Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 7s (2025)

# Capability of Reactive Power Compensation of Vehicle-to-Grid (V2G) Technology using off-board EV Battery Charger

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***Article History:***

***Received:** 26-10-2024*

***Revised:**10-11-2024*

***Accepted:**18-12-2024*

**Abstract:**
This study investigates the potential for V2G in reactive power compensation, one of its lesser-known capabilities. With a focus on V2G-enabled electric vehicles, the research explores using an off-board EV battery charger, connected to the grid, to supplement or replace power transmission for RPC. It presents a control strategy for EV chargers, based on the analysis of nonlinear residential load currents and PCC voltages, to align voltage patterns and predict active load current components. At the system's core is a three-phase bidirectional inverter and a DC/DC bidirectional converter, interconnected through a DC link. Simulation results confirm the method's effectiveness, which involves modifying the control algorithm and power stage for efficient RPC. Additionally, a 20 kVA off-board charger simulation model was developed in MATLAB/Simulink to validate the proposed control strategy for Grid-to-Vehicle (G2V), V2G, and RPC operations. The proposed framework optimizes power flow and improves grid stability, power quality, and efficiency through V2G technology. Advanced control techniques, such as dynamic charging profiles during charging, minimize reactive power losses and extend battery life, making the grid more reliable and efficient. The charger control methodology adheres to the latest IEEE Standard 1459-2010.

**Keywords**: Reactive Power, Electric Vehicle, Electrical Vehicle (EV) Battery Charger, Reactive Power Compensation, Grid Stability

## 1. Introduction

Electrical vehicle is one of the critical factors that will impact the future development of smart grids. Since most electric vehicles require less than 80% of their battery capacity for daily uses, and automobiles are seldom used for up to 95% of their lifespan, there is untapped potential to leverage stored power through grid integration. Vehicle-to-grid (V2G) applications, enabling bidirectional power transmission between the grid and Plug-in Electric Vehicle (PEV) batteries, exemplify this concept. [1], [2], [3]. The main auxiliary services like voltage regulation, frequency matching are made easier by the V2G for the grid balancing [4], [5].

In order to support the grid, this research presents a unique control technique for injecting reactive power. It investigated the operation of V2G under balanced voltage decreases in a grid. MATLAB software Simulink is used to develop and test the new approach [6]. Chargers with such designs may operate in several modes because they allow electricity to flow both inward and outward. EV batteries may contribute to grid stabilization because of their high energy content. For more than a decade, research has been conducted on the idea of transferring electricity from automobiles back to the grid, or V2G [7], [8].

The off-board fast-charging infrastructure of EVs is a major factor in their high adoption rate. The charging stations, which may act both vehicle-to-grid and grid-to-vehicle, provide excellent opportunities for grid integration since energy is stored onboard in the form of batteries. Other tactical measures must be taken, too, because there are ongoing worries regarding battery deterioration when using V2G mode. These include chargers that may provide auxiliary services like reactive power compensation, voltage control, and grid harmonic adjustment all without using any energy from the EV batteries directly. This helps to prolong the life of EV batteries [9].

With the increasing popularity of electric vehicles and renewable energy sources in recent years, the usage of electronically powered converters, such as electronics converters, has become crucial in distribution networks. Based on battery power references, the paper presents a sophisticated EV battery charger architecture that combines active power control and reactive power correction. Several reactive power scenarios are examined to guarantee appropriate power flow control. The program incorporates safety measures like reactive current saturation to maintain system stability [10].

According to SAE Standard J2894 [12] and Building on the EPRI Recommended Practice TR-109023 [11], the quality of voltage and current during vehicle charging is specified. The recharge time of EV batteries, which is dependent on the energy capacity of the battery pack and the charger's available power, is another crucial factor to take into account while building charging equipment. In order to facilitate effective power flow between the battery and the grid, the chargers are made to sustain three-phase voltages in the grid with steady three-phase power supply. This article presents an off-board three-phase battery charger that was created especially for smart grid applications. It has a new control method that enables it to perform dual functions, like charging EV batteries and sending power back to the grid (G2V and V2G). The suggested technique allows the battery to either discharge back to the grid during times of high energy consumption or charge from the grid for instant usage when the vehicle is parked.

Power quality is a crucial component of the EV battery charging system in addition to the controlled integration of EVs into power networks [13]. In this case, the AC current needs to be sinusoidal and in phase with the grid voltage in order to maintain the proper power factor [14]. The integration indicates that future smart grids would depend heavily on electric transportation [15].

A multitude of global smart grid initiatives are underway, one of which is investigating DC distribution in power systems [16]. The idea of smart houses with effective energy management systems is also gaining traction with the development of smart grids [17]. Smart EV battery chargers are crucial in this situation to maximize charging efficiency and compatibility with home energy control systems.

