Microgrid Integration with Electric Vehicle Charging

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***Abstract*—As per a report from Electric Vehicle (EV) Volumes [1], the transportation sector accounts for approximately 27.2 percent of total emissions in the United States, which is driving growth in the EV sector. Recognizing the increasing demand for EVs, it becomes evident that an expanded charging infrastructure network is essential to meet energy demands. To fully harness the potential of EVs as sustainable transportation, integrating EV charging systems with renewable sources is imperative. Consequently, there is a growing global momentum towards adopting microgrid integration for EV charging. However, this presents significant challenges and opportunities for power system stability, which must be addressed. Numerous studies have explored the integration of renewable sources such as solar photovoltaic (PV), wind, geothermal, and hydropower, replacing conventional generators. Our project focuses on the design of a microgrid that integrates solar energy with EV charging stations. Microgrids are localized energy systems that can operate independently or in conjunction with the main power grid, facilitating power flow management among interconnected sources and loads. To integrate EV charging stations within microgrids, a more reliable and efficient control mechanism is required. To ensure stability and reliability, we studied various literatures for the selection of inverters, converters, and batteries, and implemented control strategies to improve overall system performance. Throughout the project, we assessed various modes of operations such as Vehicle-to-Grid (V2G), Grid-to-Vehicle (G2V), and PV incorporation modes for a lithium-ion battery. The circuit will be simulated using Matlab Simulink software to evaluate and verify the outcomes like battery voltage and current, grid voltage and current, and state-of-charge (SOC); generating plots for different modes of operation.**

Keywords: Microgrid, Solar Photovoltaic, Inverters, Converters, Lithium-ion battery, Vehicle-to-Grid, Grid-to-Vehicle, State-of-Charge

I. Introduction

Historically, electrical grids were typically relying on synchronous generators driven by fossil fuels to maintain mechanical inertia. These systems serve as backup measures to address unforeseen events and natural disasters [2]. In recent years, there has been a global surge in efforts toward decarbonization, with numerous countries entering agreements to reduce carbon emissions. The journey toward achieving 100 percent renewable energy in electrical grids is shaped by technological challenges and emerging solutions. The renewable energy sources are connected to the grid through inverters but can weaken the grid inertia thereby impacting the system stability.

The rising adoption of electric vehicles (EVs) presents both substantial challenges and opportunities for the power system. Through the effective design of power converters and controllers, maintaining a stable voltage can be achieved. Additionally, ensuring frequency synchronization and proficient power flow management is crucial for enhancing dynamic stability during the transition from grid-connected to islanded mode.

Our project delves deeply into EV charging, specifically exploring V2G and G2V modes, while integrating with a solar PV module. The circuit initiates with a front-end converter, acting as an active rectifier, which converts AC grid voltage to DC while maintaining a steady voltage across the DC bus. Additionally, a bi-directional buck-boost converter is employed to regulate battery current during charging and discharging processes. Voltage and current controllers are developed for the EV charger simulation, executed with discrete settings and a sampling time of 1e-6 seconds. The solver type is configured as orde23t with a simulation duration of 1 second. The simulation results depict the system operating in V2G mode, showcasing voltage and current out of phase, along with battery voltage and current during V2G mode, maintaining a battery current of 12 amps and a regulated DC bus voltage of 400 volts. Transitioning the system to G2V mode involves reversing the polarity of the current reference, aligning the voltage and current in phase. The simulation then demonstrates the system operating in G2V mode, displaying battery voltage and current with reversed polarity and a regulated DC bus voltage of 400 volts.

II. V2G and G2V Power Transfer Operation

The AC-DC converter and DC-DC converter are important elements for a bidirectional EV charger. An AC-DC bidirectional converter converts AC to DC during EV charging mode. During EV discharging mode, the AC-DC converter converts the DC of the battery to AC and supplies it into the power grid. The setup following illustrates the arrangement of a DC fast charging for integrating V2G-G2V infrastructure into a microgrid is depicted. External chargers link electric vehicle batter-

ies to the DC bus. A grid-connected inverter connects this bus to the utility grid via an LC filter and Buck Boost Converter. Below are detailed descriptions of the key components of the system For DC fast charging, Integral to these chargers with V2G capability is a bidirectional DC-DC converter, acting as the fundamental unit. It serves as the intermediary between the EV battery system and the DC distribution grid, as illustrated in Fig. The converter, featuring two IGBT switches, operates continuously with complementary control signals[6].
The fundamental block diagram of the systems is shown in the figure below.

