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DESIGN AND IMPLEMENTATION OF THREE PHASE BIDIRECTIONAL V2G/G2V TECHNOLOGY FOR DC FAST CHARGING IN ELECTRICAL VEHICLES

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ABSTRACT

According to reports 60.9% there is rise in adoption of electrical vehicles (EVs), as natural fuel scarcity, price instability and environmental pollution is a concern globally. The pivotal urge of EV applications led to stored energy in batteries by with AC or DC chargers. For V2G and G2V in EV charging systems power electronic converters (PECs) play essential role. The batteries in the EV are basically a device to store energy in microgrids. As required stored energy helps in the energy management of the micro-grid. Two-way transfer of electricity, i.e., Grid-To-Vehicle (G2V) as per requirement of electricity, and Vehicle-To-Grid (V2G) transferring the energy to grid as per energy demand in response to growing popularity. To create such an idea, reliable and appropriate infrastructure, along with mechanisms, should be established. In the current research, level-3 fast charging has been employed to develop the design of V2G and G2V system in a micro-grid. A micro-grid experimental setup using DC rapid charging situation is modeled to illustrate V2G-G2V energy transfer via simulation. The test results illustrate that the batteries of electric vehicles operate in G2V-V2G modes to actively succeed energy in the microgrid. Based on test results, batteries of electrical vehicles can dynamically regulate power in microgrid via G2V-V2G modes. The design of charging station promises the less harmonical distortion of grid-injected current, and controller provides active functioning for balancing dc bus voltage.

KEYWORDS: Electric Vehicle Model, DC Fast Charging, V2G Operation, G2V Operation.

1. INTRODUCTION

The fast growth in the field of electric vehicles has strengthened into an essential solution for emissions of greenhouse gases, environmental issues with standard ignition engine vehicles and the exhaustion of fossil fuels. Compared to conventional transportation systems, EV technology promotes increased energy efficiency and a lower carbon impact. However, widespread EV adoption poses serious problems for power networks, especially regarding variations in load demand, grid stability, and distribution infrastructure limitations.

V2G and G2V technologies have potential to turn EVs into supplied energy storage devices i.e. batteries that can exchange electricity with the grid in both directions, according to recent research. While stored energy is returned to the grid during times of peak demand, EV batteries in G2V mode absorb excess energy during off-peak hours. Supplementary services involving reactive power support, frequency management, peak cut off and gap filling are made possible by this idea [1], [2]. V2G technology, in comparison to traditional charging systems, boosts grid flexibility and facilitates the amalgamation of renewable energy.

Implementing V2G systems in micro-grid situations, where integration is relatively easier than in major utility grids, has been the subject of several studies [3]. Efficient energy storing systems are necessary to handle interruption in micro-grids by using non-conventional energy options like solar and wind power. Use of EV batteries function as dynamic storage resources when connected via intelligent charging infrastructure [4].

On board charger rating place limitation on conventional level -1 and level -2, AC charging approaches rendering them inappropriate for large capacity bidirectional energy exchange. level 3 off board DC fast charging topologies have been suggested as a solution to these issues [5].

DC fast charging stations use grid connected inverters, LCL filters, and off board bidirectional DC -DC Converters to enable high power transfer while preserving acceptable harmonic performance. Cascaded vector regulator for grid connected inverters and continuous current control for battery chargers are examples of advanced control techniques which stabilized DC voltage and effective regulation of active as well as reactive power [6],[7].

Despite encouraging developments, increased EV penetration may give rise to harmonic distortion, increase distribution transformer loading, and impact power quality if improperly coordinated [8], [9]. Therefore, to determine if large-scale V2G deployment is technically feasible, modeling, simulation, and effect assessment studies are crucial. A detailed investigation of DC fast charging-based V2G-G2V topologies in micro-grid systems is provided in this review study. Power electronic setups, control strategies, harmonic reduction techniques, and grid integration issues identified in recent literature are all critically examined. The objective is to offer a comprehensive technical understanding of EV-based bidirectional energy systems and their function in the development of future smart grids [10].