Fig.1 shows the setup of three-phase Bidirectional Battery Charger (BBC). This consists of a simple five-stage process, namely connection control that carries out the control on the battery power. The other is AC to DC Converter, which converts the AC power into DC to feed the input to the Buck-Boost and DC/DC Converter, which again converts the DC power into DC power. Then comes the battery switching control, which we can make use of for switching.

V2G is of two classes: unidirectional and bidirectional. The power grid in unidirectional V2G is supported by EVs that charge at different rates; however, energy from the battery does not go back to the grid. Bidirectional V2G can charge and discharge at different speeds; this enables the energy flow from the batteries back to the grid. The schedule for charging an EV has already been optimized for both types of V2G [22].

Various objectives for V2G optimization have been investigated. As an example in [23], the goal was to save expenses in solar-powered parking lots by figuring out the optimal charging rates every 30 minutes. In an effort to diminish energy losses and enhance voltage stability in the power supply, different research [24] employed an algorithm to plan EV charging on an hourly basis. A more intricate optimization technique was employed in [25] to optimize the EV charging schedule every hour in order to reduce the power system's running expenses.

Most of these optimization problems are generally focused on the quantity of active power that will flow between electric vehicle batteries and the grid, sometimes at the expense of neglecting the role that reactive power may play in stabilizing the grid, which electric vehicle chargers can also provide [26], [27], [28].

**Figure 1: Three-Phase Bi-directional Battery Charger**

## 2. Role of V2G Reactive Power in Enhancing Grid Stability

Mojdehi et al. [18] proposes an EV charger that is capable of providing reactive power compensation to the grid. However, this requires controlling the DC link voltage with EV batteries to maintain the compensation, which shortens its life by increased cycles of charging/discharging. Furthermore, research has ignored reactive power compensation when any charger operates simultaneously in G2V mode as well as in V2G mode. Buja et al. [19] and Abeywardana et al. [20] also utilize the charger for meeting the grid's reactive power demand, while using EV batteries to control the DC connection voltage can be done at the risk of degraded performance and lifetime. In [21], the author presents the multipurpose EV battery charger with reactive power correction capability. In this work, charging capability operating with several modes simultaneously is not considered; thus, there is still a lot of potential left in this area.

Power system stability is defined as the ability of a power system to return to its normal operation following a disturbance. The stability of a smart grid is significantly affected by power outages. Electric vehicles can potentially give rise to a host of stability issues in the power network due to their nonlinear demand nature. The use of power electronic devices like inverters and DC-DC converters in EVs has the potential to degrade power quality, thus affecting the grid.

Additionally, it is challenging to forecast load behaviour in the smart grid due to uncertainty surrounding EV charging durations, power ratings, and connection locations. Consequently, there are serious issues with EVs being widely connected to the grid [29]. EVs are nothing but it is just an energy storage device; in other way we can say that they are also behaves like a power electronic device and dynamic loads that affect the power system's stability [30]. Table 1 summarizes the implications of

EVs on stability in smart grids. For example, when the system is overloaded due to any reason the demand of reactive power is not satisfied , voltage instability may arise. Voltage stability in smart grids depends on EVs being planned and operated properly [31]. It is well recognized that the features of electric vehicle loads can cause voltage instability, particularly when EVs use more energy at low voltages, which further compromises system stability [32]. To lessen these issues, it is important to carefully plan the optimal numbers, locations, and power ratings for EV charging stations in line with the network architecture [33].

**Table- I Effect on Power System Stability of EV**

| Impact | Reason |
|---|---|
| On Voltage [32] | Depending on where, how many, and what kind of EV charging stations and EVs are linked as loads |
| On Frequency [34] | Due to variations in the supply and demand of power |

### 2.1 Power Loss

The term power losses describes the instantaneous loss of energy inside the system, and when several EVs are linked to the smart grid, it can drastically lower the system efficiency. A large amount of active power is required for the integration of several EVs, which may have an adverse effect on electrical energy performance. While the charging of EVs normally increases off-peak power losses, it can result in substantial enhancements of the loss and voltage variance owing to inadequate EV charging [35].

The extra power demand from several EVs linked to the smart grid may put stress on the current system, possibly overloading some parts and reducing transformer life[36]. Various technologies were developed to remedy the impact of the EVs' effect on the smart grid. Active coordinated charging significantly reduces power losses by increasing the load factor. Appropriate site choice and capacity of energy storage stations will give energy loss mitigation. The integration of automobiles into the grid may be effectively managed to improve power system stability in a smart grid. Combining home energy production with charging infrastructure, such as through the use of sustainable energy resources, is one practical strategy to lessen the impact of EVs[37].

### 2.2 Off / On Board Framework

There are two ways to set up an electric vehicle's charging system: within the vehicle (on-board) or off-board at a public place such as a mall, hospital, or university [38]. Using control techniques and PWM signals, the on-board charger enables the EV to charge or discharge anyplace there is an electric socket accessible [39], [40].

