for other grid-support services.

2.10 Overall Findings from Previous Research

From the studies discussed above, it can see that V2G technology has been studied from different point of view. Kempton and Tomic introduced and developed the basic V2G concept and its possible grid services. Mahmud et al., focused on peak-load management, while Zheng et al. discussed EV-grid integration and scheduling. Other researchers have studied renewable-energy integration, distribution-network applications, power electronics and frequency regulation.

However, V2G performance depends on several factors such as the number of EVs, battery capacity, state of charge, charging and discharging power, EV availability, grid demand and renewable-energy generation. Therefore, a suitable charging and discharging strategy is required to obtain maximum grid benefit without affecting the requirements of EV users.

Based on the reviewed studied, this research focuses on a relatively simple V2G strategy for peak-load management and renewable-energy utilization. The effect of controlled EV charging and discharging will be studied by comparing the grid operation with and without V2G.

2. RESEARCH GAP

The literature review shoes that Vehicle-to-Grid (V2G) technology has been studied by many researchers for different applications such as peak-load management, renewable-energy integration, frequency regulation, voltage support, economic benefits and battery management. Previous studies have clearly shown that EV batteries can provide useful support to the electrical grid when suitable charging and discharging control is applied.

However, some areas still need further study. Many studies focus mainly on one particular application of V2G, such as peak-load reduction or frequency regulation. In practical operation, several factors can affect the performance of V2G at the same time. These include the daily load pattern, availability of EVs, battery state of charge, charging and discharging limits and renewable-energy generation.

Another important issue is the coordination between EV charging and renewable energy. Solar power generation is usually higher during the daytime, while electricity demand may increase during the evening. Therefore, EV batteries can be used to store excess solar energy and supply it later when the demand is high. However, an appropriate charging discharging strategy is required so that the grid receives support without unnecessarily affecting the battery state of charge.

Battery degradation is also an important concern. Although V2G can provide benefits to the grid, frequent charging and discharging can increase the number of battery cycles. Therefore, the V2G operation should be controlled within suitable battery state-of-charge limits.

Based on these observations, there is a need for a simple and practical V2G analysis that considers peak-load management, renewable-energy utilization and battery state of charge together. The present study addresses this gap by developing a controlled charging and discharging strategy for EVs and evaluating its effect on grid power demand and renewable-energy utilization.

The main focus of this research is therefore to compare the operation of the power system without V2G and with controlled V2G operation. The comparison will be carried out using parameters such as peak demand, grid power exchange, and EV battery state of charge and renewable-energy utilization. This approach can help in understanding the practical benefits and limitations of V2G technology for future smart-grid applications.

3. RESEARCH OBJECTIVES

The main objective of this research is to study the use of Vehicle-to-Grid (V2G) technology for supporting the electrical grid and reducing peak electrical grid and reducing

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peak electricity demand. The study also considers the use of EV batteries for better utilization of solar energy.

The specific objectives of this research are:

1. To study the operating principle of Vehicle-to Grid (V2G) technology and understand the bidirectional power flow between EV batteries and the electrical grid.
2. To analyze the effect of EV charging on grid demand and understand the problems that may occur when a large number of EVs are charged during peak-demand periods.
3. To develop a controlled EV charging and discharging strategy in which EVs are charged during suitable low-demand periods and can discharge during high-demand periods.
4. To investigate the role of V2G in peak-load management by comparing the peak demand of the system with and without V2G operation.
5. To study the interaction between EVs and solar photovoltaic (PV) generation, particularly the use of EV batteries for storing excess solar energy.
6. To analyze the battery state of charge (SOC) during charging and discharge and maintain it within suitable operating limits.
7. To evaluate the overall performance of V2G operation using parameters such as peak load, grid power exchange, battery SOC and renewable-energy utilization.
8. To identify the major practical challenges of V2G implementation, including battery degradation, EV availability, charging infrastructure and user requirements.

(a) Research Questions

Based on the research gap and objectives, the following research questions are considered:

Q1: How does uncontrolled EV charging affect the electricity demand of the power grid?

Q2: Can controlled V2G operation reduce the peak electricity demand?