2. DC FAST CHARGING STATION DESIGN WITH V2G-G2V OPERATION

Fig. 1[10] shows the DC fast charger design for V2G-G2V structure in micro-grid via off-board charger. A front-end converter with transformer (step-up) and L-C-L filter via DC bus to utility grid. Below are described the main components of charging station.

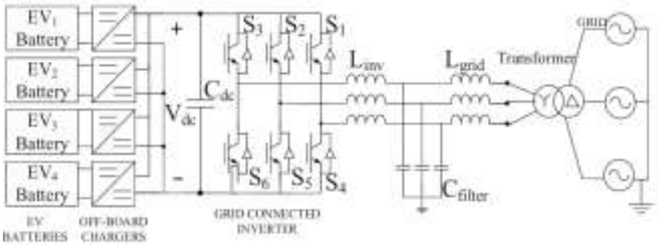

Fig. 1. Architecture Of Dc Fast Charging Station V2g-G2v Operations

1.1 Configuration of Battery Charger

In DC fast charging Vehicle-to-Grid (V2G) systems, the charger of battery is a crucial port that enables bidirectional energy exchange between an EV battery and a micro-grid of DC bus. DC fast charging stations utilize off-board bidirectional DC–DC converters in contrast to traditional on-board chargers to achieve higher power capability, improved thermal performance, and enhanced control flexibility [10]. This arrangement is especially well suited for V2G implementation in micro-grid environments and high-power level-3 charging applications [11].

The bidirectional DC–DC converter which is usually made up of two actively controlled semiconductor switches like IGBTs or MOSFETs, by using DC-link capacitor, anti-parallel diodes, and an inductor, operates in two fundamental modes: buck mode during charging (G2V) and boost mode during discharging (V2G) [12], [13]. To control power flow and avoid short circuit situations, corresponding switching signals are employed. The working mode and power transfer magnitude are determined by the current reference that the controller generates [10]. Fig. 2 indicates the converter arrangement. It is made by using double IGBT's or MOSFET switches that always helps in controlling by complementary signals.

2.1.1 Operation of Buck Mode (Grid to Vehicle -Charging Mode)

Fig. 2 shows a converter that functions as buck converter, reduce the input DC voltage V_{dc} to battery charging voltage V_{batt} when upper buck switchS_{buck} in operation mode. The current passes to battery via inductor and upper switch while it is in the on state. In this charging process, power is moved from grid to vehicle (G2V). In the closed switch condition, the current returns through the diode connected at lower end and through inductor. Thus, completing the circuit. The upper switch's duty ratio decides the voltage of the battery[14].

$$V_{batt} = V_{DC} * D$$

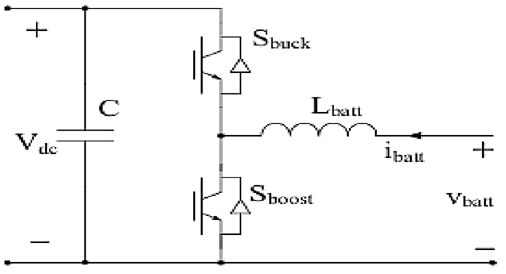

Fig. 2. Battery charger/Discharging Operations

2.1.2 Operation of Boost mode (Vehicle to grid discharging mode):

When S_{Boost} is turned on, the converter operates as boost converter as illustrated in fig.2. Although lower switch S_{Boost} is operated, current can flow through the inductor, completing the path via the capacitor and diode of the S_{buck} switch connected in antiparallel. In this situation, battery enters in discharge mode and net power is directed from EV to grid (V2G). Under boost mode, output voltage will be equal if large capacity capacitors are used to force a continuous DC voltage[10]:

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

Where D′ represents the lower switch's duty cycle

1.2 Operational Significance in V2G Systems

Intelligent control methods, which usually use PI-based constant current control schemes, regulate the shift between buck and boost modes [5]. Under various grid conditions, these controllers guarantee smooth bidirectional power transfer, control battery current, and preserve DC bus voltage steadiness.

Thus, in contemporary micro-grid systems, the bidirectional DC–DC buck boost converter is the essential component of a DC fast charging station, allowing for high-power, quick response, and effective V2G–G2V operation [15 -20].

