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FEASIBILITY ANALYSIS FOR REACTIVE POWER COMPENSATION OF GRID BY EV CHARGER USING BIDIRECTIONAL POWER FLOW (G2V /V2G)

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Abstract: This paper presents the design, simulation, and detailed analysis of a bidirectional electric vehicle (EV) charger to support reactive power compensation in the electrical grid. The charger operates both in grid-to-vehicle (G2V) and vehicle-to-grid (V2G) modes, leveraging voltage-oriented control (VOC) and constant current control for optimal performance. MATLAB Simulink results demonstrate a stable State of Charge (SOC), regulated DC link voltage, and excellent power quality across various operational scenarios. Rigorous testing of transitions and load changes shows the system's suitability for smart grid environments, with a unity power factor.

Keywords: EV Charger, Bidirectional Power flow, Reactive Power Compensation, EV,V2G, G2V, MATLAB Simulation

I. INTRODUCTION

With the rising adoption of electric vehicles (EV), advanced charging infrastructure is needed not only for fast and efficient battery replenishment but also for providing ancillary grid services such as reactive power compensation and voltage support. Modern bidirectional chargers, using grid-compliant power electronics, enable two-way energy flow between vehicles and the grid, facilitating grid stability, improved power quality, and the integration of renewable energy sources.

EV and plug-in hybrid electric vehicles (PHEV) have emerged as promising tools for enhancing power grid performance, particularly through reactive power compensation and vehicle-to-grid (V2G) and grid-to-vehicle(G2V) operations. The increasing deployment of EV has led to a surge in charging infrastructure, creating challenges such as power imbalance and reduced power quality due to large inductive loads [1]. To address this, solutions like Static Var Generators (SVG) with cascaded H-bridges have been proposed [1], along with control methods such as Proportional-Resonant (PR) controllers to improve power factor and provide reactive power support during charging [2]. Bidirectional charging systems, incorporating both DC/DC and AC/DC converters, allow seamless transitions between battery charging, V2G operations, and reactive power compensation [3]. Advanced feedback systems and control algorithms—such as phase-detector-based control [4], adaptive notch filters [5], and Active Disturbance Rejection Control (ADRC) [12]—further enhance the stability and responsiveness of these systems. Several studies propose using EV chargers not only for power flow control but also for grid support during disturbances, voltage sags, and fluctuations [13, 25]. The integration of solar PV with EV chargers adds another layer of sustainability and grid support [9, 10]. Additionally, innovations such as inductive power transfer systems [14] and firmware-based virtual flux control [22] offer flexibility without requiring significant hardware upgrades. However, concerns about increased battery wear and charging costs due to continuous reactive power provision have been raised, leading to proposals for optimization frameworks that balance cost and functionality [6]. Other researchers have explored single-phase charger impacts on residential grids [18], reactive power effects on grid losses [20], and socio-technical challenges in adopting PHEV and V2G systems [19]. Lastly, advanced control strategies—like Model Predictive Control (MPC) [24], Finite Control Set MPC [26], and unified bidirectional converter designs [28, 29]—support multi-mode operations, enabling EV to provide both active and reactive power services reliably and efficiently.

II. PROBLEM DEFINITION

In V2G and G2V setups, bidirectional converters with advanced control of the DC/DC and DC/AC stages manage reactive power exchange between batteries in electric vehicles and the electricity grid, helping the system stabilize grid voltage during EV charging and discharging. The DC-connected capacitor in the V2G charger that is bidirectional supplies the required reactive power under these control strategies, addressing voltage drops caused by EV operation and adjacent electrical load.

The proposed charger, depicted in Fig.1, has a DC link capacitor, a bidirectional DC-DC converter, and a bidirectional AC-DC converter on the AC side. In contrast to conventional configurations, the EV battery avoids exposure to DC link ripple by connecting to the DC bus via a converter, which is a DC-DC type. The DC-to-DC converter allows independent selection of DC bus voltage, enhancing flexibility. Charging current smoothness is achieved through output filter of the converter, and control of the battery charging current is facilitated by adjusting the duty cycle.

Between the electric car (EV) system and the lower-voltage (LV) distribution system, an RL filter lowers the harmonics that the converters produce. In order to meet the demands for inductive or capacitive reactive power, the charger controls both active and reactive power with the grid. Whereas the DC/DC stage depends on current control for charging and discharging, the AC/DC stage uses voltage control for the grid and DC-link stable voltage.

The converter, which is a DC-DC type, through current-controlled operation, manages the battery current’s direction and level to set charging or discharging modes. While the DC-DC converter handles voltage adaptation between the battery and the DC connection, the bidirectional AC-DC converter handles correction of power factors and grid-side current control.

In V2G applications, both of these stages work together to offer accurate, bidirectional management of power flow, giving grid operators improved visibility and operational control

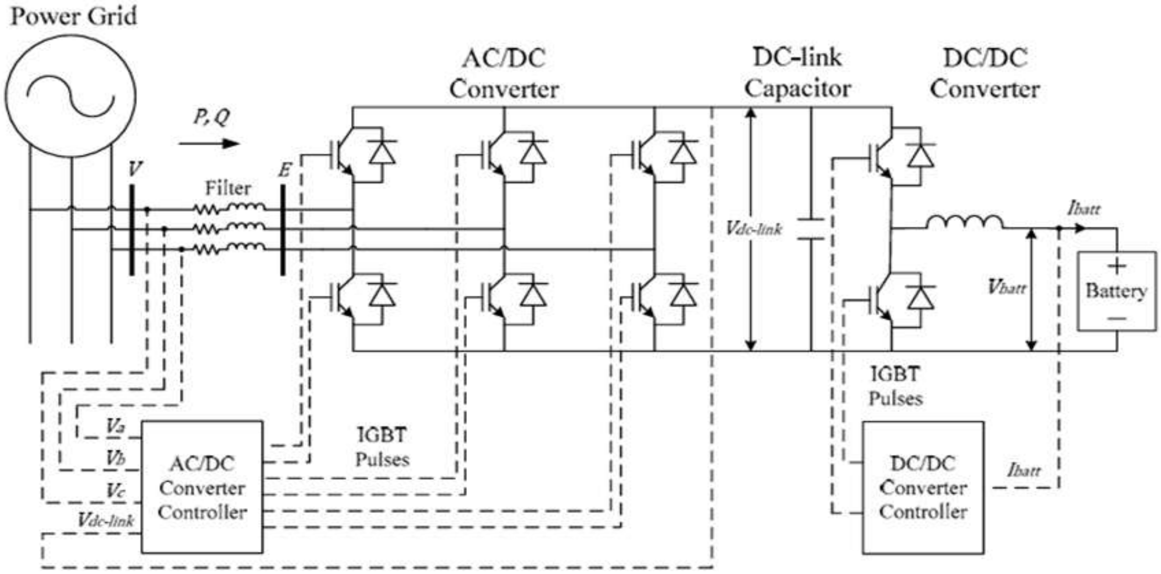

Fig.1 Three-Phase Bidirectional EV Charger

III SIMULATION MODEL AND PARAMETERS OF PROPOSED EV BIDIRECTIONAL CHARGER

Fig.2 shows the basic MATLAB Simulink topology of a three-phase bidirectional EV charger for V2G and G2V applications.

