Design and Development of Bidirectional Converter based on V2G and G2V Operation

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Abstract. The rapid progression of electric vehicles (EVs) in the transportation sector poses a potential challenge of increased peak energy demand on existing grid structures. Consequently, the significance of V2G power conversion technology becomes paramount in managing sudden surges in energy requirements. To address this issue, the authors propose a "Bidirectional Converter Based on V2G and G2V Operation" which focuses on facilitating energy transfer between vehicles and the grid through bidirectional converters, catering to both V2G and G2V operations. In this work, the authors analyzed a bidirectional buck-boost converter interface with an H bridge AC/DC converter together with the related control method in a reduced topology. The efficiency of the developed system is evaluated with the help of a developed simulation model in MATLAB/SIMULINK. The developed model was tested under various conditions and was able to perform effectively.

1 Introduction

Electric vehicles (EVs) are becoming more and more popular as fossil fuels become scarcer. This trend is fueled by the global need to minimize greenhouse gas emissions and carbon footprints. Since they are less expensive and emit fewer greenhouse gases than conventional cars that run on fossil fuels, electric vehicles (EVs) have become more and more popular. But despite their advantages for the environment, obstacles including high upfront costs, a lack of adequate charging infrastructure, and short driving ranges prevent widespread adoption [1] Integrating EVs into energy grids poses additional complexities. High-level EV charging strains power supplies, exacerbating imbalances between electricity consumption and generation, especially with the intermittency of renewable sources like wind and solar. Bi-directional electric car chargers offer a promising solution by enabling V2G and G2V operations. These chargers can discharge or inject electricity into the grid, enhancing its stability and efficiency.

Battery energy storage systems play a crucial role in this scenario, facilitating G2V and V2G functions. Rapid charging capabilities of EV chargers are essential, while their integration into smart grids enhances grid reliability. V2G implementation alleviates grid stress by allowing EV batteries to discharge during peak demand periods, potentially earning vehicle owners monetary rewards for their stored energy contributions [2] Proposals for compact, bi-directional chargers adaptable to both fully electric and hybrid vehicles are gaining traction. These chargers promise to relieve grid strain once deployed, offering versatile support for EVs' dual roles as energy storage units and transportation solutions. Research efforts focus on conceptualizing, outlining functionalities, and simulating charging and discharging operations of chargers, aiming to bridge the gap between EVs and grid integration.

With this motivation, various researchers have worked on similar technology and proposed their ideas. Some of the works presented by the authors and their limitations are as follows: in [3] author developed the design and simulation of a bidirectional buck-boost converter for a plug-in hybrid electric vehicle (PHEV) system with a ripple compensation circuit. Further authors in [4] the author explore the impact of V2G on battery life and the challenges associated with continuous charging/discharging cycles, authors in [5] proposed another technique named small-signal analysis and state-space modeling to elucidate the converter's steady-state and dynamic performance achieving high efficiency and low total harmonic distortion Finally authors in [6] discuss buck converter specifications, indicating parameters such as input and output voltage, duty ratio, inductor, and capacitor values for efficient operation

2 System Description

To implement the proposed system, the block diagram of the completed system has been framed and has been presented in Fig. 1. It shows the system integration for the Bidirectional converter for V2G and G2V operation and it explains the connection of each component with

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the other. The proposed consists of a two bidirectional converter as well as a filtering circuit which serves the aim of diminishing harmonics. For DC voltage boost up and to maintain a bus voltage of 400 volts a controller for variable DC/DC converter stage has been used.

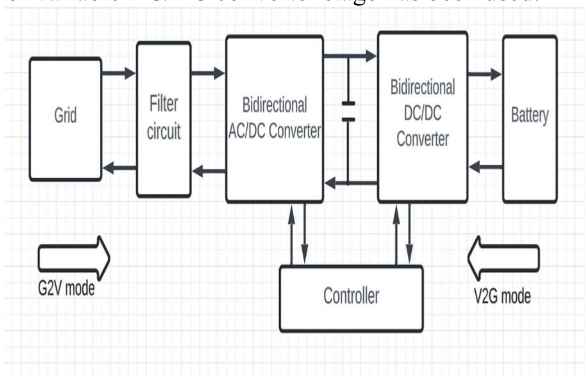


Fig. 1. Block Diagram of system intégration

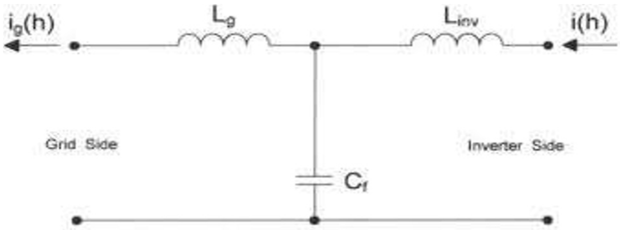


Fig. 2. LCL Filter circuit

The description of each component is given as follows:

The authors have considered a single-phase 230V AC grid. During G2V mode it will act as a source by which the battery gets charged and during V2G mode Grid will act as a load and receive the power from the battery. A bidirectional AC-DC Converter makes the connection with the power grid smooth. When working in the G2V mode, this AC-DC converter is an active rectifier therefore it produces a sinusoidal current and UPF. In V2G mode, it becomes an inverter, acting as a Constant Current Source (CCS) to supply the required power back to the grid [7]. The Bidirectional DC-DC Converter plays a major role in the bidirectional communication between the battery and the other devices. In G2V mode, this converter executes its bidirectional work as a buck converter, which will lower the grid voltage to battery voltage, and manage the current and voltage throughout the steps of charging the battery. Contrary to V2G operation, here the DC/DC converter performs a boosting function that contributes to an increase in the battery voltage [10]. Lithium-ion battery with a rating of 170V,12A is chosen, which can be considered as an electric vehicle. During G2V mode the battery gets charged and whenever it acts in V2G mode battery gets discharged and will act as a source. The purpose of the controller in a bidirectional converter for V2G and G2V operation is to manage the flow of energy between the electric vehicle and the grid. Further, authors in [11] developed 3 3-level hybrid active filters for Electric vehicle applications. Similarly, authors in [12, 13] proposed their system with the incorporation of various renewable energy resources for the application of effective power transfer between sources and loads.

3 System Designing

Bidirectional power flow converters help to produce a high power factor and low total harmonic distortion (THD) value by enhancing the power quality of the network, whether it is intended for consumers or the grid [8]. To improve the performance of the G2V and V2G systems in both modes, we therefore suggest a bidirectional converter. Fig. 2 shows the LCL filter, which is used to lower the total harmonic distortion level by lowering the grid side current. To interact between the grid converter transfer of energy from G2V and from V2G is required. It is expected that the current direction in the converter is positive for energy transfer from the grid. The design of the system is carried out by considering the equations given in [9].

The bidirectional converters that are used for the charging and discharging purposes are given in Fig. 3. and 4.

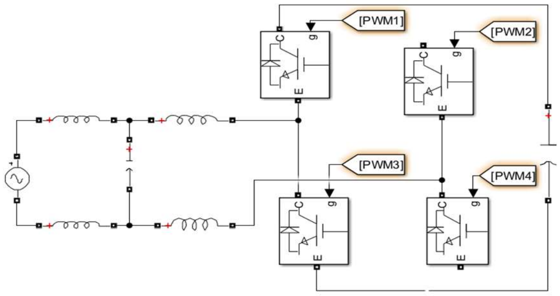


Fig .3 Bidirectional AC/DC Converter

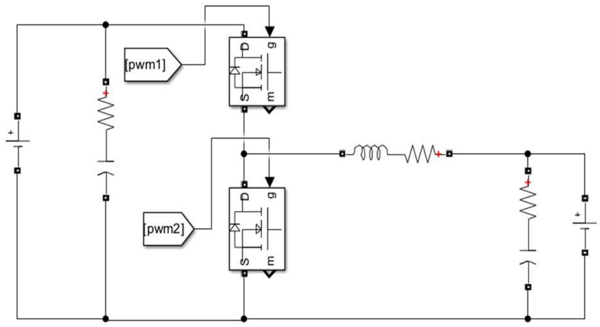


Fig.4. Bidirectional DC/DC Converter

The rating of the system is as follows: 230V and 50Hz of frequency, 400V DC bus, the capacitance (C) is 6.23µF, and the inductance values are 4.36mH and 4.06mH. There is 5.6 mF in the bus capacitance.

The bidirectional converter is given in Fig. 3, and 4 works in both charging and discharging mode. During charging mode, it functions as a buck converter, bringing the input voltage down to the point where the battery needs to be charged. Once the switch is turned on, current passes via the inductor, switcher, and battery. Then power is transferred from the G2V which indicates the charging process. When the bottom switch on the converter is engaged, the converter functions as a boost. The battery voltage (170V) is raised until the DC bus voltage (400V) is reached. When the switch is turned on, current flows via the capacitor, anti-parallel diode, and inductor. Power moves from the car to the grid while

 https://doi.org/10.1051/e3sconf/202454703002

feeding electricity into the system during the battery discharging phase.