In order to enable high-power, quick reaction, and effective V2G-G2V operation in contemporary micro-grid systems, the bidirectional DC– DC buck boost converter is the essential component of fast charging station [3], [4].

1.3 Active Front End Converter and LCL Filter connected to grid

1.3.1 Active Front End Converter connected in grid

In DC fast charging, an A.F.E i.e. active front-end converter connected to grid for AC -DC power conversion stage is widely used. The AFE converters uses as controlled semiconductor switch such as IGBT or MOSFET with advanced modulation technique to achieve bidirectional power flow, improve power quality and high efficiency[10].

In EV fast charging architecture, AFE converter is connected between grid and DC link of charger. The primary function of AFE Converter is three phase AC Grid voltage to regulate DC Voltage. which is suppled to DC-DC Buck – Boost Converter [15 -20].

The AFC converter also reduced harmonic content and improved power quality also. Those are essential specifications for contemporary power electronics converters connected to the grid.

The AFE converter generally consists of voltage source inverters with three phases implemented using six controlled switches arranged in a bridge configuration. A pulse width modulation control Strategy, such as sinusoidal PWM (SPWM) IS typically used to control switching devices. With the help of this technique, it is possible to control the converter output voltage and current precisely.

An LCL filter is installed between the Front-end converter and grid. The filter reduces switching harmonics produced by the converter.

The major advantages of using an AFE Converter in EV fast charging stations include bidirectional operation for vehicle to grid and grid to vehicle application, reduced THD, power factor nearly one and improved dynamic performance. Due to these benefits, AFE converters are widely adopted in high power EV fast charging ranging from 10 KW to several hundred kilowatts.

As illustrated in Figure 1, the grid-tied AFC transforms the bus voltage at DC into a three-phase AC output. This process relies on the diodes connected in antiparallel manner with each leg's switches to allow reverse current flow. To eliminate harmonic distortion and ensure a clean, pure sinusoidal waveform for both voltage and current, an LCL filter is added to the inverter's output. The specific parameters of this filter were calculated using the design approach outlined in [10].

3. CONTROL STRATEGIES

1.4 Constant Control strategies for control battery charger

Figure 3 illustrates a constant current control scheme [10] that relies on PI controllers to manage the battery's charge and discharge cycles. The system first determines the operating mode by checking the polarity of the reference current specifically, whether it is above or below zero. Once the appropriate mode is set, the system calculates the error between the reference current and actual measured current. This error signal is then processed by the PI controller for generating the necessary switching pulses to operate the circuit correctly [20-24].

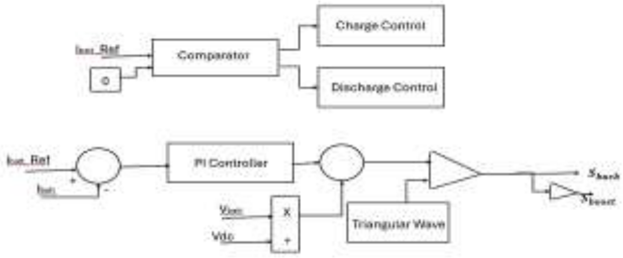

Fig. 3. Battery charger constant current control strategy

3.2. Standalone V-I control for Inverter.

In this four-phase synchronous reference-based cascade control strategy is utilized for inverter controller. The classic strategy of vector control Figure 4 [10], which is made up of cascade structure of four PI controllers. 2 inner current control loops and 2 outer voltage control loops contribute to making a control system. The active AC current is regulated by the inner loop. The DC bus voltage is regulated by the d-axis outer loop simultaneously. In the same way, the q-axis regulates the reactive current, which in turn modifies the magnitude of AC voltage. Additionally, new feed-forward voltage signals for transient events and dq decoupling terms of L are considered to further enhance the performance [20-24].

