International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 03 | March – 2025 DOI: 10.55041/ISJEM02383
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

Design of Simulation Model for Vehicle-To-Grid Bidirectional Power Transfer system

Prof. Anurag Borkhade[1], Akash P. Misal[2] , Radhika A. Gimonkar[3] , Diksha P. Mate[4]

[1,2,3,4]Department of Electrical Engineering, Jawaharlal Darda Institute of Engineering and Technology Yavatmal, India

Abstract

The Vehicle-to-Grid (V2G) bidirectional power transfer system is an innovative concept that allows electric vehicles (EVs) to not only consume electricity from the grid but also supply power back to it. This system enables a sustainable and efficient way of managing energy resources by utilizing the EV battery as a mobile energy storage unit. The objective of this paper is to design and simulate a V2G bidirectional power transfer system, analysing the dynamic interaction between electric vehicles and the grid under various operating conditions.

The proposed model integrates key components, such as the EV battery, bidirectional converter, and grid connection system, with the control strategies required to ensure safe, efficient, and reliable power transfer. A comprehensive simulation framework is developed using advanced modelling tools (e.g., MATLAB/Simulink), which allows for real-time assessment of the power flow, voltage regulation, frequency stabilization and grid support capabilities. The performance of the system is evaluated based on factors like charging/discharging efficiency, energy transfer rates, grid impact and response to fluctuating renewable energy sources. Additionally, the study investigates the economic benefits of V2G systems, including energy cost savings, potential revenue generation for EV owners, and reduced grid dependency [1].

1. Introduction: -

Vehicle-to-Grid (V2G) technology is an innovative system that allows electric vehicles (EVs) to interact bidirectionally with the power grid. This means that EVs can not only draw electricity from the grid for charging but also return stored energy to the grid when required. Acting as mobile energy storage units, EVs with V2G capabilities help stabilize the grid, balance energy supply and demand, and support the integration of renewable energy sources like wind and solar. As a result, V2G technology has emerged as a key enabler of clean energy transitions and smarter grid management.

The concept of V2G was first introduced in the late 1990s when researchers recognized the untapped potential of EVs to enhance grid reliability. In 1997, Willett Kempton and Steven Letendre published a seminal paper that laid the foundation for V2G, proposing models for technical and economic viability. They highlighted how EV batteries could provide services such as peak demand reduction, frequency regulation, and emergency power supply. These early ideas formed the backbone of V2G's development, inspiring further research and experimentation.

In the 2000s, early prototypes and pilot projects began testing the feasibility of V2G systems. While advancements in bidirectional charging technology emerged during this period, the limited adoption of EVs and inadequate infrastructure posed significant challenges to large-scale implementation. Governments and research

International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 03 | March – 2025 DOI: 10.55041/ISJEM02383
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

institutions in regions like the U.S., Europe and Japan began

investing in studies to better understand the potential of V2G for grid management.

The 2010s saw significant progress as the adoption of EVs gained momentum globally, driven by manufacturers such as Tesla, Nissan, and BMW. This surge in EV popularity created a foundation for the commercial deployment of V2G technology. Advancements in communication protocols, such as ISO 15118 and OCPP, as well as the development of smart grid technologies, enabled seamless integration of V2G systems into energy networks. Pilot projects in countries like Denmark and Japan demonstrated V2G's ability to provide ancillary grid services, including load balancing and energy storage for renewable sources. Regulatory bodies and governments also began offering financial incentives to encourage EV owners to participate in V2G programs. [Ref. Shi Rui, Chi Zhong "Bidirectional Power Transfer Control Based on V2G concept]

In the 2020s, V2G has evolved into a vital component of modern energy strategies, particularly in managing the intermittency of renewable energy sources like wind and solar. Large-scale pilot projects, often collaborations between automakers, energy providers, and governments, have demonstrated the technology's scalability and economic viability. The falling costs of EVs and bidirectional chargers, along with ongoing improvements in battery technology, have made V2G systems more accessible to a broader audience. Countries such as the Netherlands, the U.K., and South Korea have integrated V2G into their national energy strategies, further accelerating its adoption.