Q3: How can EV batteries be used to store excess solar energy and supply it to the grid when required?

Q4: What effect does V2G operation have on the state of charge of EV batteries?

Q5: How does the performance of the grid change when V2G is used compared with conventional EV charging?

Q6: What are the major technical and practical limitations that need to be considered for implementing V2G technology?

b. Expected Contribution of the study

The main contribution of this research is the analysis of a controlled V2G operation that considers both peak-load management and renewable-energy utilization. The study will compare the system under conventional EV charging and controlled V2G operation.

The expected contribution can be summarized as follows:

- Development of a simple V2G-based charging and discharging strategy.
- Comparison of grid demand with and without V2G.
- Analysis of peak-load reduction through EV battery discharge.
- Study of EV batteries as storage for excess solar energy
- Analysis of battery state of charge during V2G operation.
- Identification of the benefits and limitations of V2G for future smart-grid applications.

4. V2G SYSTEM ARCHITECTURE AND OPERATING PRINCIPLE

Vehicle-to-Grid (V2G) technology provides a bidirectional connection between electric vehicles (EVs) and the electrical power grid. In a conventional charging system, electricity flows from the grid to the EV battery. However, V2G enables power to flow in both directions, allowing EV batteries to supply stored electrical energy back to the grid when required. This capability allows electric vehicles to serve not only as transportation devices but also as flexible energy resources for power-system operation.

The basic architecture of a V2G system consists of the electrical grid, EV battery, bidirectional charger, control and communication system and connected electrical loads. The bidirectional charger enables energy transfer between the EV battery and the grid, while the control system manages charging and discharging according to grid demand, battery state of charge (SOC) and vehicle Availability. A solar photovoltaic (PV) system may also be integrated into the architecture to investigate the coordination of EV charging with renewable-energy generation.

The operating principle of V2G depends on the direction of power flow and the requirements of the power system. During periods of low electricity demand, EV batteries can be charged using grid electricity. When solar energy is available, charging can also be scheduled to make better use of PV generation. During peak-demand periods, connected EVs can supply a portion of their stored energy to the grid, provided that sufficient battery energy is available and the vehicle owner's mobility requirements are satisfied. This coordinated operation can reduce the net power drawn from the grid during periods of high demand.

The effectiveness of V2G depends on an appropriate charging and discharging strategy. Battery SOC must be maintained

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within specifies operating limits to ensure that sufficient energy remains available for vehicle use. The control strategy must also consider the maximum charging and discharging power, the duration for which vehicles remain connected and the availability of bidirectional charging infrastructure. Furthermore, frequent battery cycling may contribute to battery degradation, making it necessary to consider battery life when developing a V2G operating strategy.

In present study, the V2G system is considered for peak-load management and improved utilization of solar energy. Its operation will be evaluated by comparing a conventional EV charging scenario with a controlled V2G scenario. The comparison will consider parameters such as peak grid demand, power exchanged between EVs and the grid, battery SOC and solar-energy utilization. This approach provides a basis for examining how coordinated EV charging and discharging may contribute to improved power-system operation.

5. PROPOSED METHODOLOGY

The proposed methodology aims to investigate the effectiveness of Vehicle-to-Grid (V2G) technology in reducing peak electricity demand and improving the utilization of renewable energy. The analysis considers the interaction between the electrical grid, electric vehicles (EVs), battery energy storage, electrical loads and solar photovoltaic 9PV) generation. A comparative approach is adopted to examine grid operation under conventional EV charging and controlled V2G operation.

a. System Modeling

The proposed system consists of an electrical grid supplying power to conventional loads and EV charging stations. Each EV is represented by a battery with a specified energy capacity, charging and discharging power limits and allowable state-of-charge (SOC) range. A bidirectional charger enables power transfer between the EV battery and the grid. Solar PV generation can also be included to examine the effect of coordinating EV charging with renewable-energy availability.