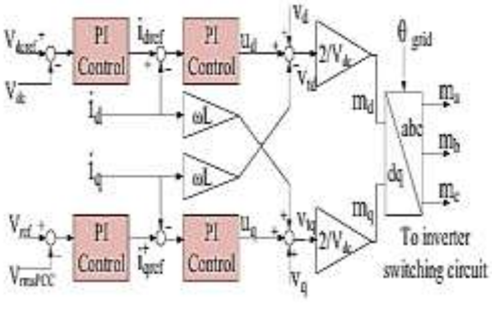

Fig. 4. Standalone Voltage and Current control system for Inverter

MICRO – GRID TEST SYSTEM CONFIGURATION

Configuration of Test system for the micro-grid, and dc fast charging station are illustrated in figure 5 below. A 100-kW wind turbine and a 50-kW solar PV system power the system. The four EV batteries are connected to a 1.5 kV dc bus via off-board chargers at the charging station. This arrangement forms the EV battery storage system. The solar PV system is connected to a boost converter with maximum power point tracking control through DC bus. The microgrid is further connected to DFIG driven wind turbine.

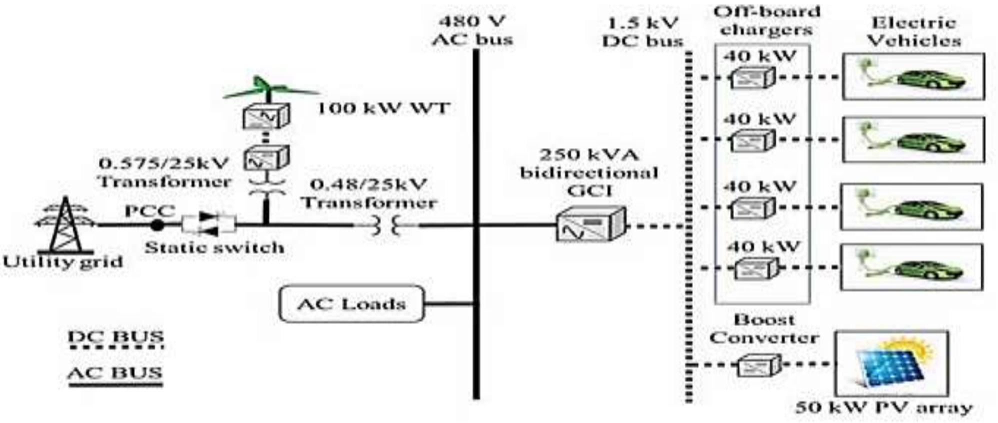

Fig 5. Micro Grid Test System

4. DESIGNING AND SIMULATION RESULT

4.1 Buck–Boost Converter Design

(Bidirectional Battery Interface for V2G/G2V Operation)

- **System Specifications**

  Battery Nominal Voltage $V_{bat} = 360$ Volt

  Output Current = 30 Amp

  $V_{ripple} = 0.36$

  $I_{ripple} = 3\ A$

  Switching Frequency $f_{sw} = 10$ kHz

  Inductor = 2 Mh

  Capacitor C = 0.625 µF

Design of Buck–Boost Inductor

Step -1 Calculation of a Duty Cycle.

For buck – boost converter,

$$D = \frac{V_O}{V_O + V_{in}} - - - - - (1)$$

$$D = \frac{360}{360 + 800}$$

$$D = 0.31$$

Step - 2 Calculation of a Inductor Current.

$$\boldsymbol{I_L = \frac{I_O}{1-D}} \quad - - - - - (\mathbf{2})$$

$$= \frac{30}{0.69}$$

$$= 43.4\ Amp$$

Step - 3 Calculation of a Ripple Current.

Ripple current is considered as 20% to 40% of a load current.

$$\Delta I_L = 0.3 * 43.4 = 13\ Amp$$

Step - 4 Calculation of the Value of inductor.

$$L = (V_{in} * D)/(F_S * \Delta I_L) - -(3)$$

$$= \frac{800 * 0.31}{10000 * 13}$$

$$= 0.0019\ H$$

$$= 1.9\ mH$$

Current rating,

$$I_{peak} = I_L + \left(\frac{\Delta I_L}{2}\right) - - - -(4)$$

$$= 43.4 + \left(\frac{13}{2}\right) = \ 49.9\ Amp$$

So, consider value of inductor L = 20 mH and 50 Amp

Design of Buck–Boost capacitor,

Output capacitor is selected to limit output voltage ripple.