Flexible in nature, on-board solutions offer a number of benefits, including low power consumption, low heat output, compact size, and steady DC bus voltage maintenance. Because they draw a steady, sinusoidal current that lowers low-frequency harmonics, these systems are "grid-friendly". They do, however, increase the weight of the EV, which may have an impact on its overall performance, range, acceleration, and speed. This means that high-power charging, which likewise takes longer (6–8 hours) and is usually appropriate for lesser power demands (under 20 kW), is not a good fit for on-board systems. Single-stage PWM converters are frequently utilized in place of two-stage converters in order to maintain the system's efficiency and compactness [41], [42].

However, because they don't require any space and can provide reactive power from a fixed location, off-board solutions work better for high-power charging. These systems are appropriate for greater power requirements (20 to 400 kW) and commercial use since they employ fast-changing technology (less than 30 minutes). Off-boarding devices give an extended driving range, enable quicker charging, and lessen the weight on the EV. Off-board, DC rapid charging is typically linked to DC renewable energy sources [43].

Off-boarding solutions, however, restrict EV owners' flexibility because charging is only possible at designated stations. Additionally, by resulting in voltage distortion, higher power loads, power losses, and current harmonics, they may have a detrimental effect on the grid [44].

## 3. Modelling of System

The proposed setup implements an off-board EV battery charger that can support V2G to provide RPC and maintain grid stability. The proposed system can allow power flow in both G2V and V2G modes using a three-phase bidirectional inverter together with a DC/DC bidirectional converter. The voltage pattern in the best RPC can be generated using a synchronizing-based control approach when nonlinear residential loads are present. This topology provides for dynamic charging profiles that adapt according to the nature of the batteries, reducing the dissipation of reactive power and enhancing battery life. Voltage regulation algorithms also ensure a stable operation at maximum power flow for maintaining grid stability during any disturbance.

As shown in Figure 1, the system under description is made up of:

a. Connection Control
b. AC-DC Converter
c. Buck-Boost Converter
d. Battery Switching Control

### 3.1 Connection Control

To improve the effectiveness and dependability of any EV charging system, the suggested charger controller provides a number of cutting-edge capabilities. The Vehicle for Grid (V4G) mode, which makes reactive power adjustment easier in both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) modes, is one of its special features. Because it permits reactive power adjustment even when the EV is neither charging or discharging, the V4G mode is especially beneficial in preserving grid stability without depleting the vehicle's battery. The connection control flowchart for this suggested model is shown in Figure 2.

Galvanic isolation, which electrically separates the input and output circuits, is a crucial component of the charger's design. By avoiding electrical failures, surges, and interference, this in turn greatly improves safety and increases the charger's dependability in intricate electrical situations. Additionally, the controller functions at unity power factor (UPF) by making sure that the current used while charging is always in phase with the voltage. This minimizes energy losses, guarantees optimal efficiency, and stops needless reactive power generation.

A feedback loop with direct power control is another feature of the control system that enables real-time power flow modifications. Maintaining grid stability requires this prompt reaction, particularly when power demands are changing due to renewable energy sources. The connection control box is another crucial component of the EV wall charger. It guarantees that the EV and the grid have a secure and dependable connection. Secure connections are indirectly made possible by parts like contactors, safety features, and communication interfaces; the connection control box itself does not manage reactive power.

Other features that the connection control box could have include V2G functionality for bidirectional power flow and smart meter integration for tracking and reporting energy use. These characteristics enhance the charger's overall performance and versatility, making it more appropriate for the demands of contemporary grid management.