The EV Charger model is divided into four parts:
(i). Three-Phase grid-connected AC/DC PWM converter
(ii). Control System of AC/DC bidirectional converter
(iii). DC/DC non-isolated buck-boost converter
(iv). Control System of DC/DC bidirectional converter

An AC-DC front-end converter on the charger's input side transforms the grid's AC voltage into a DC voltage that the EV battery can use for buck-boost. The AC/DC converter's control system is crucial for preserving the DC link voltage.

An EV battery is charged and discharged using a buck-boost converter. The buck and boost converters are used by the controller to control battery current during charging and discharging. In addition to controlling the 800V DC bus voltage constant, the DC link capacitor, which is positioned between the AC-DC and DC-DC Stages, preserves voltage stability during transients. Grid frequency is 50Hz, and 415V rms is the grid voltage. When using the LCL filter, the capacitance is 30μF on each side, and the filter inductance is 5mH on both sides.

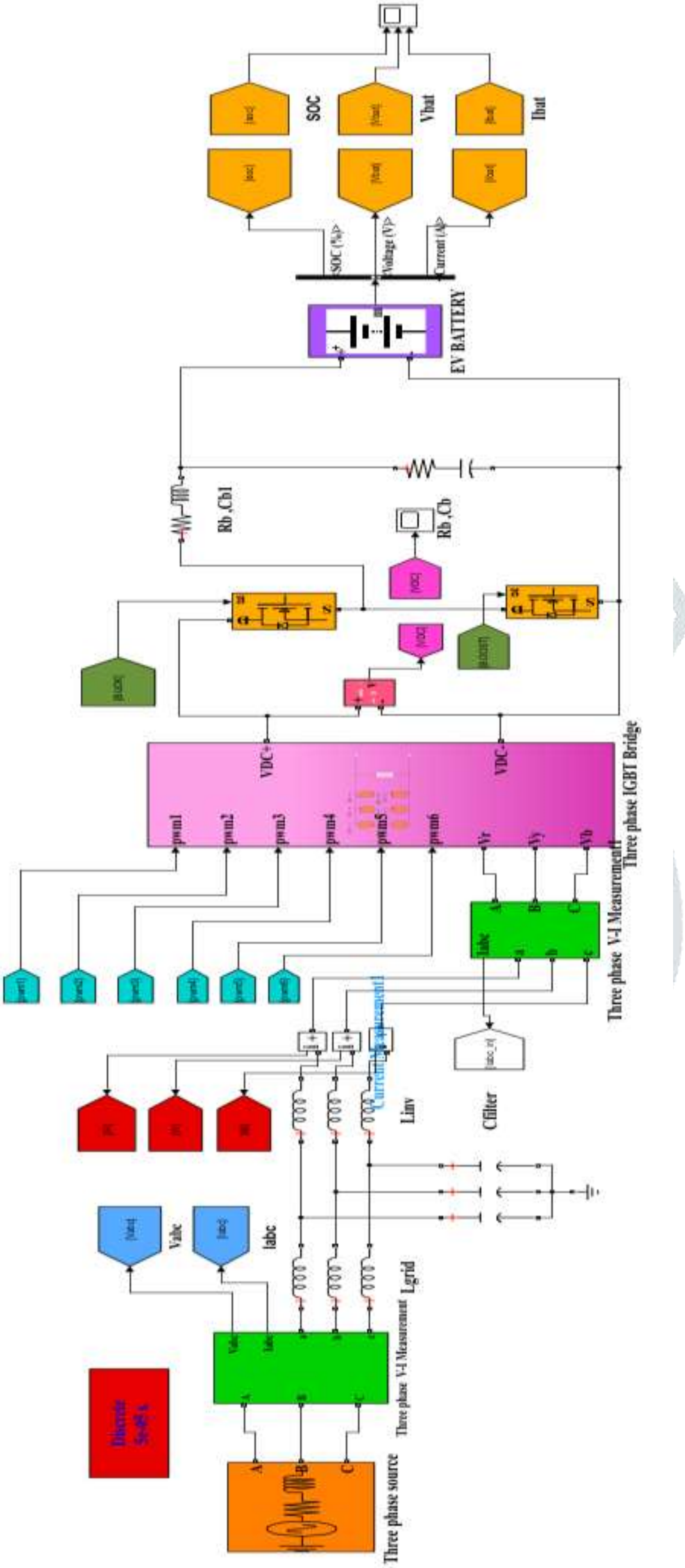

Fig. 2 Simulink Topology of a Three-Phase Bidirectional EV Charger

The PFC AC/AC converter and buck-boost DC/DC converter parameters listed in Tables 1, Table 2, and Table 3 are used to simulate the EV bidirectional charger. To evaluate the system's performance under various circumstances, the simulation methodology comprised creating multiple scenarios, varying input variables, and running simulations.

Table 1: The Parameters of the PFC AC/DC Converter

Parameter	Symbol	Value
Rated power	P	10kW
Grid rms value	Vg	400V
DC link voltage	Vdc	800V
DC link capacitor	Cdc	5600mF
Switching Frequency	Fsw	10kHz
Proportional coefficient of inner control loop	Kp-ig	9
Integral coefficient of Inner control loop	K_I-ig	30
Proportional coefficient of Outer control loop	Kp-$_V$	0.0042
Integral coefficient of Outer control loop	$K_{I\text{-}V}$	0.26

Table 2: The Parameters of the Bidirectional DC/DC Converter

Parameter	Symbol	Value
Rated power	P	10kW
Buck-Boost inductor	L_B	20mH
Buck-Boost capacitance	C_b	0.625μF
Switching Frequency	F_{sw}	10kHz
DC-PWM proportional coefficient	$K_{P\text{-}DC}$	0.05
DC-PWM Integral coefficient	$K_{I\text{-}DC}$	10

Table 3: The Parameters of Li- ion Battery

Parameter	Symbol	Value
Battery nominal voltage	V_b	400V
Rated capacity	(Ah)	150Ah
Battery power	P_{bat}	10kW
Maximum capacity	Ah	150Ah

IV RESULTS AND DISCUSSION

A 10-kW bidirectional charger's Simulink simulations show that the system effectively regulates the flow of active and reactive power between the grid and the EV battery. Reactive power compensation is made easier by the AC/DC converter's voltage-controlled approach, which also addresses grid voltage drop problems during EV charging and other grid loads. The proposed EV bidirectional model is simulated and analyzed with various configuration including V2G and G2V.

The model simulation is carried out for V2G at $I_{bat\text{-}ref}$ =25A, SOC=50%, and simulation results for Battery Output waveform of SOC, battery voltage, battery current, DC link Output voltage waveform, Output voltage and current waveform of the grid, PWM Buck Boost waveform of DC-DC converter, PWM waveform of AC-DC bidirectional converter for V2G for $I_{bat\text{-}ref}$ =25A, SOC=50% are shown in Fig.3, Fig.4, Fig 5, Fig.6, Fig.7, respectively.