Assume voltage ripple is consider as $\Delta V_O = 1.5\ Volt$

Output Capacitor is given by ,

$$C = (I_O * D)/(F_{Sw} * \Delta V_O)\ - (5)$$

$$= \frac{30 * 0.31}{(10000 * 1.5)}$$

$$= 0.00000062\ F = 0.62\ \mu F$$

So, consider as value of capacitor is C = 0.62 5μF

4.2 For Frond End Convertor integrated with LCL Filter

For the DC Fast Charging 10 KW, using front end converter integrated with LCL filter is commonly used between the inverter and grid to reduce switching harmonics produced by grid.

Selected Value for Π filter (LCL filter)

- **Inverter side inductor $L_1 = 5\ mH$**
- **Inverter side inductor $L_2 = 5\ mH$**
- **Filter Capacitor $C_f = 30\ \mu\ F$**

Are choose manly harmonic reduce and power quality improvements, stable Current and stable grid interfacing.

4.3 *Modeling of DC Fast Charging Station Configuration for V2Gand G2V.*

Specification

Parameter	Value	Parameter	Value
Rated capacity	250 KW	**EV rated capacity**	10 KW
V_{batt}	360 V,50 A.	C_{filter}	0.625 μF
Battery Capacity	30 Ah.	L_{filter}	2 mH
$L_{1grid}, L_2 inv$	5 mH, 5 mH	C_{filter} **inv side**	30 μF

The values used in the recharging station design process are mentioned in Appendix. The wind turbine is designed in such a way that it can reach max power of 100 kW. For producing rated maximum power of 50kW, the solar PV is simulated to operate in standard test conditions of 1000W/m2 irradiance and 25° C temperature. In this system, 150-kW resistive load is linked to 480 V AC bus. For running it on unity power factor, the reactive current reference to GCI is set to Zero. EV batteries start off at around 50% state of charge. When steady-state is attained, the batteries of EV1 and EV2 as described in figure 1 help to implement V2G-G2V transfer.

4.3.1 *Modeling simulation of DC fast charging station structure for G2V/V2G operation*

AFE Converter Modeling

The front-end converter is realized with the help of three-phase IGBT bridge and implementing the control strategy by using sinusoidal PWM (SPWM). The DC bus voltage as well as the grid current are controlled by dq vector control system. With the help of Park transformation method the three-phase grid voltages as well as the current are changed from abc reference frame to the dq reference frame. Control system's synchronization with the grid voltage is done by using phase-locked loop (PLL). The bus voltage is than compared with the reference value of 800 V and then feeds to PI voltage controller. For controlled flow of current in grid nested control loop is used. The reference voltage signals generated in dq frame by controller then passes through the abc frame, this reference sinusoidal compared with carrier signals at 10kHz frequency to generate 10kHz SPWM gate pulse. Various control strategies allow the front-end converter to regulate the voltage on the DC bus. These strategies also help in controlling the direction and magnitude of the active power exchange with the grid.

Bidirectional Buck – Boost converter Modeling

Charging and discharging current of EV batteries is controlled with help of bidirectional DC–DC buck boost converter having two MOSFET switches, one inductor, and one capacitor by maintaining switching frequency to 10 kHz. For controlling the battery current, battery current loops are used, the said current is compared to the reference value. This generated difference passed via PI controller; PI controller's output helps in controlling the gate pulse for the MOSFET switches.

The generated refence value is positive in G2V mode, bidirectional DC–DC converter is used in buck mode to charge the battery while the generated refence value is negative in V2G mode, bidirectional DC–DC converter is used in boost mode to discharge the battery.

Role of LCL filter

The LCL filter forms the interface between the grid and the front-end converter. It minimizes the high-frequency harmonics that are introduced by the switching devices. It was also noted that the LCL filter is effective in attenuating the harmonics compared to the inductive filter while maintaining low inductance values.

The LCL filter consists of two inductors and a capacitor. The grid side and the converter side each have one inductor while one capacitor is connected across the two inductors. This configuration provides a smooth current injection to the grid.

4.3.2 *Simulation Result and Analysis*

DC Bus Voltage Performance

The bus voltage level at DC is regulated at a fixed level of 800 V, as indicated in the closed-loop control system, which operates in the front-end converter.