Looking ahead, V2G technology continues to evolve with a focus on smart grids, microgrids, and AI-powered optimization to improve efficiency and scalability. These advancements aim to unlock V2G's full potential, making it an integral part of future energy systems. By leveraging EVs as dynamic storage units, V2G not only supports grid resilience but also plays a pivotal role in achieving global sustainability goals [2].

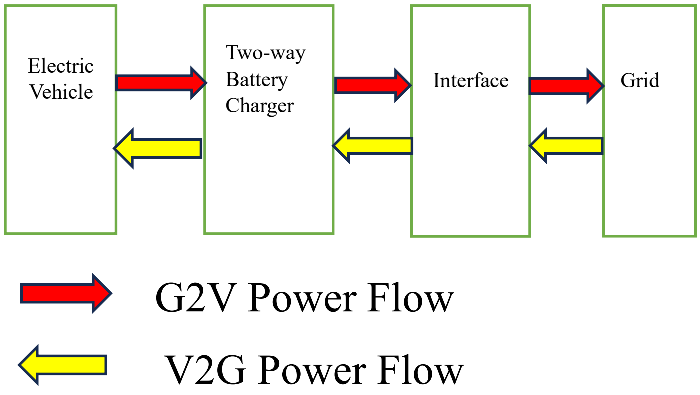


Figure 1. resents a power flow block diagram of V2G technology [7].

2. System Architecture:-

The general block diagram of Vehicle-to-Grid (V2G) technology illustrates the bi-directional energy flow between the electric vehicle (EV) and the grid. The process begins with the EV plugged into a charging station, where an AC/DC converter adjusts the grid voltage for the vehicle's battery. When the battery is charged, energy can be transferred from the vehicle back to the grid through a DC/AC converter and an increasing converter to step up the voltage. Conversely, when the battery charge is low, energy flows from the grid to the vehicle, utilizing a step-down converter and an AC/DC converter to adapt the grid power to the battery's needs. A similar structure is observed in Vehicle-to-Home (V2H) systems, where the vehicle's battery provides power to the home when needed. A controllable switch before the transformer decides whether power will be exchanged with the grid or supplied to the home. An energy management system and home load manager ensure that the energy transfer is efficient and seamless, adjusting the flow based on grid demand and battery status. The integration of these systems highlights the potential for electric vehicles to function as both energy storage and backup power sources, offering enhanced grid efficiency and reliability [1].

International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 03 | March – 2025 DOI: 10.55041/ISJEM02383
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

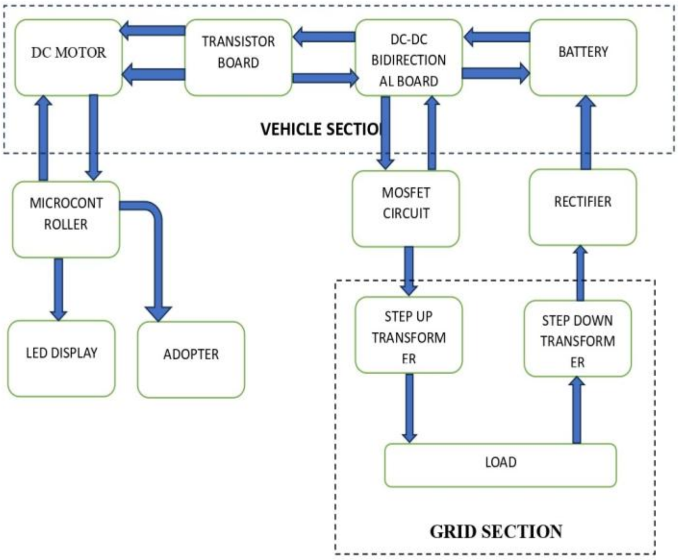


Figure 2. block Diagram of Vehicle to Grid and Grid to Vehicle

3. Full Bridge Bidirectional Converter and the Reversible DC-DC Converter: -

The architecture of the Full Bridge (FB) topology is one of the most widely used types of Bidirectional AC-DC Converter (BADC) due to its versatility and efficiency in energy conversion. The IGBT-based BADC, as described by Pinto et al., integrates with a non-isolated DC-DC converter via a bus capacitor. This combination allows for seamless Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations, facilitating bi-directional power flow between the electric vehicle (EV) battery and the grid.