Battery reference current is set to 25A in DC- DC controller, the SOC of the battery is set to 50%, and the battery voltage is 400V. The boost mode is activated in the DC-DC bidirectional converter by DC-DC controller. From Fig.3, the voltage of the EV battery decreases from 431V to 428.5V in 0.5s. The SOC of the EV battery starts decreasing, which means power is going to the grid from the vehicle, showing discharging. The battery current is positive, increases slightly, and experiences some fluctuation, and after 0.01 sec current becomes almost constant at 25.10A because we are using the Constant current charging method.

In Fig.4, it is seen that the DC voltage controller in the AC-DC controller maintains the DC link voltage almost constant at 800V. The output three-phase voltage and current waveform of the grid are in phase for $I_{bat-ref}$ =25A, SOC=50% is shown in Fig.5. PWM Buck Boost waveform of DC-DC converter, PWM waveform of AC-DC bidirectional converter for V2G for $I_{bat-ref}$=25A and SOC 50% is shown in Fig.6 and Fig.7, respectively.

The boost mode is activated by a PWM pulse generated by the DC-DC pulse generator, whose frequency is set to 10kHz, as shown in Fig.6. The boost mode will increase the voltage by taking power from the vehicle's battery to almost 800V DC link voltage.

An AC-DC converter converts DC voltage to AC voltage by using an AC/DC controller that acts as an inverter, which is synchronized with the grid. Fig.7 shows six PWM pulses (pwm1, pwm2, pwm3, pwm4, pwm5, pwm6) generated by a pulse generator (2-level) whose frequency is set at 10kHz for inverter operation.

For G2V simulation results of Bidirectional EV charger with $I_{bat-ref}$ =-25A and SOC=20%, and their output waveforms are shown in Fig.8, Fig.9, Fig.10, Fig.11, Fig.12 respectively.

Battery reference current is set to -25A in DC- DC controller, the SOC of the battery is set to 50%, and the battery voltage is 400V. The buck mode is activated in the DC-DC bidirectional converter by DC-DC controller. From Fig.8, it is seen that the voltage of the EV battery increases from 431.5V to 432V in 0.5s, the SOC of the EV battery starts increasing, meaning power is going to the vehicle's battery from the grid, showing charging. The battery current is negative, increases slightly, and experiences some fluctuation. After .01s current becomes almost constant at -20.86A because we are using the Constant current charging method.

From Fig.9, it is realized that the DC voltage controller in the AC-DC controller maintains the DC link voltage almost constant at 799.5V, slightly decreasing. The grid voltage and current are aligned in phase, which means power is being injected from the grid to the vehicle's battery is shown in Fig.10.The reactive power reference I_q is set to zero for unity power factor operation (UPF). Fig.11 shows the PWM pulses for the buck-boost DC-DC converter for G2V operation. The buck mode is activated by a PWM pulse generated by the DC-DC pulse generator, whose frequency is set to 10kHz. Buck mode will decrease the voltage of the DC link bus (800V), which is compatible with the battery voltage.

An AC-DC converter converts AC voltage to DC voltage by using an AC/DC controller that acts as a rectifier, maintaining the DC link bus voltage about 800V by injecting the current from the battery, which is synchronized with the grid. Fig. 12 shows six PWM pulses (pwm1, pwm2, pwm3, pwm4, pwm5, pwm6) generated by a pulse generator (2-level) whose frequency is set at 10kHz for rectification operation.

Simulation results of Bidirectional EV charger for V2G to G2V with $I_{bat-ref}$ =25A to –25A and SOC=50% is shown in Fig.13 and Fig.14. Battery reference current is set to 25A in the DC-DC controller, the SOC of the battery is set to 50% and the battery voltage is 400V for 0.5s for V2G mode, and battery reference current changes to -25A after 0.5s to 1s for G2V mode with the same battery voltage and SOC. The boost mode is activated in the DC-DC bidirectional converter by DC-DC controller. From Fig.13, the voltage of the EV battery decreases from 430V to 429.5V in 0.5s, the SOC of the EV battery starts decreasing up to 0.5s, meaning power is going to the grid from the vehicle, showing discharging. The battery current is positive, increases slightly, and experiences some fluctuation, and after .01s current becomes almost constant at 25.10A. After 0.5s to 1s, G2V operation is executed, in which buck mode is activated to charge the battery from the grid in a DC-DC bidirectional converter by dc-dc controller. Fig.13 shows that the voltage of the EV battery increases from 429.5V to 430 from 0.5s to 1s. The SOC of the EV battery starts increasing from 0.5s up to 1s, meaning power is going to the vehicle battery from the grid (G2V), showing charging. The battery current is negative, increases slightly, and experiences a fluctuation, and after 0.01s current becomes almost constant at -25.10A because we are using the Constant current charging method. From Fig.14, it is seen that the DC voltage controller in the AC-DC controller maintains the DC link voltage almost constant at 800V for V2G mode for 0.5s, and from 0.5s to 1s, G2V mode DC link voltage slightly decreases to 797.5V, almost a constant value of 800V.

Results of Bidirectional EV charger for G2V to V2G with $I_{bat-ref}$ =-25A to 25A and SOC=80% are shown in Fig.15 and Fig.16. Battery reference current is set to -25A in DC-DC controller, the SOC of the battery is set to 80% and the battery voltage is 400V for 0.5s for G2V mode, and battery reference current changes to 25A after 0.5s to 1s for V2G mode with the same battery voltage and SOC. The buck mode is activated in the DC-DC bidirectional converter by dc-dc controller. From Fig.15, it is visible that the voltage of the EV battery increases from 433.5V to 434.5V in 0.5s, the SOC of the EV battery starts increasing up to 0.5s, meaning power is going to the vehicle's battery from the grid, showing a charging operation. The battery current is negative, increases slightly, and experiences some fluctuation, and after 0.01s current becomes almost constant at -25.10A because we are using the Constant current charging method.

After 0.5s to 1s, V2G operation is executed, in which boost mode is activated to discharge the battery to the grid in a DC-DC bidirectional converter by DC-DC controller. From Fig.15, it is seen that the voltage of the EV battery decreases from 434.5V to 433.5V from 0.5s to 1s. The SOC of the EV battery starts decreasing from 0.5s up to 1s, meaning power is going to the grid from the vehicle's battery (V2G), showing discharging. The battery current is positive, increases slightly, and experiences some fluctuation, and after 0.01s current becomes almost constant at 25.10A.