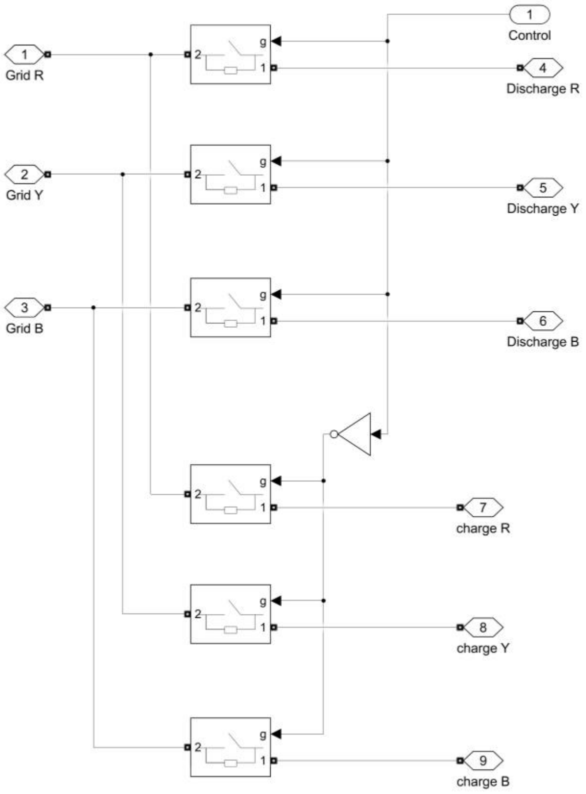

Figure 2: Connection Box

### 3.2 AC-DC / DC-AC Converter

The AC to DC converter's Simulink configuration, which includes parts like the transformer, control system, and measurement units, is shown in Figure 3. The converter will play a key part in managing reactive power, which is essential to the grid's effective operation. To charge the EV's batteries, this grid-sourced AC electricity will be transformed into DC. Additionally, it facilitates bidirectional power flow, which allows electricity to move from the grid to the EV during G2V charging and back to the grid during V2G operations. The system effectively manages reactive power while charging the EV from the grid in its primary role as an AC-DC converter. Even when reactive power is useless, maintaining the voltage levels needed for electrical equipment to operate correctly is still essential. Ineffective reactive power management can cause grid instability and inefficiency.

The converter employs methods including Active Power Factor Correction (APFC), a more sophisticated and effective technology, and passive filtering, which removes undesired harmonic distortions from the current waveform. Active PFC increases energy efficiency and lowers reactive power required from the grid by reshaping the current waveform to closely resemble the grid's voltage waveform. It would put more strain on the grid, use more reactive power, and have a worse power factor without PFC. The converter functions as a DC-AC converter while in V2G mode, allowing an EV to provide power back to the grid. When necessary to ensure grid stability, the converter may inject or absorb reactive power into or out of the system in addition to the flow of electricity. This can be helpful for managing and sustaining a certain voltage level while running high-demand networks, especially ones with variable renewable generation supplies.

Reactive power control efficiency is determined by converter design and control systems. High efficiency converters conserve energy and generate less reactive power because they have little power loss during conversion. By managing variations in the demand or voltage situation, the converter control algorithm can function effectively. Reactive power usage during battery charging is reduced by the use of passive filtering and active power factor adjustment. In V2G mode, it has the ability to actively inject or absorb reactive power. The converter's efficient design and configuration control might help stabilize the grid even more. As a result, the grid's reactive power demands are reduced, making the entire power system more reliable and effective.

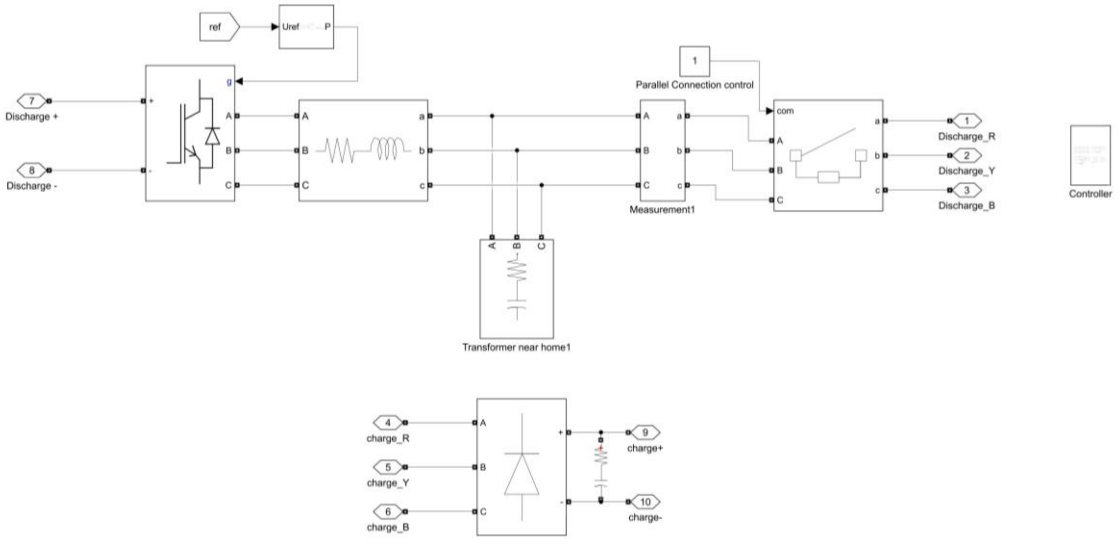

**Figure 3: AC-DC Converter**

### 3.3 Buck-Boost Converter

One essential part of an EV charger that subtly aids in reactive power control in the charging system is the buck-boost converter. Its main purpose is to control the DC voltage that is sent to the battery. It is situated in the circuit of the charger after the AC-DC converter. By either raising (boosting) or lowering (bucking) the DC voltage as necessary, it guarantees that the battery receives a steady and suitable voltage for charging. Because it guarantees that the right voltage levels are maintained for safe and effective charging, this is especially important for EVs with high-voltage battery packs [45]-[47].