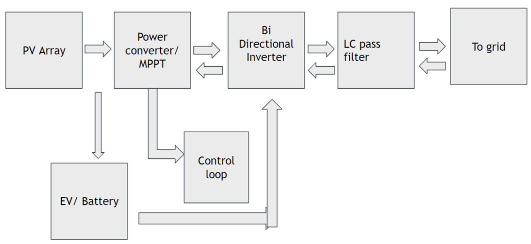

Fig. 1: Block Diagram

A. PV Setup

The Solar panel with MPPT is used to generate a power of 8 KW to charge a 160V battery setup in a microgrid integration setup. The mode control block in MATLAB is used to calculate the maximum power output. The BMS block is used to charge the battery in such a way that all fundamentals of the battery are kept to be linear.

B. Grid to Vehicle Mode (Buck Mode)

In this mode, the upper switch directs the converter to function as a buck converter, reducing the input voltage to the battery charging voltage. During the switch's on state, current flows through the switch and inductor to charge the battery, facilitating power flow from the grid to the vehicle (G2V). When the switch is off, current returns through the inductor and the diode of the lower switch, completing the circuit[6]. The battery voltage, determined by the duty ratio of the upper switch, is given by:

$$V_{\text{batt}} = V_{\text{dc}} \times D$$

C. Vehicle to Grid Mode (Boost Mode)

Here, the lower switch operates, transforming the converter into a boost converter, elevating the battery voltage to the DC bus voltage. During the switch's on state, current continues through the inductor, completing its path through the anti-parallel diode of the upper switch and the capacitor. This configuration facilitates power flow from the vehicle to the grid (V2G), with the battery operating in discharge mode. If the capacitor is sufficiently large to maintain a constant DC voltage[6], the output voltage during boost mode is given by:

$$V_{\text{dc}} = \frac{V_{\text{batt}}}{1 - D'}$$

III. Control Strategy

A cascade control system in synchronous reference frame is proposed for the inverter controller. Illustrated in Fig., the conventional standard vector control utilizes four PI controllers in a nested loop. The control structure comprises two outer voltage control loops and two inner current control loops. The outer loop on the d-axis regulates the DC bus voltage, while the inner loop controls the active AC current. Similarly, the outer loop on the q-axis adjusts the AC voltage magnitude by regulating the reactive current, managed by the inner current loop on the q-axis. Additionally, dq decoupling terms (L) and feed-forward voltage signals are incorporated to enhance performance during transients.

IV. Simulation and Results

The following Fig shows the Circuit Diagram in MATLAB simulink.

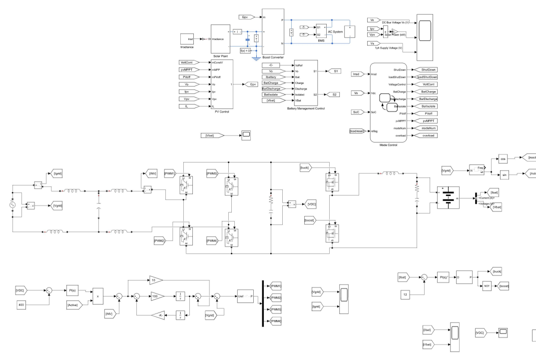

Fig. 2: MATLAB Simulink Circuit Diagram

The PV setup is used to charge the battery rated at 160V dc, the Battery power is supplied to Grid or vise versa using Bi-directional Inverter and Buck Boost converter, The PI controller is used to maintain the power output to be constant at all time ensuring the operation. PI controller used in the front-end converter which regulates the voltage across the DC bus. The controller used for the bidirectional buck-boost regulates the battery charging and discharging current. Phase Locked Loop (PLL) system synchronizes the bidirectional converter with the power grid voltage.
The following figures will explain the 3 primary blocks of the circuit