Two operating scenarios are considered. In the first scenario, EV are charged from the grid without supplying energy back to it. In the second scenario, EV charging and discharging are controlled according to electricity demand, battery SOC and vehicle availability. The results from these scenarios will be compared to assess the potential contribution of V2G technology to peak-load management.

b. EV Charging and Discharging Strategy

The charging and discharging schedule plays an important role in determining the performance of a V2G system. During periods of low electricity demand, EVs can be charged to store energy for subsequent use. When demand increases, connected EVs with sufficient stored energy can discharge part of their battery energy to support the grid. Where solar PV generation is available, charging can also be coordinated with solar output to improve the utilization of renewable energy.

The battery state of charge is an important operating parameter because it indicates the amount of energy stored in the EV battery. Its variation can be represented by the following energy-balance equation:

$$SOC_{t+1} = SOC_t + \frac{\eta_c P_{ch,t} \Delta t}{E_b} - \frac{P_{dis,t} \Delta t}{\eta_d E_b}$$

The charging and discharging schedule must satisfy the battery's operating limits and the energy requirements of the EV owner. Therefore, V2G discharging should be permitted only when the vehicle is connected, sufficient energy is available and the selected operating conditions allows power to be supplied to the grid.

c. Analysis of Net Grid Power Demand

The net power demand supplied by the grid depends on the electrical load, EV charging demand, V2G power injection and solar PV power used locally. Under a simplified power-balance model, net grid demand can be expressed as:

$$P_{\text{grid},t} = P_{\text{load},t} + P_{\text{EV,ch},t} - P_{\text{V2G},t} - P_{\text{PV,used},t}$$

This relationship provides the basis for examining how controlled EV charging and discharging influence grid demand. Charging during low-demand periods can help avoid adding unnecessary demand during peak hours, while discharging during high-demand periods can reduce the net power required from the grid. The actual effect depends on EV availability, battery energy, charger ratings and the timing of electricity demand.

d. Performance Evaluation

The performance of the proposed V2G system will be evaluated by comparing the maximum grid demand under conventional charging with the maximum grid demand under controlled V2G operation. Peak-load reduction can be calculated using;

$$\text{Peak Load Reduction } (\%) = \frac{P_{\text{peak,base}} - P_{\text{peak,V2G}}}{P_{\text{peak,base}}} \times 100$$

In addition to peak-load reduction, the analysis will consider battery SOC variation, power exchanged between EVs and the grid and solar-energy utilization. These parameters will help assess whether the proposed operating strategy reduces peak demand while maintaining suitable battery operating conditions and making effective use of available renewable energy.

e. Comparative Analysis

The final stage of the proposed methodology involves comparing the two operating scenarios using the same underlying electrical load profile and comparable EV availability assumptions. The analysis will consider grid-

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demand variations throughout the selected study period and examine the changes introduced by controlled V2G operation. Where solar PV generation is included, its contribution to local demand and its interaction with EV changing will also be evaluated.

The methodology establishes a systematic basis for evaluating the potential of V2G technology for peak-load management and renewable-energy utilization. The effectiveness of the proposed approach will be determined from the results obtained through the selected simulation or analytical procedure.

6. SIMULATION SETUP AND SYSTEM PARAMETERS

The simulation setup is designed to evaluate the performance of Vehicle-to-Grid (V2G) technology under different electrical load and EV charging conditions. The proposed model considers the electrical grid, EV batteries, charging infrastructure, electrical load demand and solar photovoltaic (PV) generation. A comparative analysis will be conducted to examine the effect of controlled EV charging and discharging on peak grid demand.

Two operating cases will be considered. In the first case, electric vehicles will be charged using a conventional charging strategy without supplying power back to the grid. In the second case, controlled V2G operation will be implemented, allowing connected EVs to discharge stored energy during periods of high electricity demand. Both cases will use comparable load profiles and EV availability assumptions to ensure a meaningful comparison.

A. system Parameters

The performance of the proposed system depends on several parameters, including battery capacity, charging and discharging power, battery state-of-charge limits, EV availability, electrical load demand and solar PV generation. These parameters will be defined before conducting the simulation.

The battery energy capacity determines the amount of energy available for charging and discharging. Charging and discharging power limits determine the maximum rate of energy transfer between the EV battery and the grid. The SOC limits ensure that sufficient battery energy remains available for vehicle operation and that the battery operators within its specified range.