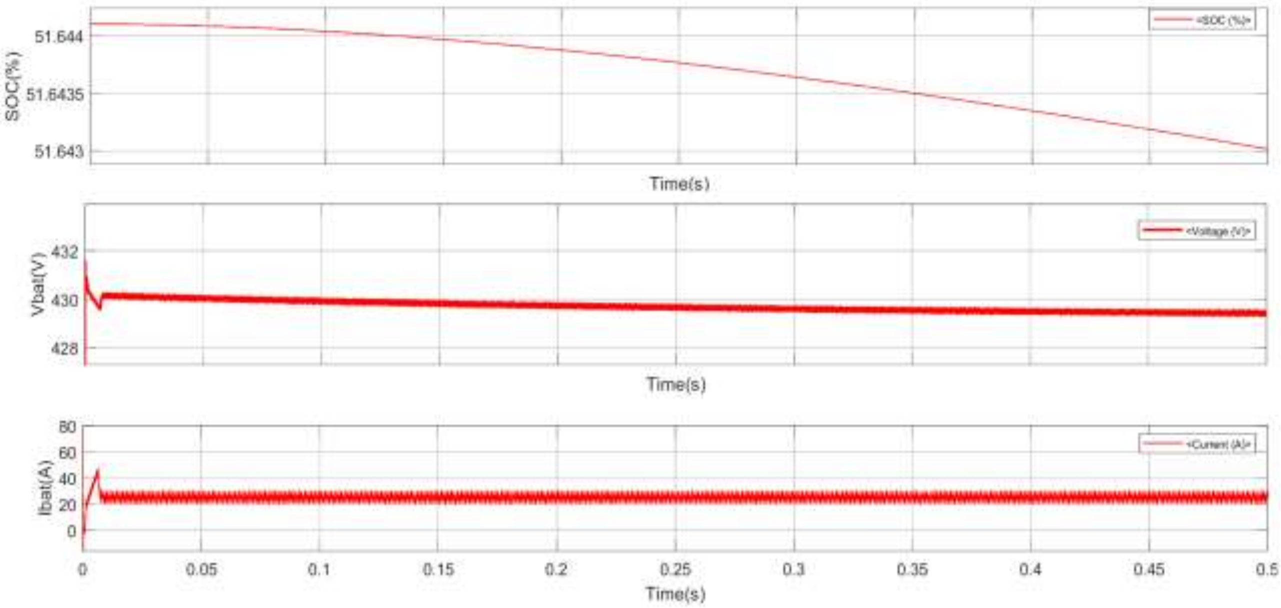

Fig.3 Battery Output Waveform of SOC, Battery voltage, Battery Current for V2G for $I_{bat-ref}$ =25A and SOC=50%,

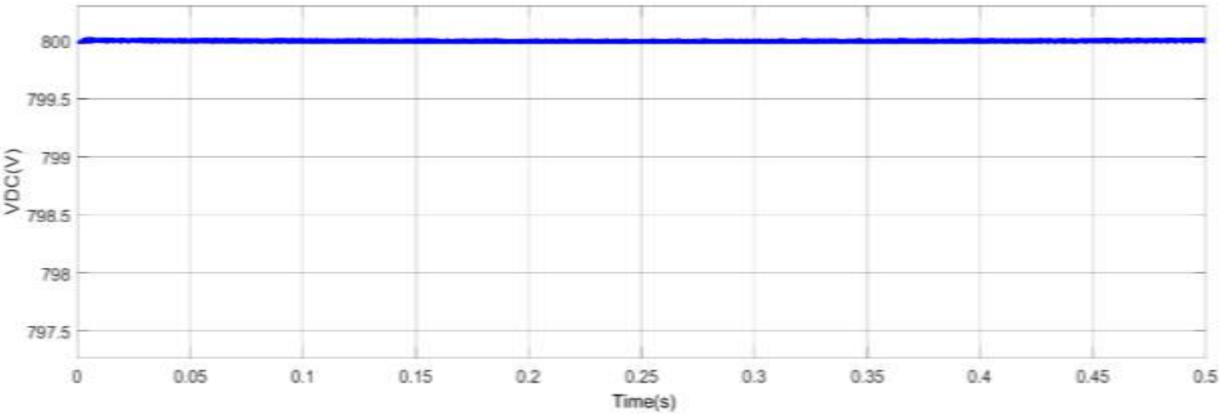

Fig.4 DC link Output Voltage Waveform for V2G (Discharging) for $I_{bat-ref}$ =25A and SOC=50%,

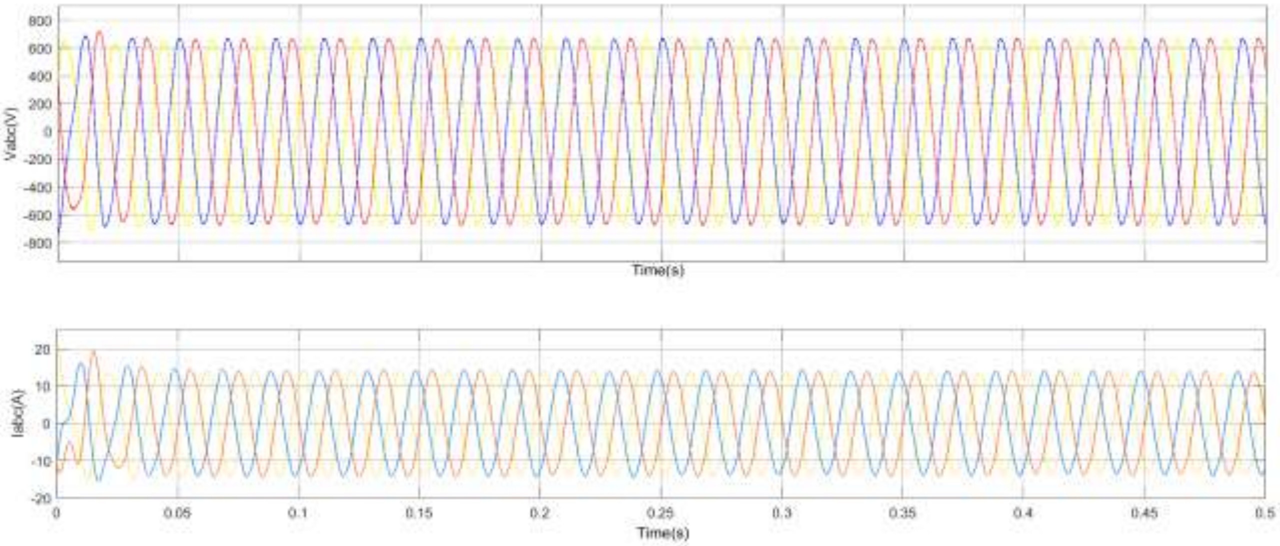

Fig.5 Output Voltage and Current Waveform of the Grid $I_{bat-ref}$ =25A, SOC=50%,