As you can see in the circuit, grid is connected with inverters (Fig 3) Circuit now further forwarded with Buck-Boost converter(Fig 4) In the last section circuit is further connected to the battery and vise versa(Fig 5)

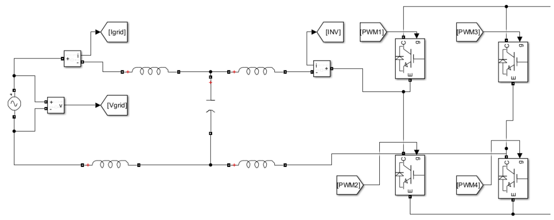

Fig. 3: Grid to Inverters

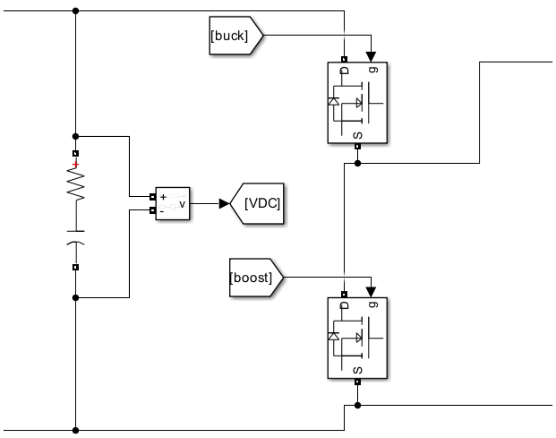

Fig. 4: Bi - Directional Buck-Boost Converter

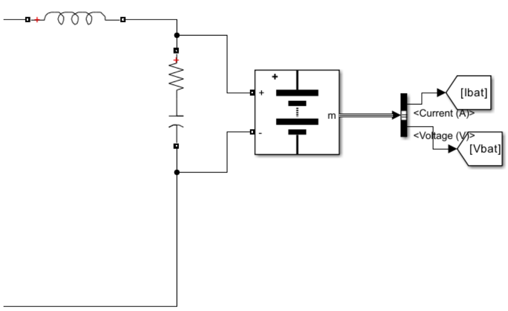

Fig. 5: Buck boost to Battery

The following figure (Fig. 6) explains the controller used in the circuit

PI controller used in the front-end converter which regulates the voltage across the DC bus. The controller used for the bidirectional buck-boost regulates the battery charging and discharging current.Phase Locked Loop (PLL) system synchronizes the bidirectional converter with the power grid voltage.

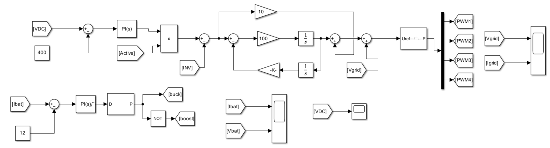

Fig. 6: PI controller

The Figures shown below are the representation of the output waveforms observed during both V2G and G2V mode.