In the G2V mode, the BADC functions as an active rectifier, ensuring that the EV battery is charged from the grid in an efficient manner. When operating in the V2G mode, the BADC acts as a regulated current source, delivering power back to the grid. This mode contributes to maintaining the power factor by supplying electricity to the utility, thus stabilizing the grid's voltage and current.

Furthermore, in situations where the main power supply is interrupted, the electric vehicle's battery can serve as a voltage-controlled source for supplying domestic loads, utilizing the BADC as part of the system's backup power solution. This flexibility makes the full-bridge bidirectional converter ideal for both grid stabilization and as an emergency power source for residential needs.

The combination of the FB BADC and the reversible DC-DC converter enables efficient energy management in various operating modes, ensuring optimal performance for both charging and discharging processes while supporting grid operations [8].

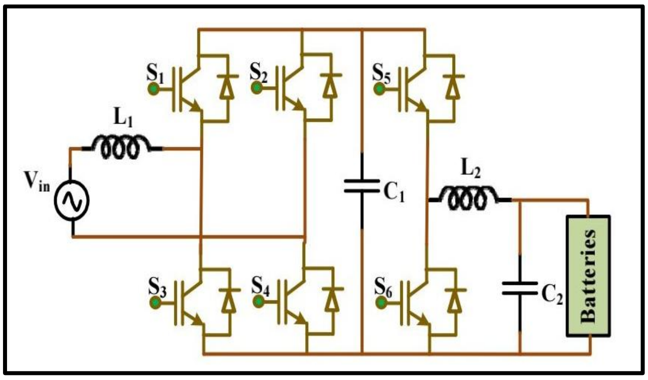


Figure 3.Full Bridge Bidirectional Converter and The Reverisable DC-DC Converter [8].

4. Control Strategy: -

The control algorithm of the proposed technique is designed to efficiently manage the bidirectional power flow between the grid and the battery, adapting to varying grid and battery conditions. As shown in the control diagram, a current mode controller is used to regulate the AC-DC converter, allowing energy transfer in both directions. To generate the grid reference current, the grid PI regulator adjusts the DC link voltage error, while a Proportional-Resonant (PR) controller is employed for more accurate tracking of AC signals, providing better synchronization compared to a traditional PI controller. The PI controller then manages the error signal by comparing the reference grid current with the actual grid current, minimizing this error to ensure smooth energy flow. The Pulse Width Modulation (PWM) generator produces gate pulses for switches S1 to S4, using the error signal as a reference, with a triangular carrier waveform to regulate the timing of the pulses. The PI controller’s goal is to minimize the voltage error (Ve(k)) to maintain a stable control signal. The output of the controller is determined by the proportional and integral gains, which adjust the system's response. Additionally, the system accounts for the current error by comparing the reference current with the actual current, using a gain factor to reduce current inaccuracies. The battery's charging and discharging modes are controlled using PWM, with the battery current output being regulated by a Proportional-Integral (PI) controller. This ensures optimal performance and efficiency, maintaining the system's stability and ensuring precise control of energy flow [1].

4.1 Mathematical Representation:-

1]**Voltage Error:** -The error signal (Ve(k)) between the reference voltage and the actual voltage is given by:

$$Ve(k)=Vref(k)-Vdc(k)V$$

2]Controller Output: The output of the controller, I*p(k), is determined by the previous output and the voltage error, as shown by:

$$I^*p(k)=I^*p(k-1)+Kp[Ve(k)-Ve(k-1)]+KiVe(k)$$

Here, Kp and Ki represent the proportional and integral gains.