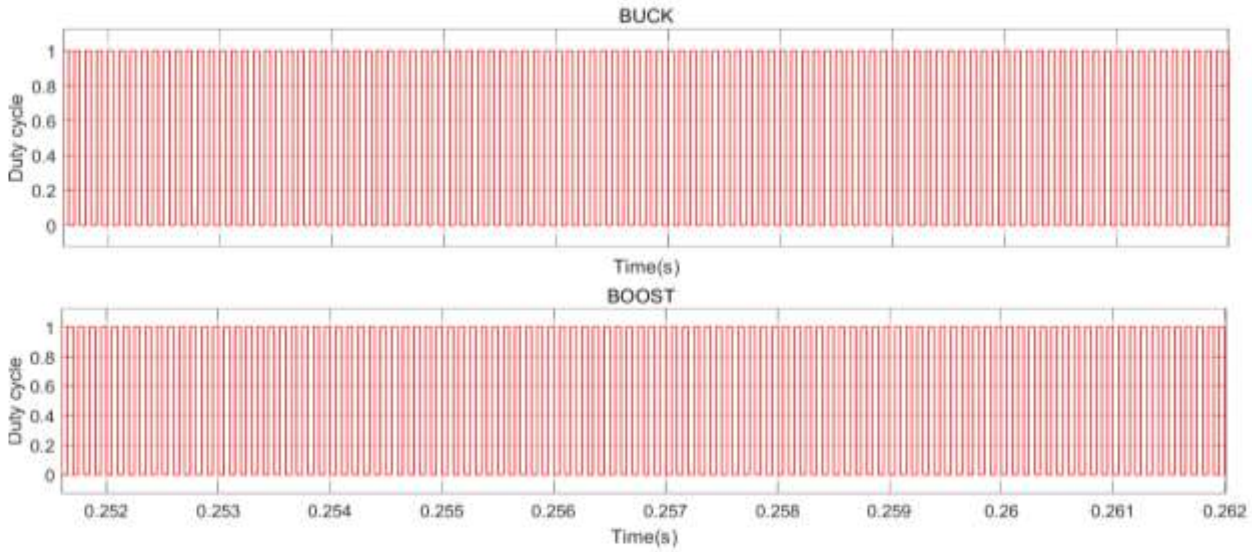

Fig.6 PWM Buck Boost Waveform of DC-DC Converter for V2G for $I_{bat\text{-}ref}$ =25A and SOC=50%

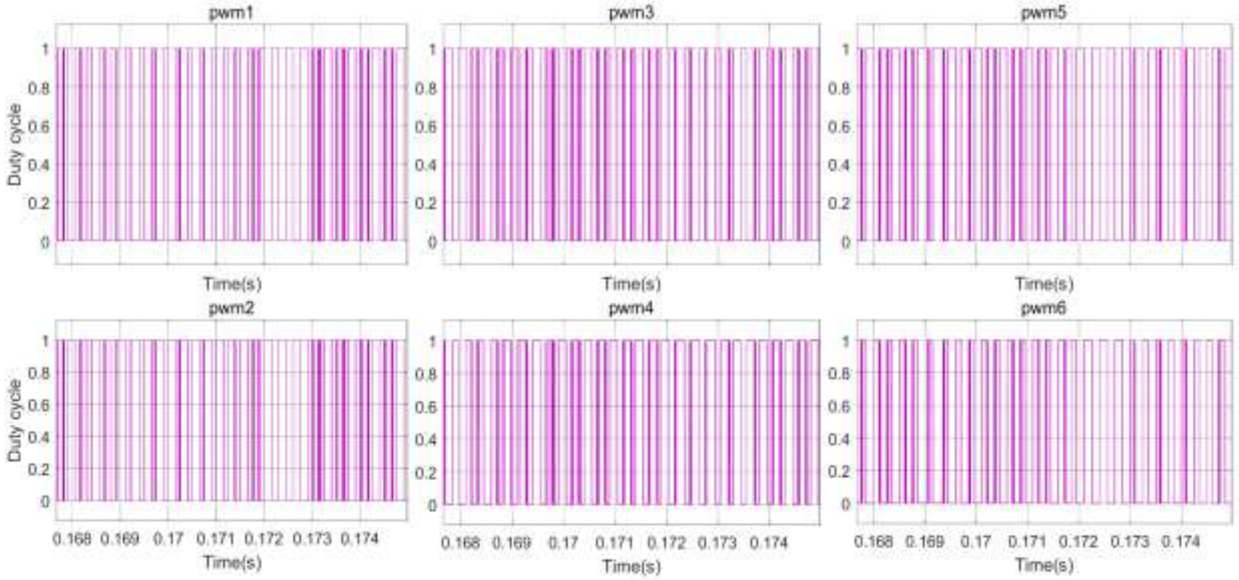

Fig.7 PWM Waveform of AC-DC Bidirectional Converter for $I_{bat\text{-}ref}$ =25A and SOC=50%

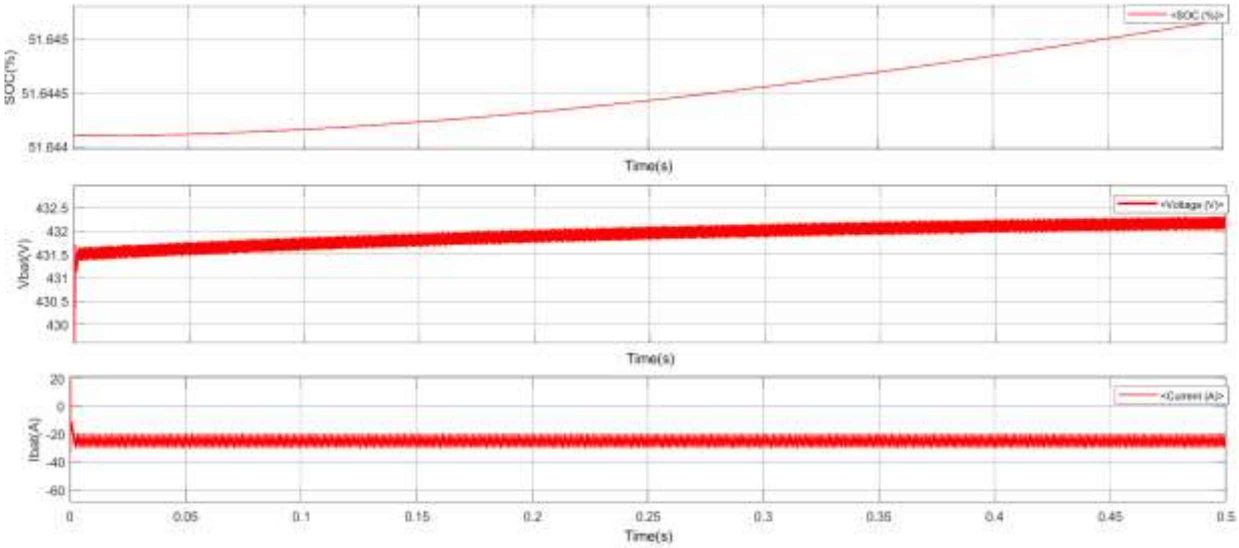

Fig.8 Battery Output Waveform of SOC, Battery voltage, Battery Current for G2V for $I_{bat\text{-}ref}$ =-25A and SOC=50%,