During simulation as soon as the system gets started, the DC bus voltage immediately stabilizes at the regulated level. This indicates the significance of the 5600 µF DC link capacitor to the stable operation of the system as a buffer between the AC grid and the DC-DC converter.

Shown in fig.6, While changing the operating mode between G2V and V2G slight change is observed in the DC-link voltage before the control system adjusts it to the reference value. This shows the effectiveness of the control tactic in the front-end converter.

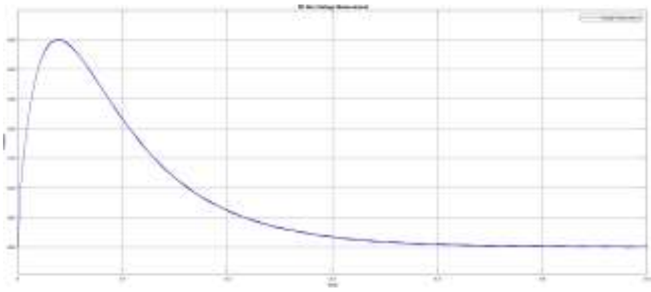

Figure: 6 DC Bus Voltage Measurement.

Grid Voltage and Current Waveform.

Shown in fig.8.the voltage and current waveforms of three-phase grid are explored to evaluate the collaborative of charging station and utility grid performance. In V2G mode, current waveform synchronizes with the waveform of grid voltage. This indicates supply of active power to the grid by Electrical Vehicles battery.

The filtering effect of the LCL filter, that successfully filters the switching harmonics produced by the inverter, ensures that the current has a sinusoidal waveform.

Shown in fig.9.While G2V mode s on the phase relationship between voltage and current s not constant hance grid current is out of phase compared to voltage. This shows the system s receiving power from grid to charge battery. Even during phase shift the waveform quality remain stable, which indicates filters achievement for reducing harmonic distortion

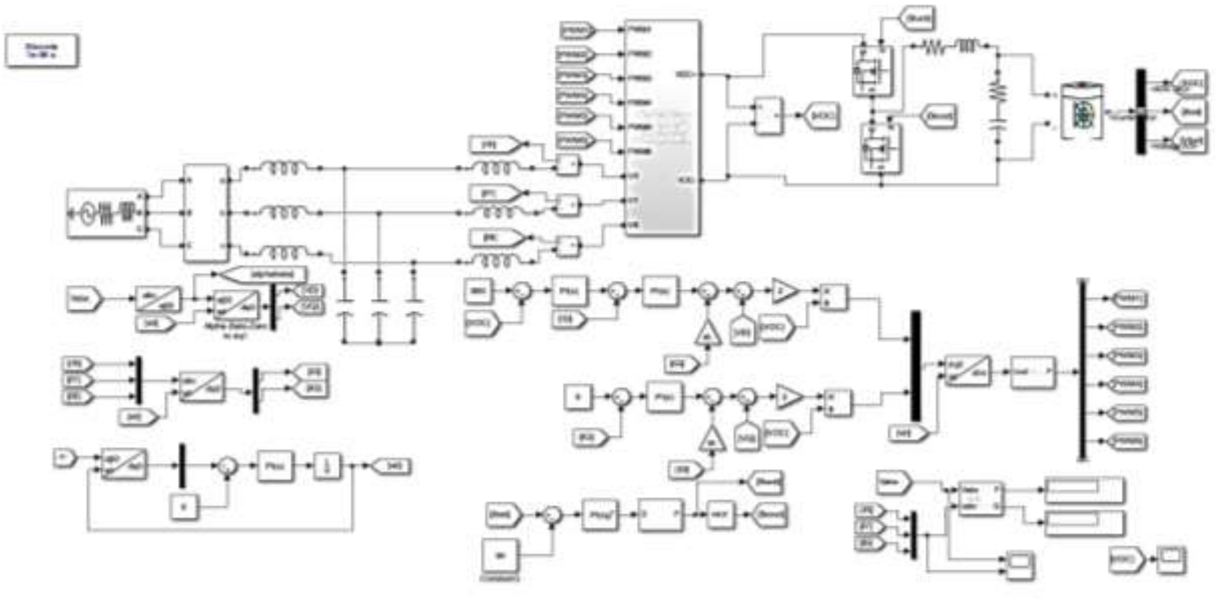

Figure 7: Modeling of DC Fast Charging Station Configuration for G2V/V2G operation.