3]Current Error: The current error is the difference between the reference current (I*p(Kp)) and the sensed current (Ip(K)):

$$Ie(k)=I^*p(k)-Ip(k)$$

4]Current Inaccuracy: The gain "K" can be used to adjust the current error. This helps improve the accuracy of the system:

$$Verror=kIe(k)$$

5]Pulse Width Modulation (PWM) technique also regulates the charging and discharging modes of the battery. The battery current output is controlled by a Proportional-Integral (PI) controller, which adjusts the current to maintain optimal performance. The current error for the battery is defined as:

$$Ibattery(k)=Ib*(k)-Ib(k)$$

Where I*b(k) is the reference battery current and Ib(k) is the actual battery current.

5. Two-Way Power Converter Simulation: -

The simulation model of the electric power system, developed in MATLAB, facilitates both Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) energy transfer, enabling seamless energy exchange between electric vehicles (EVs) and the grid. In this model, the EV battery is charged and discharged using two key converter circuits: a single-phase AC-DC bidirectional converter and a synchro-rectification DC-DC buck-boost converter. The AC-DC bidirectional converter allows for bidirectional power flow, enabling the battery to either charge from the grid (G2V) or discharge back to the grid (V2G). The synchro-rectification DC-DC buck-boost converter ensures voltage regulation, stepping up or down as needed to maintain efficient energy transfer. In the V2G mode, the battery discharges excess energy to the grid, typically when the battery is fully charged or during off-peak times, while in the G2V mode, the EV battery charges from the grid during low-demand periods. The MATLAB-developed model allows for the analysis of power flow, converter behavior, and energy transfer under various conditions, providing valuable insights for optimizing V2G and G2V systems for improved grid efficiency and energy management [3].

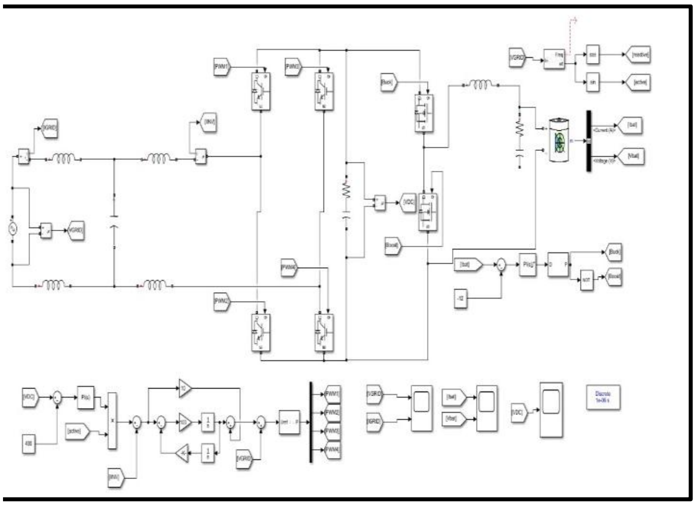


Figure 4. Simulation diagram Bidirectional Converter [1]

International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 03 | March – 2025 DOI: 10.55041/ISJEM02383
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

5.1 Vehicle to Grid operation: -

Vehicle-to-Grid (V2G) technology allows for the bidirectional flow of electricity between electric vehicles (EVs) and the electric grid. In the Grid-to-Vehicle (G2V) mode, when the EV is plugged in, the grid supplies power to charge the EV's battery through a bidirectional AC-DC converter. The charging process typically occurs during low-demand or off-peak hours, optimizing the use of cheaper and abundant energy. Once the EV's battery is charged, it can switch to the Vehicle-to-Grid (V2G) mode, where the battery discharges stored energy back to the grid when the grid requires additional power. During this phase, the bidirectional converter converts DC energy from the EV battery into AC energy suitable for the grid, ensuring that it is synchronized with the grid's voltage and frequency. This also helps maintain the power factor, contributing to grid stability. Additionally, V2G systems allow the EV to act as an uninterrupted power supply (UPS), providing backup energy to homes or buildings during power outages. The system is integrated with smart grid technology, enabling real-time communication and control of energy flow between the grid and the EV, which can be further optimized through time-of-use pricing strategies. V2G technology offers several benefits, including enhanced grid stability, cost savings for EV owners and support for the integration of renewable energy sources, ultimately creating a more resilient and sustainable energy ecosystem.