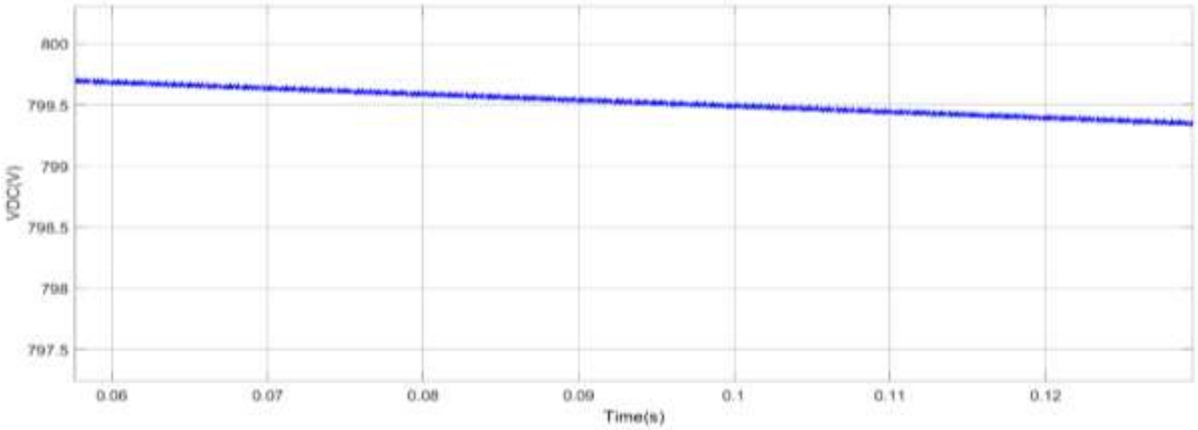

Fig.9 DC link Output Voltage Waveform for G2V(Charging) for $I_{bat-ref}$ =-25A and SOC=50%,

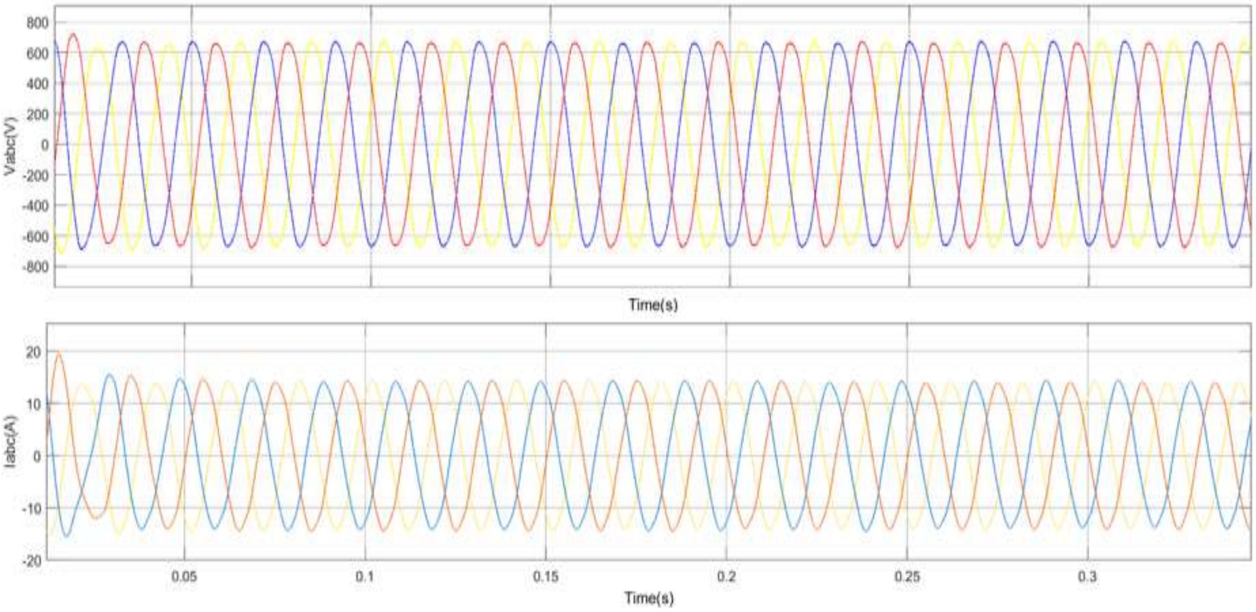

Fig.10 Output Voltage and Current Waveform of the Grid for $I_{bat-ref}$ =-25A and SOC=50%

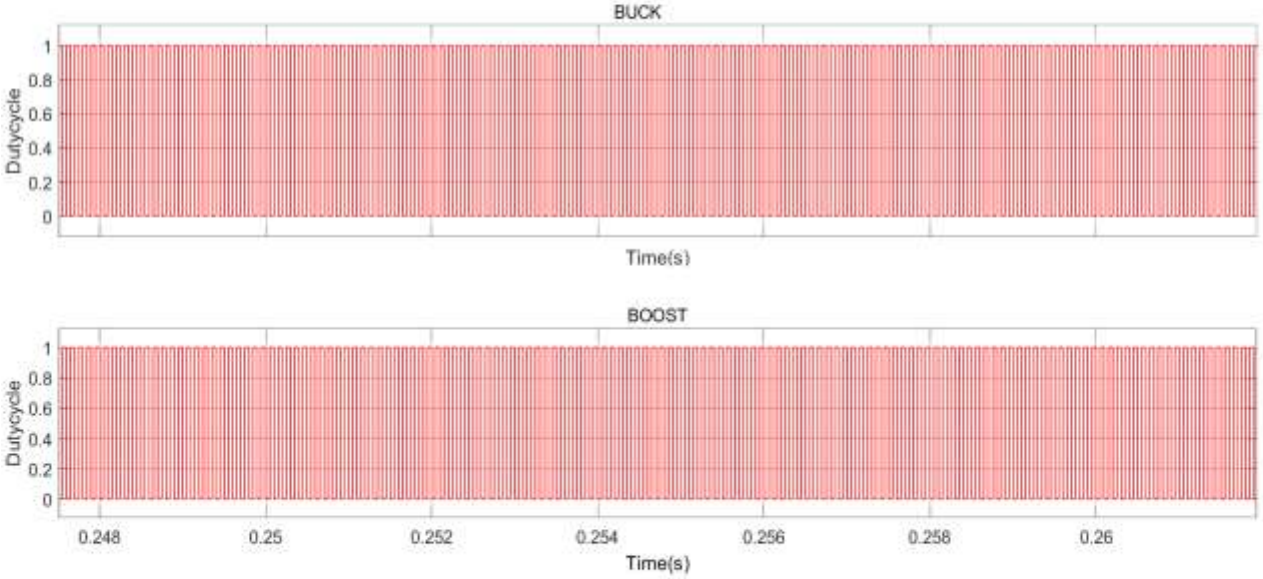

Fig.11 PWM Buck Boost Waveform of DC-DC Converter for G2V(Charging) for $I_{bat-ref}$ =-25A and SOC=50%