These results show that the station for charging stays connected to the grid while running at a power factor close to one.

Fig.8 Grid Voltage and Current Waveform – V2G Mode

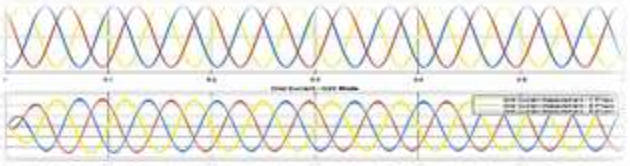

Fig.9 Grid Voltage and Current Waveform – G2V Mode

Battery charging and discharging characteristics

The charging station's bidirectional ability can be seen by the battery current waveform. The battery current is controlled by the current controller according to the control system's reference value.

Shown in fig.9.The battery current is positive when G2V is running, indicating that energy is moving from the electricity grid to the battery. To provide controlled battery charging, the current gradually reaches the reference charging value.

Shown in fig.10.When the battery is discharging and returning electricity to the grid, the current turns negative during V2G operation. Because a PI current controller and PWM-based switching control are used, there are not any major current spikes during the smooth change between charging and discharging modes.

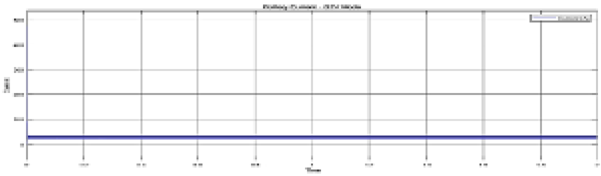

Fig 9 Battery Charging Current – G2V Mode

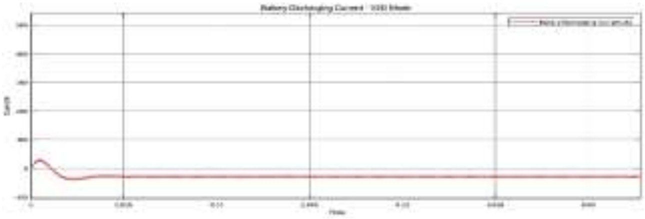

Fig 10 Battery charging Current – V2G Mode

Active and Reactive Power Analysis

Shown in fig 11. The measured active power is positive during V2G operation, signifying that the EV battery is providing energy to the utility grid. As a result of this functionality, Shown n fig 12,

the EV can support the grid during times of high demand by functioning as a renewable energy storage unit.G2V operation, on the other side, initiates the active power to go negative. This indicates that the energy has been obtained from the grid to charge the battery. Throughout the results of the simulation, the reactive power output stays very close to zero, indicating that the converter runs with a near-unity power factor.

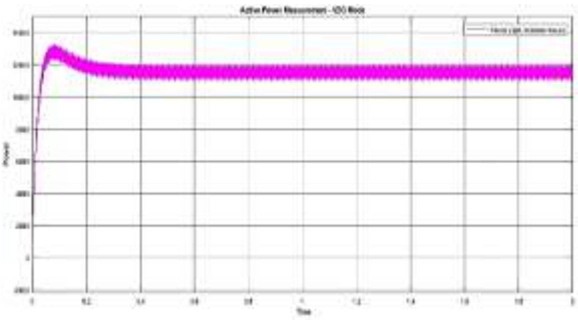

Fig 11 Active Power Measurement - V2G Mode

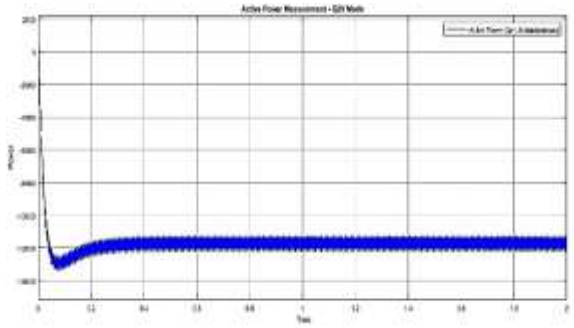

Fig 12 Active Power Measurement - G2V Mode

State of Charge (SOC) Analysis

Shown in fig 12 and fig 13,for the purpose to look at the energy transfer between the battery and the grid, the battery's State of Charge (SOC) is monitored during the simulation. The SOC gradually increases when electrical energy is stored in the battery during charging operation (G2V). On the flip side, as the battery provides energy to grid during V2G operation, the SOC decreases. The SOC variation exhibits a smooth profile free of sudden fluctuations, indicating that the bidirectional converter controls current flow and avoids the battery from being overloaded.