Although it does not directly handle reactive power, the buck-boost converter indirectly aids reactive power management by guaranteeing the battery receives consistent power, as seen in Figure 4. Energy that helps maintain grid voltage levels but does no beneficial work is referred to as reactive power. When the DC voltage is stabilized, the grid's demand power oscillates less and doesn't fluctuate in relation to reactive power. Although power factor and reactive power cannot be controlled since it is a buck-boost converter, the converter lessens the effects of these variations on the grid.

The efficiency of the buck-boost converter is among its most significant advantages. It guarantees that the majority of the power taken from the grid will be used effectively to charge the EV's battery and reduces energy losses when the voltage has to be controlled. Reactive power and other unnecessary power use are decreased, which helps prevent an unstable and unreliable grid. Furthermore, power flow and efficiency may be further optimized by integrating the buck-boost converter with the charger's overall control system. The buck-boost converter assists in balancing the power flow between the EV and the grid by cooperating with the AC-DC converter and control algorithms.

Although it does not directly regulate reactive power or power factor, the buck-boost converter is essential to a seamless and effective charging process. Accurately controlling the battery's DC voltage indirectly improves reactive power management, which raises the system's stability and effectiveness. In the end, this improves the grid's efficiency and the EV charging system's dependability.

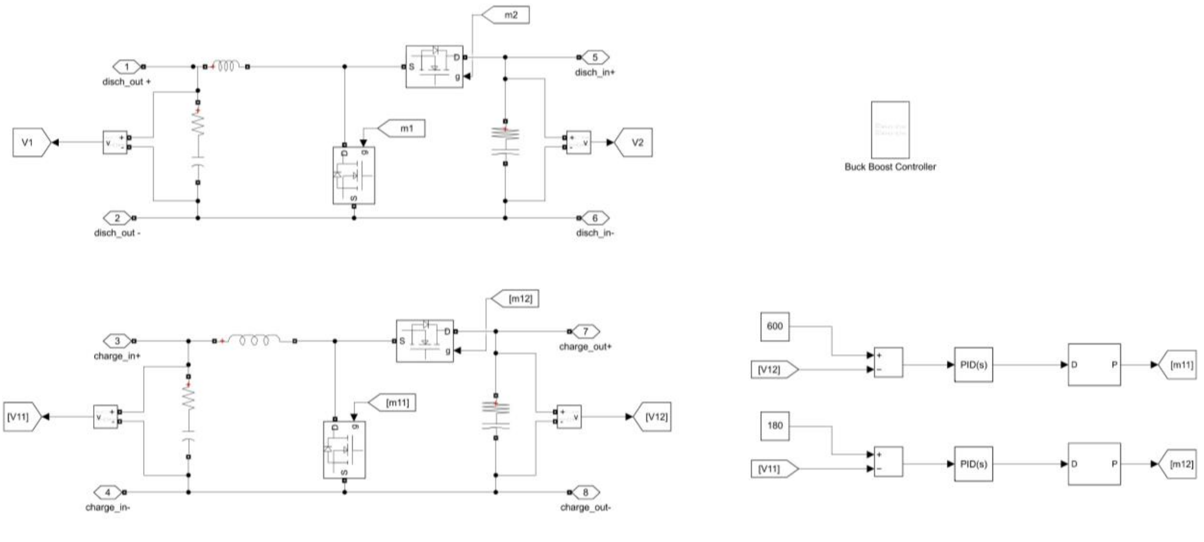

**Figure 4: Buck-Boost Converter**

### 3.4 Battery Voltage Regulation Using DC-DC Converter

The DC-DC converter, which is shown in Figure 5 together with a battery controller, is an essential part of an EV charger. The power grid's stability is further guaranteed by this design, which guarantees safe and effective charging with low reactive power usage. The main purpose of the DC-DC converter is to modify the DC voltage from the AC-DC side or a buck-boost converter's side so that it may be used to charge the EV's battery. However, the operation needs to be done with positive accuracy so that the voltage and current supplied match the battery's in order to prevent any harm while charging. The battery controller works with the DC-DC converter to improve the charging process based on real-time data while keeping an eye on vital battery metrics including health and state of charge (SOC).

This system's ability to optimize the charging profile is one of its main advantages. For example, the system can prioritize quicker charging to cut down on charging time when the battery's state of charge (SOC) is low. To avoid overcharging and prolong battery life, the system progressively reduces the charging rate as the battery gets closer to full capacity. In addition to stabilizing grid power demand, this steady adjustment lessens swings that may result in reactive power problems. Consistent electricity demand lowers system stress and increases grid efficiency.