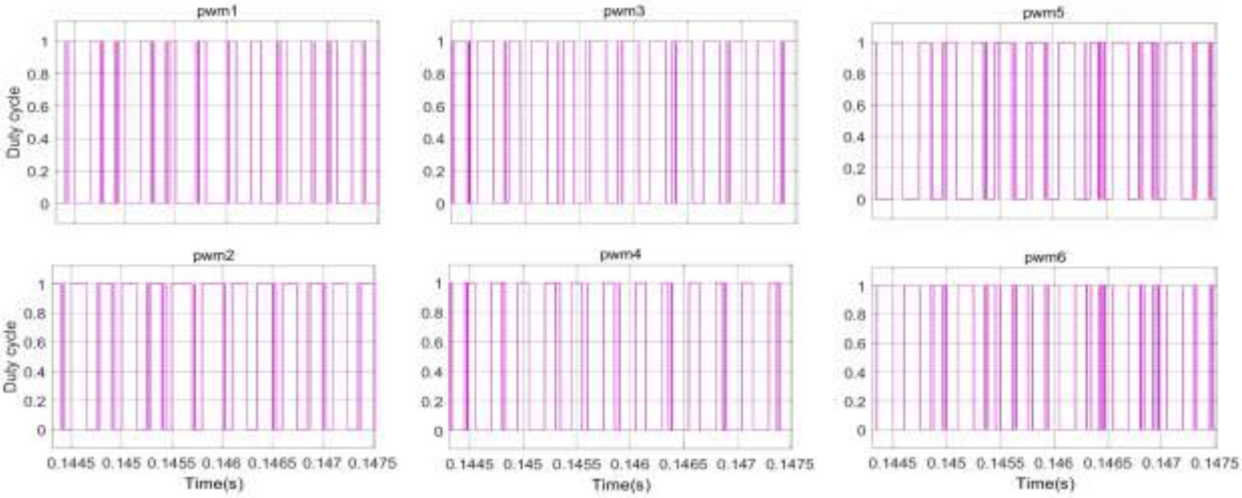

Fig.12 PWM Waveform of AC-DC Bidirectional Converter, Display Results of V2G for G2V for $I_{bat-ref}$ =-25A and SOC=50%

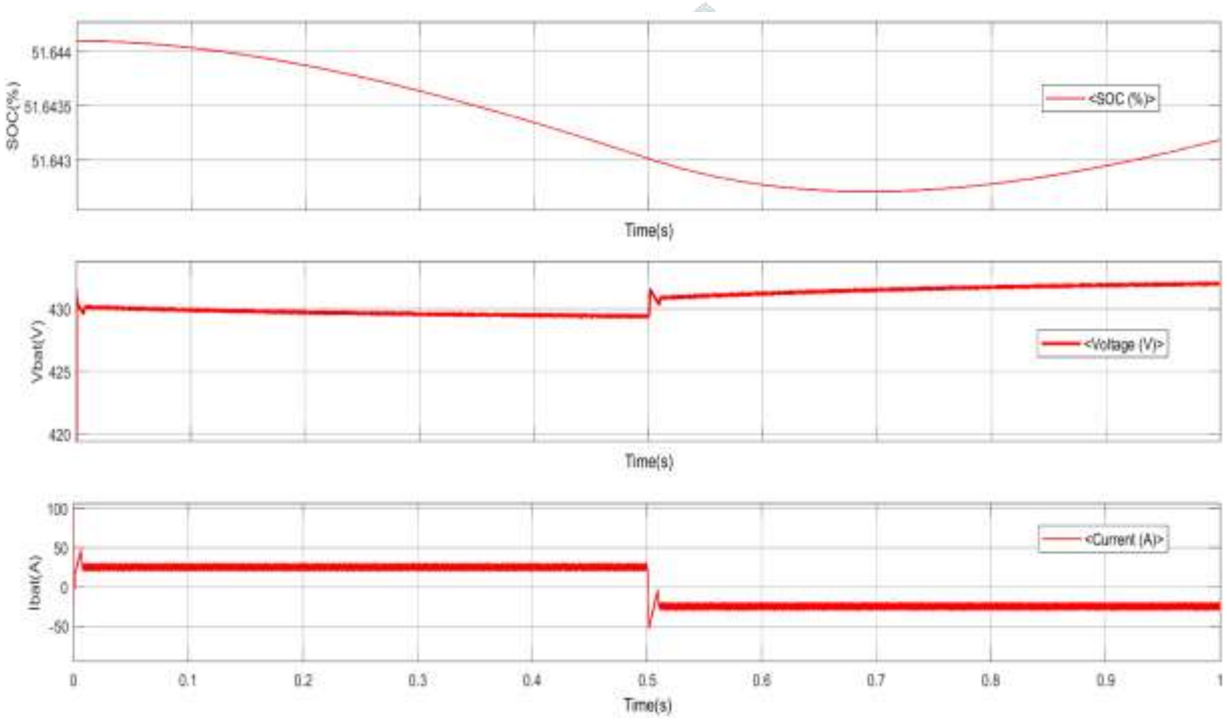

Fig.13 Battery Output Waveform of SOC, Battery voltage, Battery current for $I_{bat-ref}$ =25A to -25A(Transition Phase) and SOC=50%

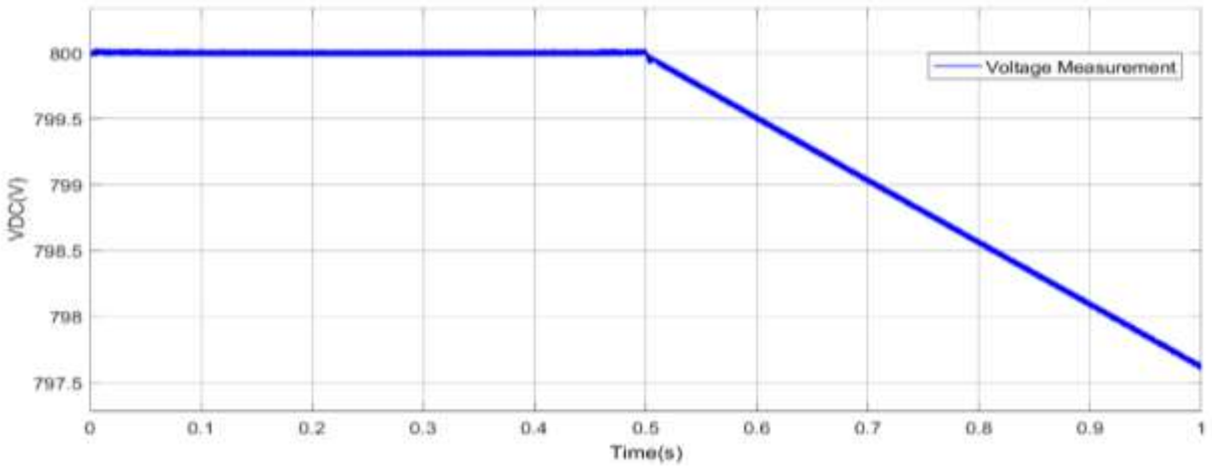

Fig.14 DC link Output Voltage Waveform for V2G to G2V for $I_{bat-ref}$ =25A to -25A (Transition Phase) and SOC=50%