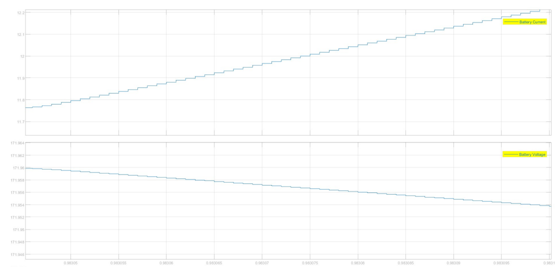

Fig. 7: V2G Battery voltage and current

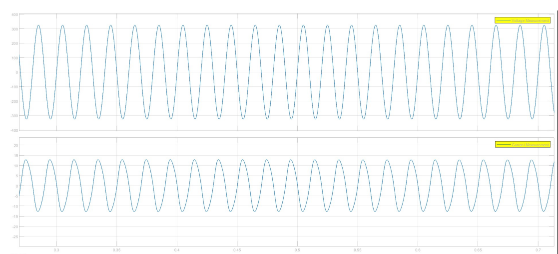

Fig. 8: V2G Grid Voltage and Current

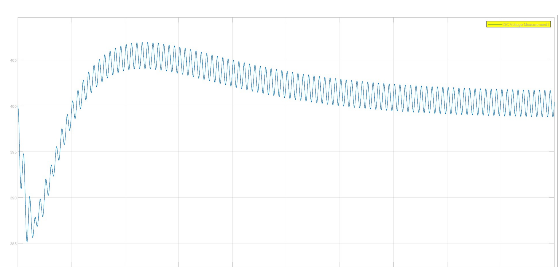

Fig. 9: V2G DC Bus Voltage

At first we will keep the initial current of the battery to be at 12A and final value as -12A, the system will run in V2G mode and the battery will be discharged. The result show an out-of-phase relationship between grid voltage and grid current, which means that the power is transferred from the battery to the grid.

Fig 7 shows the battery voltage and battery current during V2G mode. The battery current is the same as the reference value of 12A but the battery voltage is showing a decreasing trend from 172V. Fig 8 Show the Grid voltage and current to be 325VRMS out of phase.

Fig 9The DC voltage for V2G mode is shown here which is regulated at 400V.

Now, by changing the polarity of the reference current, we make the circuit operate in G2V mode. Here both the grid voltage and grid current are aligned in phase which means the power is transferred from grid to the battery.

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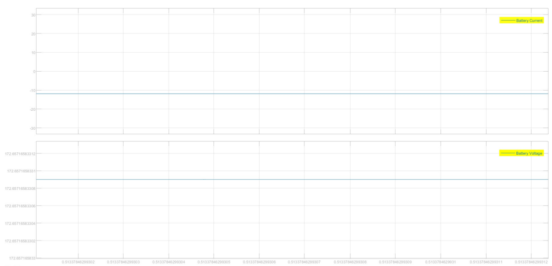

Fig. 10: G2V Battery voltage and current

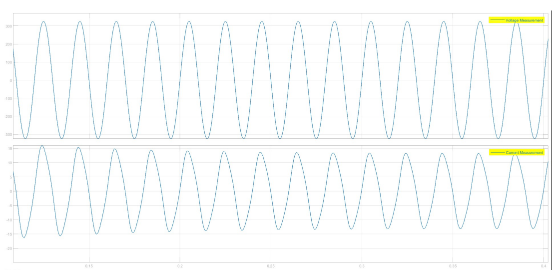

Fig. 11: G2V Grid Voltage and Current

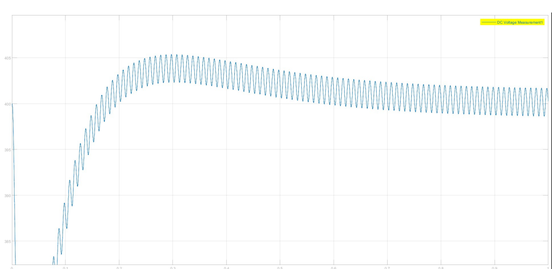

Fig. 12: G2V DC Bus Voltage

In G2V mode, we see in Fig 10 that the battery current is maintained at -12A i.e. it is reversed polarity. Fig 11 Show the Grid voltage and current to be 325VRMS In the phase.

The Fig 12 DC bus voltage during battery charging is regulated at 400V. The simulation results obtained with the two modes of operation are in accordance with the expected design.

V. Conclusion

This project presented the design of microgrid integrating renewable energy with EV charging, focusing on the selection of the inverters, converters and batteries as well as exploring various control strategies; capable of operating in Grid-to-Vehicle (G2V), Vehicle-to-Grid (V2G) and PV incorporation modes. An onboard bidirectional charger has been developed, capable of synchronizing with the electric grid as well as PV modules. The proposed charging structure has been designed for lithium ion based electric vehicles. Validation of the system design is conducted using Matlab Simulink, with results confirming its alignment with the intended design. While the current literature predominantly focuses on design principles and commonly used control strategies, future research could explore unaddressed areas. This may involve refining the control structure to compare and evaluate various control methods, thereby optimizing the utilization of the microgrid's reserve capacity and its interaction with the battery in vice versa cases.

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