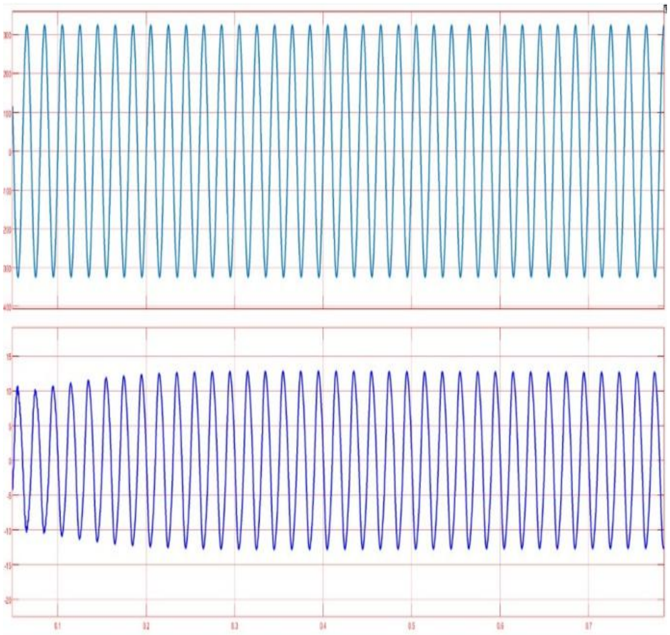


Figure 5. voltage and current V2G mode

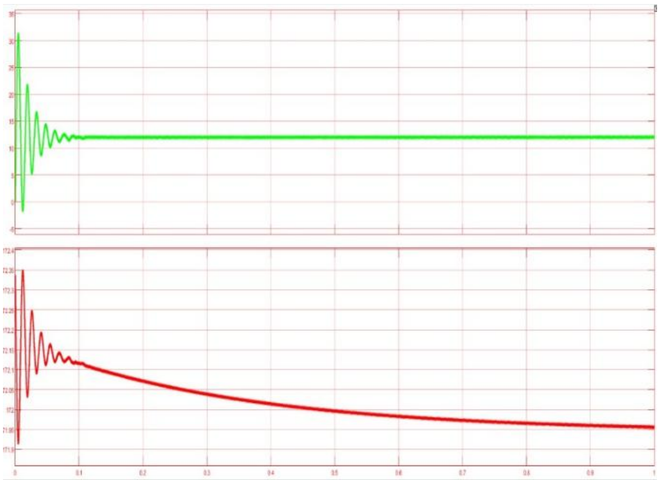
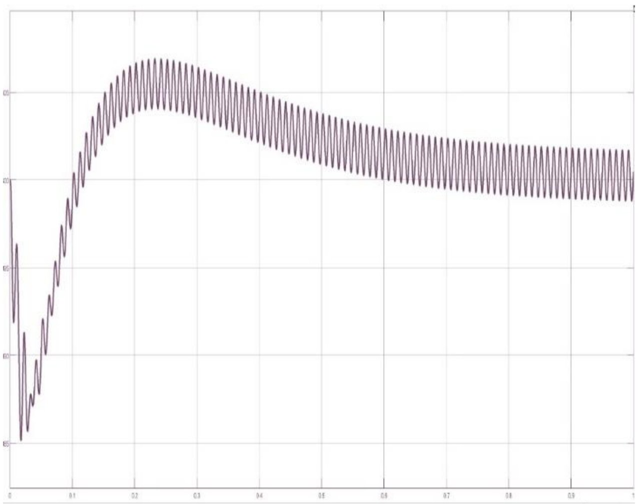


Figure 6. Battery Current and Voltage during V2G mode



International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 03 | March – 2025 DOI: 10.55041/ISJEM02383
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