The other crucial component of the battery controller is safety. Preventing possible problems that might harm the battery or present safety risks is made easier with protection against damage like overcharge or excessive current. In this manner, the charging process is regulated and a sudden power fluctuation that might cause grid issues or reactive power changes is also reduced. The DC-DC converter's efficiency is another crucial factor. With high-efficiency converters, the majority of the energy that is collected from the grid is contributed to charge a battery rather than being wasted as heat during the conversion process. By lowering part of the reactive power consumed on the grids, all of this increases efficiency and creates a system that is well-balanced.

Additionally, better charging is facilitated by efficient communication between the battery controller and DC-DC converter. In order to improve charging procedures, it promptly modifies a battery's state of charge while making pertinent real-time judgments about the grid's power supply requirements. Through effective reactive power control, such optimization contributes to greater energy savings. The battery controller and DC-DC converter work together to minimize the adverse effects of reactive power on the grid while ensuring that power is provided to the battery safely and effectively. This configuration improves the EV charger's overall performance and strengthens grid stability.

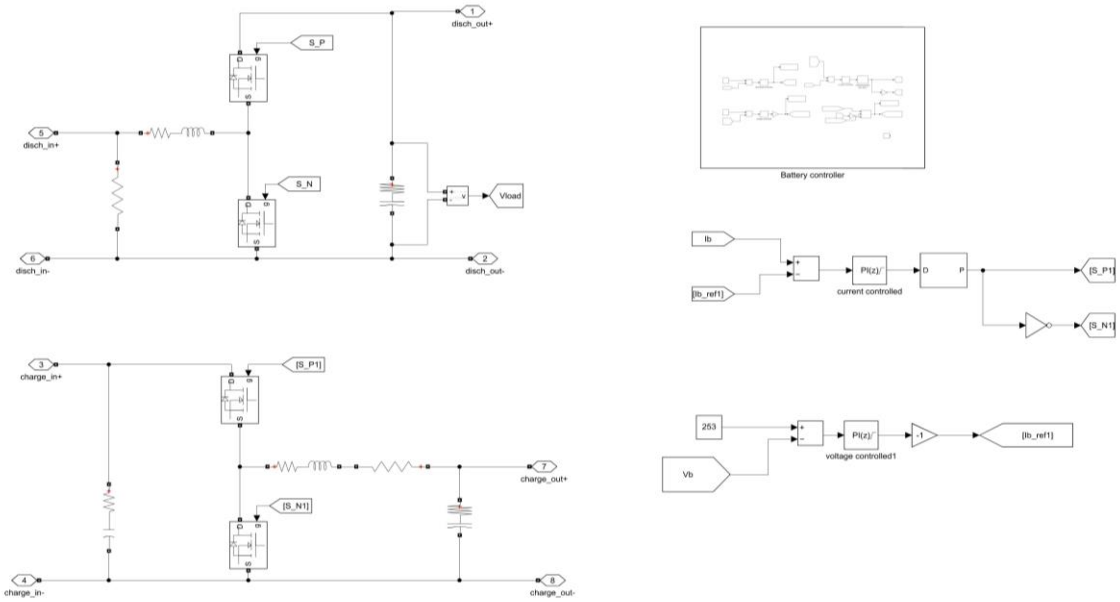

**Figure 5: DC to DC Converter with Battery Controller**

### 3.5 Battery Switching Control

One of the primary functions of the EV battery charger is the control of the battery switching. The main purpose of this switching is to maintain the power flow either from V2G or from G2V. This system is designed to manage how batteries are connected and used during charging. While it plays a key role in organizing the charging process, it has minimal direct impact on managing reactive power, which is the type of electricity needed to maintain stable voltage levels in the power grid but doesn’t perform useful work. This is due to the fact that battery switching management does not directly affect reactive power; instead, its main goals are to improve the charging system's availability, efficiency, and safety.

When several battery or modular battery designs are employed, the primary purpose of battery switching control is to oversee the selection and connecting of battery packs. For instance, several battery packs may be able to be chosen or replaced in certain EV models or sophisticated charging systems in order to maximize performance, extend battery life, or satisfy particular operating requirements. This feature is very helpful for fulfil the objective to improve the charging system's overall efficiency and guarantee safe operation which is maintained by ensuring that the right battery pack is always being charged or drained.

Switching between batteries doesn’t directly affect reactive power, but in some cases, it can have an indirect impact. As they consume or produce the amount of the reactive power their initial aging characteristic is change. In these situations, the battery switching management system may be set up to select batteries with the lowest reactive power, increasing grid efficiency and stability. This method considers the battery's age and other factors, as well as the necessity of efficiently controlling reactive power.

In the future, if improved BMS systems are integrated into the switching system, Battery Switching Control (BSC) might play a more advanced role in reactive power management by greatly improving. This implies that the switching mechanism chooses the best battery to utilize at any given moment. These BMS systems will offer comprehensive data on each battery's performance, allowing data-driven choices to maximize charging efficiency and safety in addition to reactive power. Furthermore, as part of a broader plan, battery switching control could also be more important in reactive power management. For example, the technology can assist with grid stabilization by utilizing G2V capabilities, which allow energy to move both ways between the grid and the vehicle. Battery switching control now plays a small part in reactive power management, but this position might grow in the future. Better technology and data access can increase the importance of these controls in making chargers more efficient and the grid stable.