4 Control Algorithm

The control scheme of the proposed technique is discussed in this section. Depending upon the grid and battery conditions these control circuits work.

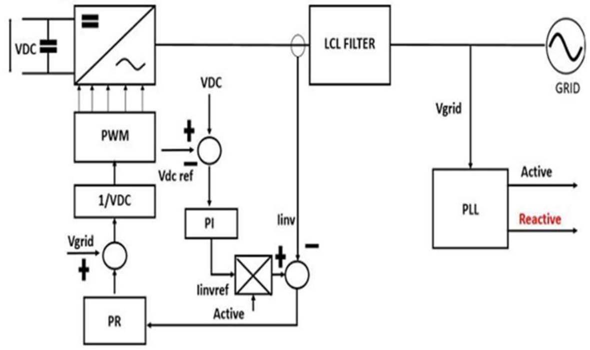


Fig. 5 Control diagram of Bidirectional AC/DC converter

The Fig. 5 illustrates the process of bidirectional power flow under both circumstances. A current mode controller is used to control an AC-DC converter. To produce the grid reference current, the grid PI regulator regulates the DC link voltage error. Because the PR (Proportional-Resonant) controller can track the AC values more accurately than the PI controller.

PI controller is used to manage the error signal that results from comparing the reference grid current with the actual grid current. The PWM generator, which generates the gate pulses for switches S1 through S4, uses the equal signal that was acquired as its reference signal. A triangular carrier waveform is used in this control technique, and reference signals are used to compare it. The PI controller's goal is to maintain the control signal V_{ref} while lowering the error $V_{e(k)}$, which is often expressed as a voltage.

Equation (1) provides the aggregate relationship between these as

$$V_e(k) = V_{ref}(k) - V_{dc}(k) \quad (1)$$

At Kth instant, the output of a controller $I_p(k)$ which is given by equation (2) as

$$I_p^*(k) = I_p^*(k-1) + K_{pv}\{V_e(k) - V_e(k-1)\} + K_{iv}V_e(k) \quad (2)$$

Here, the controller's integral gain is represented by K_{iv}, while its proportional gain is represented by K_{pv}. Equation (3) provides the current error in terms of the reference current (IP * (k)) and sensing current (IP (k).

$$I_e(k) = I_p^* - I_p(k) \quad (3)$$

Use of gain "K" is possible to increase the current inaccuracy indicated in equation (4) is possible to use the above current error as

$$V_{cs} = kI_e(k) \quad (4)$$

Due to the usage of the Pulse Width Modulation technique, the charging and discharging modes of the battery are controlled here. Battery current output can be regulated by a Proportional Integral Controller.

$$I_{eT}(k) = I^*b(k) - Ib(k) \quad (5)$$

5 Results and Discussion

The simulation model of the electric power system which allows the V2G energy transfer and the G2V energy transfer developed in MATLAB. This is a presentation of the MATLAB-developed simulation model of the electric power system that enables energy transfer between vehicles and the grid. The EV battery is charged and discharged using a single-phase AC-DC bidirectional converter case and a synchro rectification DC-DC buck-boost converter.

G2V mode: While the vehicle is connected to the grid during this mode, the display shows the indications of the battery. In this condition, DC and AC waveforms are in phase at 0° phase difference; power is flowing from the grid to the vehicle. Reversing the direction of the current in the battery and maintaining the bus voltage at the value of 400V.

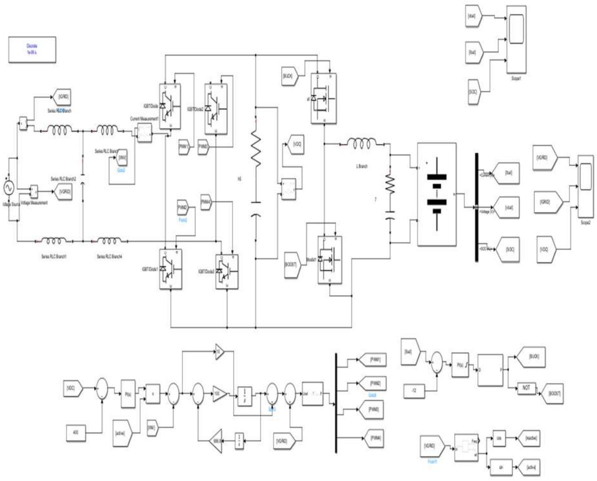


Fig. 6. Simulation diagram Bidirectional Converter

The battery SOC (State of Charge) is higher than the initial one meaning that the battery is charged. SOC seamlessly confirms the charging process by pumping the current in the opposite direction. Its actual voltage can be changed according to its state of charge, and by increasing the load. Fig 7, and Fig 8 show the output waveforms of battery voltage, current, soc, and grid parameters