Figure 7. DC bus voltage during V2G mode

5.2 Grid to Vehicle operation: -

Grid-to-Vehicle (G2V) operation refers to the process where electricity flows from the grid to charge an electric vehicle (EV). When the EV is plugged into a charging station, power is drawn from the electric grid. The electricity supplied by the grid is typically in alternating current (AC), but since the EV's battery requires direct current (DC) for charging, a bidirectional AC-DC converter is used to convert AC to DC. This converter ensures that the voltage and current are appropriately adjusted for safe charging of the battery. The charging process is controlled by an integrated charging management system, which monitors the battery's state of charge and regulates the charging rate to prevent overcharging. In many modern systems, G2V is integrated with smart grid technology, enabling real-time monitoring and communication between the grid and the vehicle. This integration allows for efficient charging based on factors such as grid demand, electricity prices, and renewable energy availability. Additionally, in regions with time-of-use pricing, G2V allows EV owners to charge their vehicles during off-peak hours when electricity prices are lower, providing cost savings while also helping to balance grid demand [1].

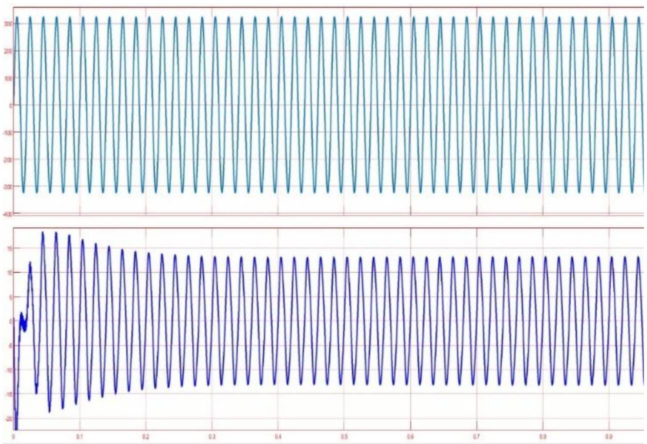


Figure 8. Voltage and current G2V mode

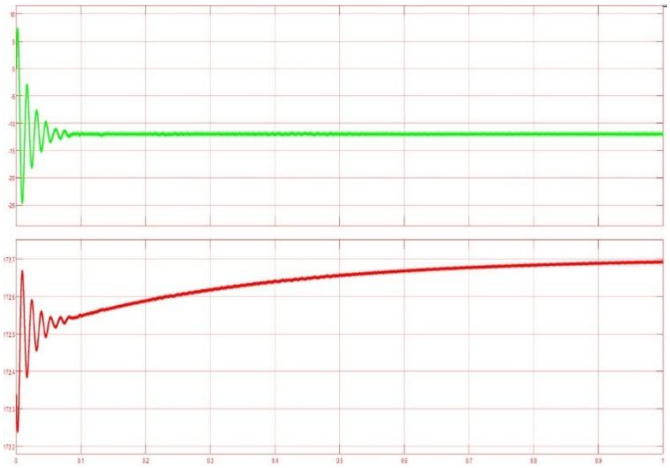


Figure 9. Battery Current and voltage during G2V mode

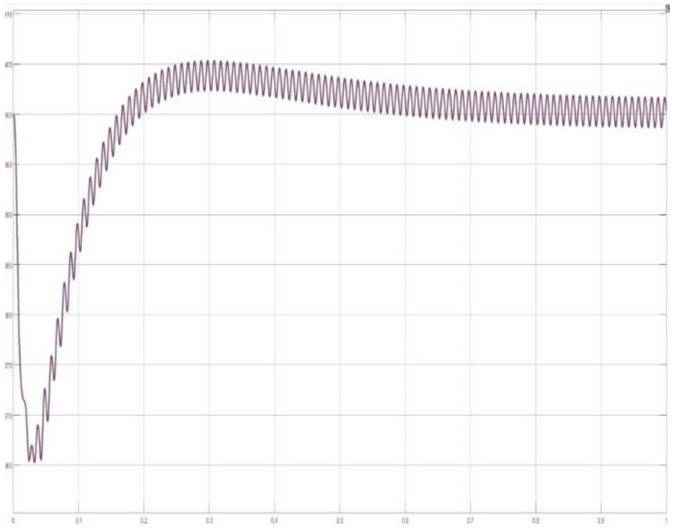


Figure 10. DC Bus voltage during G2V mode

6. Future Scope:-

The benefits of V2G technology for both commercial and residential areas become evident when electricity stored in parked vehicle batteries is utilized where needed. This system helps stabilize electricity demand, reducing the need for additional power generation infrastructure while also minimizing reliance on the grid.