## 4. Proposed Control Strategy

Optimizing EV charging is the proposed project's control strategy, which aims to reduce reactive power variations and enhance grid stability. The plan includes a number of elements aimed at improving the charging system's dependability, safety, and efficiency.

Flexible charging profiles that adapt in real time to changes in battery characteristics, such as the state of charge (SOC) set at 60%, are a component of the method. Based on this information, the system modifies the charging pattern and rate to meet the battery's current requirements. By reducing abrupt variations in reactive power while charging, this method guarantees a more steady and seamless charging experience. To precisely control the charging voltage in accordance with the battery's requirements, sophisticated voltage regulation algorithms are used. This guarantees that the battery won't be overloaded or exposed to excessive voltage. By maintaining proper voltage levels, the system reduces reactive power losses, enhancing charging effectiveness and safeguarding the battery. Intelligent battery selection and switching control are key components of the method. Based on factors including battery performance, age, and reactive power characteristics, the system maximizes battery utilization during charging. In order to lessen its impact on the grid and increase overall efficiency, it dynamically chooses the battery that uses the least reactive power. Adaptive control algorithms allow the system to react in real time to variations in load demands and grid circumstances. In order to maintain the system's flexibility and resilience, these algorithms dynamically modify the charging settings. Better reactive power management is made possible by the adaptive method in a variety of operational circumstances, such as when renewable energy is integrated or grid demand fluctuates. Reactive power management is improved with the integration of Vehicle-to-Grid (V2G) capability and Advanced Battery Management Systems (BMS). Real-time battery health and performance data is provided by the BMS, and bidirectional energy flow between the EV and the grid is made possible by V2G capabilities. When combined, these characteristics enable the system to maximize battery selection and charging tactics while promoting grid efficiency and stability. Figure 6 illustrates grid voltage and current value for complete simulation which is 0 second to 0.5 seconds. The vehicle-to-grid functioning by displaying the grid voltage and current for 0.2 to 0.4 seconds, which show the constant or fixed voltage of the grid maintain 400V. Similarly, the figure 7 shows the inverter voltage and current for the same period of time for V2G operation. This operating simulation demonstrates that the grid supplies active and reactive power from 0 second to 0.2 seconds because we use (Reactive load) for the value of 1kV active 2kV Reactive load. Whereas after connecting the EV battery the inverter is working at 0.2 second and load is shared by the inverter or EV battery to support the grid or we can say that it compensate the demand of reactive power till it is operated which is 0.4 seconds. The graph in figure 8 clearly shows the reactive power compensation under vehicle-to-grid operating mode. Figure 8 shows two graphs in one window where the upper parts shows the active power of grid and EV battery and bottom part shows the reactive power of grid and EV battery.

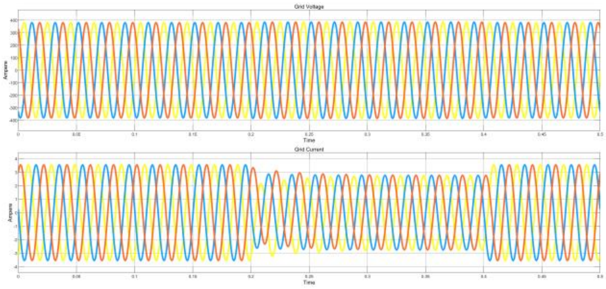

**Figure 6: Voltage and Current of Grid**

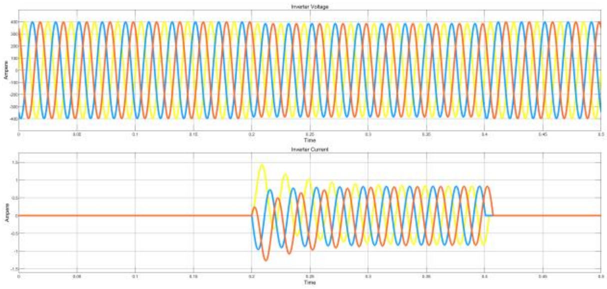

**Figure 7: Inverter Voltage and Current**

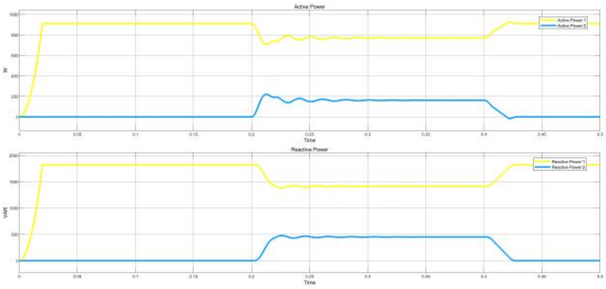

**Figure 8: Active and Reactive Power of Grid and Voltage**

## 5. Simulations and Results

The graph below shows how the wall charger connection box works with the battery, focusing on three main factors: state of charge (SOC), current, and voltage. These factors help explain how the charging process works and how efficient it is. Figure 9 presents three signals: grid voltage vs. time, inverter voltage vs. time, and a combined signal. The x-axis represents discrete time, while the y-axis shows values for SOC, current, and voltage while table II represents the system parameters.