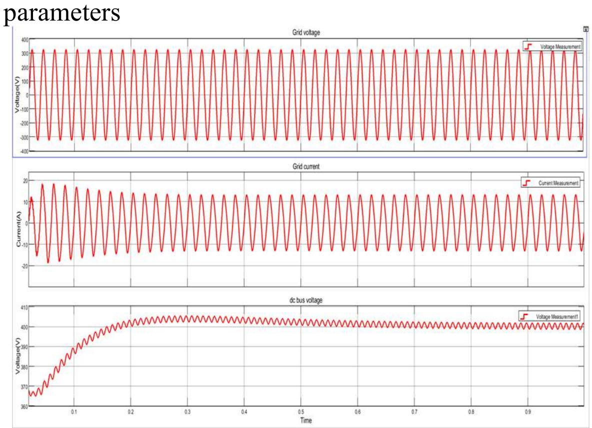


Fig 7 Output waveforms of G2V mode operation at grid side

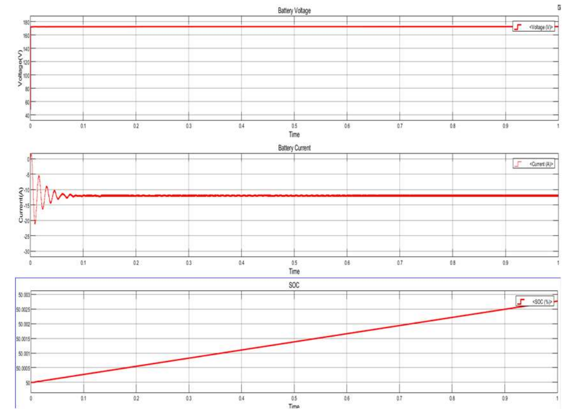
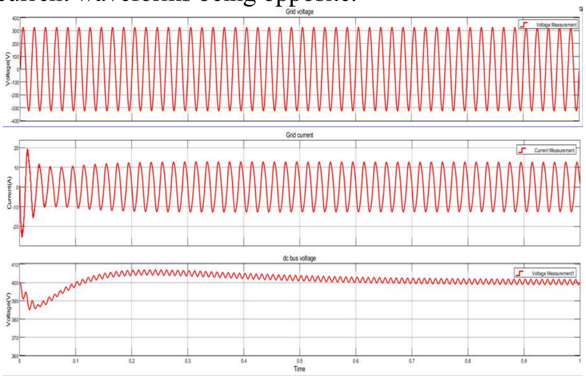
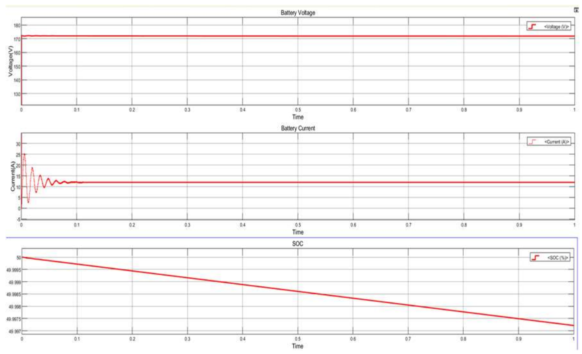


Fig. 8 Output waveforms of V2G mode operation at battery side

V2GMode: Fig. 9 illustrates battery measurements in V2G mode which power is transferred from vehicles to the grid That the vehicle is now supplying electricity to the grid is confirmed by the signs of the voltage and current waveforms being opposite.



(a)



(b)

Fig. 9. Output waveforms of V2G mode Operation

In addition to maintaining the DC bus voltage at 400V, the battery current is positive and matches the reference value of 12A.Vehicle2Grid operation causes a decrease in the State of Charge relative to the initial value from the battery, which corresponds to the discharging process. The flow of the current direction (current discharging) is always seen as positive in the entire battery discharge process. The voltage of the battery remains constant during the V2G mode. In a nutshell, a vehicle during V2G operation behaves as a wide-spread energy source that feeds the grid directly when there is insufficient capacity.

6 Conclusion

By developing the proposed converter, V2G and G2V operations have been successfully tested under two different conditions. Moreover, the harmonic level of the system is also reduced. V2G functionality enables EV owners to contribute their excess energy to the grid through a local aggregator, who manages oversight and control responsibilities in exchange for a predetermined revenue share. Through simulations, it's evident that the EV battery can relieve pressure on the grid by discharging stored power during V2G operation, thus providing surplus energy to the grid. This supports as a tool for grid stabilization.

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