The electrical load profile will represent variations in power demand over the selected study period. If solar PV generation is included, its generation profile will be used to examine the effect of coordinating EV charging within renewable-energy availability. The simulation time interval will be selected to capture changes in electricity demand and EV charging behavior.

I. Simulation Procedure

The simulation will begin by establishing the baseline grid-demand profile under conventional EV charging. The resulting peak demand will be identified and used as the reference for comparison. Controlled V2G operation will then be introduced using the selected charging and discharging strategy, subject to battery SOC limits, charger power ratings and EV availability.

The net grid power demand will be calculated for each simulation interval. Battery SOC will also be monitored to evaluate changes in stored energy during charging and discharging. Where solar PV generation is included, its contribution to local demand and its interaction with EV charging will be examined.

Finally, the results obtained from the two operating cases will be compared using peak grid demand, percentage peak-load reduction, battery SOC variation and solar-energy utilization. The comparison will provide a basis for evaluating the potential benefits and practical limitations of V2G technology for grid support and peak-load management.

7. Results and Discussion

The performance of Vehicle-to-Grid (V2G) technology is evaluated by comparing conventional EV charging with controlled charging and discharging operation. The analysis focuses on changes in grid power demand, peak-load reduction, battery state of charge (SOC) and solar-energy utilization. These parameters help assess the potential contribution of V2G technology to power-system operation.

A. Effect on Peak Load Management

The impact of V2G technology on peal-load management can be evaluated by comparing the maximum grid demand under conventional EV charging and controlled V2G operation. Under conventional charging, EVs increase electricity demand when their batteries are connected to the grid for charging. If charging coincides with existing peak-demand periods, the maximum power required from the grid.

Under controlled V2G operation, connected EVs can supply stored energy during periods of high electricity demand. This power injection may reduce the net demand supplied by the grid. The extent of peak-load reduction depends on the number of available EVs, their battery SOC, charging and discharging power limits and the duration of peak demand. The actual reduction must be determined from the comparative analysis of the two operating scenarios.

a. Effect on Battery State of Charge

Battery SOC is an important parameter in evaluating V2G operating because it determines the energy available for supplying power to the grid. During charging periods, battery SOC increases, whereas discharging reduces the stored energy. Therefore, the charging and discharging strategy must maintain SOC within specified operating limits.

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The SOC profile can be used to examine whether the proposed control strategy provides sufficient energy for grid support while maintaining the transportation requirements EV owners. Battery degradation should also be considered because repeated charging and discharging may affect battery life. Consequently, peak-load reduction should be evaluated alongside battery operating conditions.

b. Role of V2G in Solar-Energy Utilization

The integration of solar photovoltaic (PV) generation with V2G technology provides an opportunity to coordinate EV charging with renewable-energy availability. When solar generation exceeds the immediate local demand, available EV batteries may be charged to store some of the surplus energy. This stored energy can subsequently to the grid when permitted by the control strategy.

The effectiveness of this approach depends on the relationship between solar generation, electricity demand and EV connection periods. Comparing solar-energy utilization under conventional charging and coordinated V2G operation can help determine whether the proposed strategy improves the use of available renewable energy.

c. Overall Performance Assessment

The overall performance of the proposed V2G system will be assessed using the peak grid demand, percentage peak-load reduction, battery SOC variation and solar-energy utilization. These parameters will provide a basis for comparing conventional EV charging with controlled V2G operation.

The findings will also be interpreted in relation to practical limitations, including EV availability, bidirectional charging infrastructure, battery degradation and the energy requirements of vehicle owners. The results obtained from the simulation or analytical study will determine the extent to which V2G technology can support peak-load management under the selected operating conditions.