**Table- II Parameters of proposed model**

| **Parameters** | **Values** |
|---|---|
| Grid Phase to Ground voltage | 400 V |
| Grid frequency | 50 Hz |
| X/R ratio | 7 |
| 3-Phase RLC Load | 380 V |
| Active Power | 1 kV |
| Grid side inductor | 1.3 mH 0.004 Ω |
| Switching Frequency | 4950 |
| Battery side inductor | 57.6 mH 0.05 Ω |
| Battery Capacity | 350V, 55 Ah |

The SOC is shown as a line graph, tracking how the battery's charge level increases over time. At the start of charging, the SOC is low, but it steadily rises as energy flows into the battery. This shows that energy is being transferred effectively from the charger to the battery. Eventually, the SOC reaches 100% of 80, indicating a fully charged battery. This smooth increase highlights the charger's ability to deliver energy in a controlled and efficient way. Because the battery absorbs energy fast, the charging current is strong at the start of the charging process. We refer to this as the bulk charging phase. In what is known as the constant voltage phase, the current will progressively decrease as the battery approaches full capacity. This tapering helps safeguard the battery's health by preventing overcharging. The temperature of the battery or modifications made by the charger's voltage regulating mechanism may cause slight changes in current. All of them contribute to the charger's flexible charging capabilities. A line graph showing the battery's supply voltage shows how steady and reliable the charging voltage is over time. For effective charging and to avoid overvoltage, which might damage the battery, a controlled voltage must be maintained. The voltage stays within a certain range during the charging process, showing that the charger can regulate the voltage to meet the battery's needs. The graph demonstrates how the wall charger connection box effectively controls the state of charge, ensuring that the battery is charged safely, effectively, and dependably by maintaining the proper current and voltage.

The power quality of an electrical system is improved in this scenario if an EV that is plugged in but not configured for G2V or V2G operation may use a charger since its sole operational converter in this mode will be AC-DC, with no energy exchanged between the battery and the EV and the grid. By addressing problems like reactive power and current harmonics, this functionality enables the EV to provide grid power quality. In G2V mode, active power flows from the grid to the charger to charge the EV battery. The charging power depends on the battery type and the charging mode. In V2G mode, the EV battery discharges energy back into the grid to provide active power support. The charger operates in slow, medium, or fast discharging modes based on commands from the power utility. Additionally, the battery’s State of Charge (SOC) and State of Health (SOH) are critical during V2G operations.

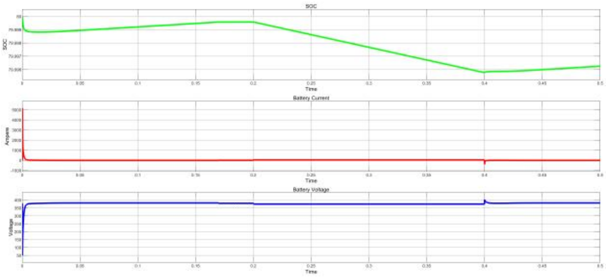

**Figure 9: Battery Result (a) SOC v/s Time (b) Current v/s Time (c) Voltage v/s Time**

## 6. Conclusion

To achieve the best reactive power compensation, a control approach synchronizes voltage patterns and handles nonlinear residential or reactive loads. The structure integrates dynamic charging profiles that adjust according to battery characteristics, diminishing reactive power dissipation and prolonging battery longevity. The multifaceted nature of reactive power management within EV charging infrastructure, emphasizing the diverse components and their varying degrees of influence. While certain elements such as the DC-AC/AC-DC converter and the DC-DC converter with battery controller directly impact reactive power management through voltage regulation and charging profile optimization, others like battery switching control play a more supportive role, focusing primarily on efficiency, availability, and safety. However, even components with limited direct impact can become relevant in specific configurations or with advancements in battery data management. Moreover, future developments such as advanced Battery Management Systems (BMS) and Grid-to-Vehicle (G2V) functionality hold promise for further integrating reactive power considerations into EV charging infrastructure. Thus, while the current landscape may present varying levels of involvement in reactive power management, ongoing advancements and system refinements suggest a potential for broader and more comprehensive approaches in the future, ultimately contributing to enhanced efficiency and grid stability in the electrified transportation sector.

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