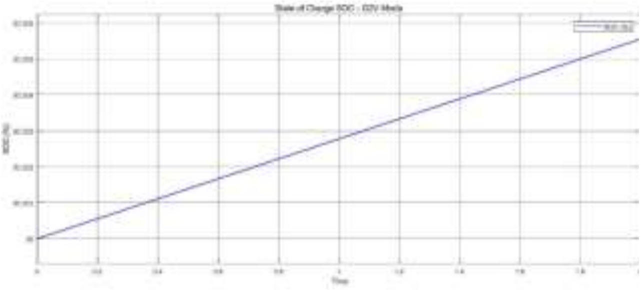

Fig 12 State of Charge (SOC) – G2V Mode

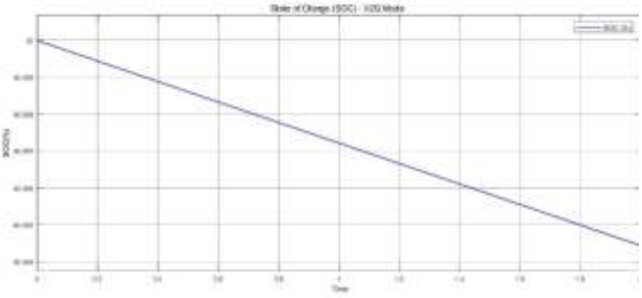

Fig 13 State of Charge (SOC) – V2G Mode

Harmonic Analysis

High-frequency harmonics generated by the inverter's switching devices are successfully reduced by the LCL filter. As such, in comparison with systems without effective filtering, the harmonic distortion is much reduced, and the grid current maintains nearly sinusoidal. This ensures grid-connected converters adhere to power quality standards.

The control system efficiently controls battery current, maintains a steady DC bus voltage, and ensures smooth bidirectional energy transfer between the EV and the grid. The suggested system shows the viability of relating EV charging stations with the utility grid for smart energy management applications given that vector control, PWM switching, and LCL filtering enable effective energy conversion while retaining good power quality. The simulation's results indicate that the suggested 10 kW bidirectional EV charging station performs effectively in both G2V and V2G modes.

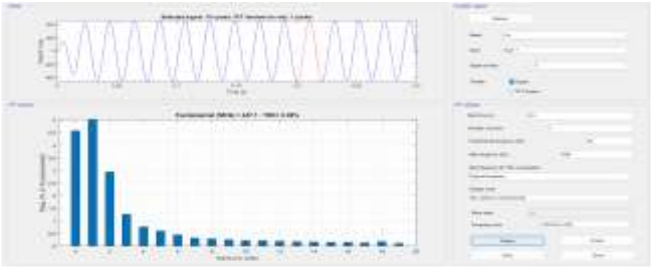

Fig 14 FFT Analysis of Grid injected current.

5. CONCLUSION

This Paper is presented Modeling and design of a 10 KW V2G System in Micro Grid using DC Fast Charging architecture. A dc fast charging station with off board charger integrated with buck boost converter and front-end converter to interface EVs to micro grid. The design of control system of Buck – Boost Converter and FAC will permit bidirectional power transfer among the EVs and the grid. The design and the result of simulation point towards a smooth transfer of power between the EVs, and grid and the quality of grid injected current from the EVs. In the terms of tracking the changed active power reference and dc bus voltage stability, the designed controller provides good dynamic performance. This work considers the micro grid's active power regulation elements. The suggested V2G system can be used for several different services, such as frequency regulation and reactive power control. Future study is advised to design a supervisory controller that provides command signals to the different EV charging controllers.

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