8. CHALLENGES AND LIMITATIONS OF V2G TECHNOLOGY

Although Vehicle-to-Grid 9V2G) technology offers opportunities for peak-load management and grid support, its practical implementation involves several technical and economic challenges. The effectiveness of V2G depends not only on the availability of electric vehicles but also on battery performance, charging infrastructure, communication system and the willingness of vehicle owners to participate. These factors must be considered when evaluating the suitability of V2G for modern power systems.

a. Battery Degradation

Frequent charging and discharging can contribute to the degradation of EV batteries over time. V2G operation introduces additional battery cycling, which may affect battery capacity and service life. The extent of degradation depends on factors such as battery chemistry, operating temperature, depth of discharge and charging strategy. Therefore, V2G control strategies should balance the benefits of grid support against potential battery wear.

b. EV Availability and User Requirements

Electric vehicles are primarily used for transportation and their availability for grid support depends on when and where they are connected to charging infrastructure. An EV cannot provide V2G services when it is disconnected or when its stored energy is insufficient. In addition, vehicle owners may require a minimum battery SOC before departure. These requirements limit the energy that can be made available to the grid and must be incorporated into the charging and discharging schedule.

c. Charging Infrastructure and Investment Costs

V2G operation requires compatible bidirectional charges and suitable electrical connections. Compared with conventional charging equipment, bidirectional charging equipment, bidirectional charging infrastructure may involve additional investment and installation requirements. The integration of this equipment into existing distribution networks may also require upgrades to protection systems, metering and control facilities. These costs can influence the economic feasibility of V2G implementation.

d. Grid Control and Communication Requirements

Coordinated V2G operation requires communication between EVs, charging stations and grid-management systems. Reliable information about electricity demand, battery SOC, vehicle availability and charging limits is necessary for effective scheduling. Communication delays, data errors and cybersecurity threats may affect system operation. Appropriate control methods and security measure are therefore required to support reliable power exchange.

e. Power Quality and Distribution Network Constraints

Large-scale EV charging and discharging can affect voltage profiles, power losses and power quality in distribution networks. Poorly coordinated charging may increase local demand, while concentrated discharging may create operational challenges under certain network conditions. The impact depends on the location and capacity of charging stations, network characteristics and the distribution of connected EVs. Appropriate planning and control are necessary to ensure that V2G operation remains within network operating limits.

f. Economic and Regulatory Considerations

The economic feasibility of V2G depends on equipment costs, electricity tariffs, battery degradation costs and the compensation offered to EV owners for supplying energy or grid services. Clear regulations and suitable market arrangements are also needed to define how EVs participate in grid-support activities. Without appropriate financial

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incentives and technical standards, vehicle owners may have limited motivation to participate in V2G programmers.

Overall, these challenges indicate that successful V2G implementation requires coordinated technical, economic and regulatory planning. A suitable operating strategy should consider battery health, EV availability, distribution network constraints and user requirements alongside the expected benefits of peak-load management and renewable-energy integration.

9. CONCLUSION AND FUTURE SCOPE

Vehicle-to-Grid (V2G) technology provides a potential approach for improving the interaction between electric vehicle and the electrical power grid. Unlike conventional EV charging, V2g enables bidirectional power flow, allowing EV batteries to receive electricity from the grid and supply stored energy back when required. This capability can be useful for managing variations in electricity demand and supporting the integration of renewable energy sources.

This paper presents a proposed methodology for examining the role of V2G technology in peak-load management and solar-energy utilization. The approach considers controlled EV charging and discharging, battery state of charge, net grid power demand and peak-load reduction. A comparison between conventional EV charging and controlled V2G operation can be used to evaluate the potential effects on grid demand under specified operating conditions.

The effectiveness of V2G depends on several factors, including the availability of connected EVs, battery energy capacity, charging and discharging limits and the timing of electricity demand. Coordinating EV charging with solar PV generation may also improve the utilization of available renewable energy. However, battery degradation, charging infrastructure costs, communication requirements and vehicle-owner preferences remain important considerations for practical implementation.

Future work may involve developing and simulating a detailed V2G model using MATLAB/Simulink or another suitable simulation platform. Different EV penetration levels, daily load profiles, solar PV capacities and charging strategies could be investigated to examine their influence on peak demand and battery operation. Further studies could also consider battery degradation costs, electricity tariffs and the economic benefits of providing grid-support services. These investigations would help establish the technical and economic feasibility of V2G technology under realistic power-system operating conditions.

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