By integrating V2G charging stations, buildings can better manage their electricity consumption, which in turn supports the overall power grid. The potential of this technology grows even further as renewable energy sources become more prominent. Currently, in the absence of V2G integration, reserve power plants serve as the primary backup energy source. This leads to increased electricity costs during peak demand periods, as generating power from these plants is expensive.

In the future, V2G technology is expected to offer economic benefits to energy companies, encouraging them to introduce incentives for consumers to participate. By plugging in their vehicles and allowing their batteries to support the grid, consumers could receive rewards. However, at present, there is a lack of sufficient infrastructure, including compatible technology, equipment, and vehicles. Over time, as adoption increases, consumers who contribute to grid balancing with their vehicle batteries may benefit from financial incentives.

7. Conclusion:-

The Vehicle-to-Grid (V2G) bidirectional power transfer system presents a promising solution to enhance grid stability, energy management, and the integration of renewable energy sources. By allowing electric vehicles (EVs) to both draw and supply power to the grid, V2G systems can significantly alleviate grid pressure during peak demand and contribute to voltage regulation and frequency stabilization. Through the proposed simulation model, it is demonstrated that V2G systems can successfully manage power flow, reduce harmonic distortion, and support grid operations efficiently.

The results further show that V2G systems can provide a flexible and sustainable energy resource, not only benefiting the grid but also offering economic advantages to EV owners through compensation for power supplied back to the grid. This creates a mutually beneficial relationship between EV owners, grid operators and energy consumers, supporting the transition toward a more resilient and sustainable energy infrastructure.

Ultimately, the integration of V2G technology holds the potential to be a key enabler for smart grids and a future-proof solution to energy storage and management challenges. As renewable energy sources continue to proliferate, V2G systems could play a crucial role in balancing supply and demand, reducing reliance on conventional power plants, and enhancing the efficiency of the overall energy system.

References: -

1] Akanksha Yadagiri1, Mahendar Meadari,” “Design and Development of Bidirectional Converter based on V2G and G2V Operation” E3S Web of Conferences547, ICSGET 2024

2] Narsa Reddy Tummuru“A Single Stage Bidirectional Wireless Power Transfer for Multiple Vehicle Charging Application” 2020 IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy (PESGRE2020).

3] Shi Rui, Chi Zhong “Bidirectional Power Transfer Control Based on V2G concept” Beijing Electric Power Research Institute Beijing Electric Power Company, State Grid Cooperation of China Beijing, China.

4] Hal Turton , Filipe Moura, “Vehicle-to-grid systems for sustainable development: An integrated energy analysis” Energy Economics Group, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland b Instituto Superior Técnico, Technical University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal, received in revised form 18 November 2007; accepted 22 November 2007

5] Shaila Boga, Vishal Pimpalkar, “VEHICLE TO GRID (V2G) & GRID TO VEHICLE (G2V) TECHNOLOGY USING DC FAST CHARGING ARCHITECTURE” © 2022 JETIR June 2022, Volume 9, Issue 6.

6] Mamatha N, Arpita Banik, “A Study on Vehicle to Grid Technology and its Scope” International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 1 (2019) pp. 8-13.

7] Bakul Vani, Devyani Chaturvedi, “Grid Management through Vehicle-To-Grid

Technology” International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878(Online), Volume-10 Issue-2, July 2021.

8]Suresh Panchanathan, “A comprehensive Review of The Bidirectional Converter Topologies For The Vehicle to Grid System”Energies2023,16,2503.https;//doi.org/10. 3390/en16052503

9] Bharat Vardani, Narsa Reddy Tummuru, “A Single Stage Bidirectional Wireless Power Transfer for Multiple Vehicle Charging Application” 2020 IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy (PESGRE2020).