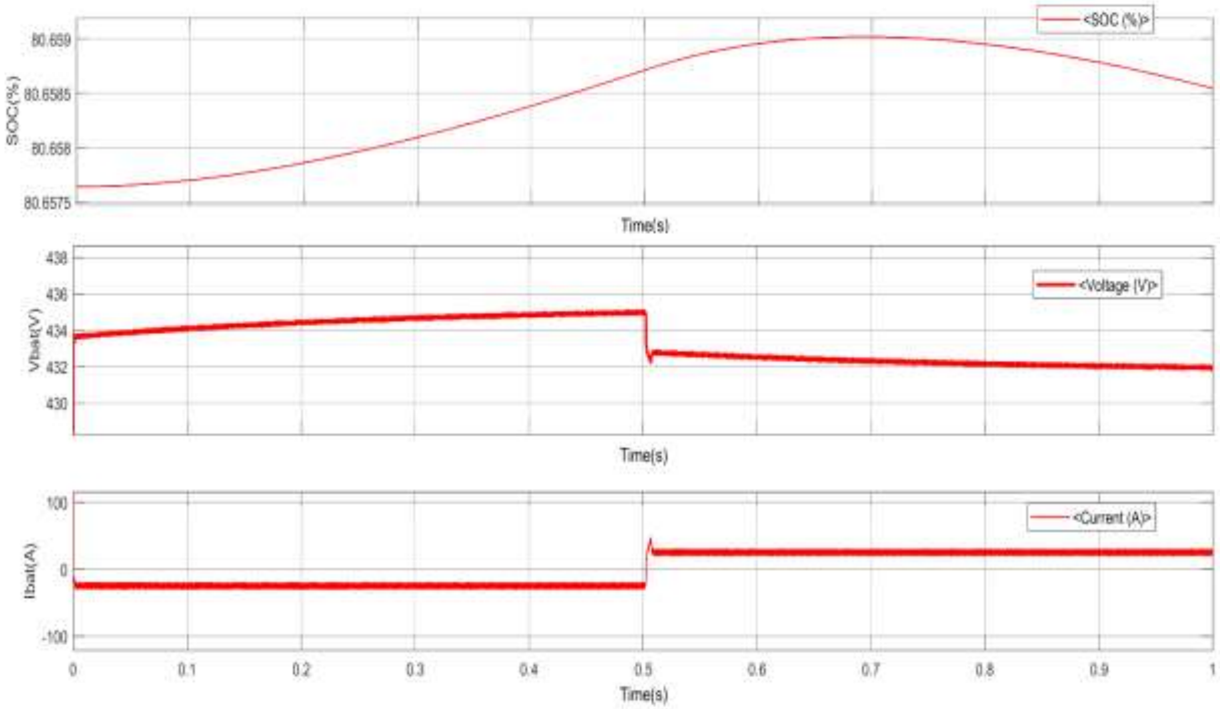

Fig.15 Battery Output Waveform of SOC, Battery voltage, Battery current for G2V to V2G for $I_{bat\text{-}ref}$ =-25A to 25A (Transition Phase) and SOC=80%

From Fig.16, it is seen that the DC voltage controller in the AC-DC controller maintains the DC link voltage, slightly decreases to 797.5V, almost constant at 800V during G2V mode for 0.5s and from 0.5s to 1s for V2G mode also DC link voltage, almost a constant value of 800V.

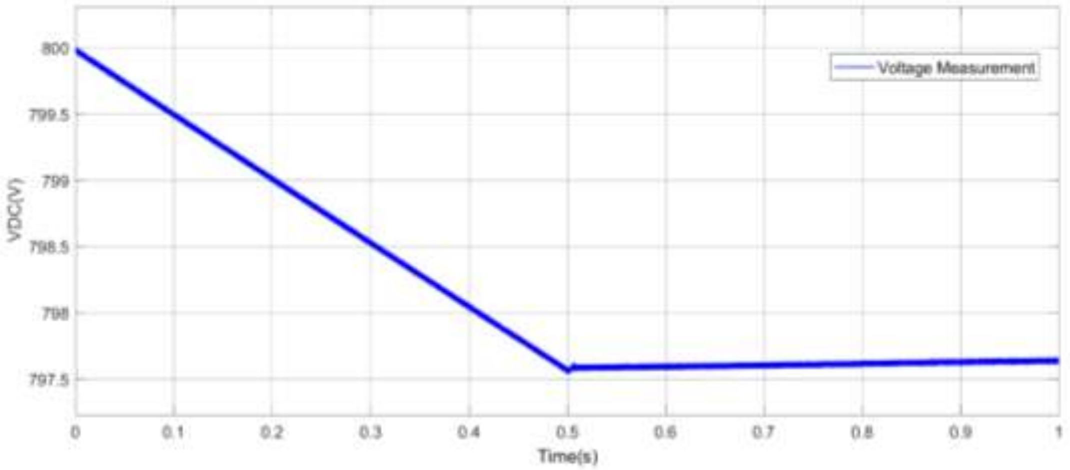

Fig.16 DC link Output voltage waveform for G2V to V2G for $I_{bat\text{-}ref}$ =-25A to 25A (transition phase) and SOC=80%

Table 4 Features of G2V and V2G Operation

Feature	**G2V (Grid to Vehicle)**	**V2G (Vehicle to Grid)**
Power Direction	Grid → EV Battery	EV Battery → Grid
Primary Goal	Battery charging	Grid support (load levelling, frequency regulation)
VOC Role	Maintains DC-link voltage and synchronizes to the grid	Maintains the DC-link while exporting power
Converter Mode	DC-DC: Buck mode	DC-DC: Boost mode
Battery Current	Negative (-20.86A to -25.10A) (charging)	Positive (~25.10A) (discharging)
Battery Voltage	Increasing (431.5V to 432V)	Decreasing (431V to 428.5V)
DC Link Voltage	Regulated at ~799.5V	Maintained at ~800V

State of Charge (SOC)	Increases over time	Decreases over time
Power Factor	Unity Power Factor (UPF)	Unity Power Factor (UPF)
Active Power Control (I_d)	Positive (into battery)	Negative (into grid)
Reactive Power Control (I_q)	Can be adjusted to support the grid (e.g., voltage regulation)	Same-grid voltage support is possible
Grid Compliance	Must follow standards (IEEE 1547, IEC 61851, etc.)	Requires tighter control due to potential grid impact

(V) FEASIBILITY ANALYSIS OF PERFORMANCE

- **G2V (Charging) Mode Performance**: During grid-to-vehicle (G2V) operation, active power is transferred from the grid to the vehicle, with the current control strategy maintaining the battery current nearly constant in the range of approximately −20.86A to −25.10A following an initial transient period of about 0.01s. Simultaneously, the AC/DC converter operates as a rectifier to regulate the DC-link bus voltage at approximately 800V.
- **V2G (Discharging) Mode Performance**: In vehicle-to-grid (V2G) mode, the EV battery provides active power back to the grid while the battery current is controlled using a constant current control technique to maintain a steady value of 25.10A. In order to efficiently transfer power to the grid, the DC-DC converter simultaneously runs in boost mode, raising the battery voltage to the necessary 800V DC-link level.
- **Transition and Stability**: The system enables seamless transitions between grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operating modes while maintaining a stable DC-link voltage, with only minor and short-lived fluctuations observed, such as a brief dip from 800V to approximately 797.5V during G2V operation. Simulation results for transitions between V2G and G2V at t=0.5s confirm the high stability of the system, as the DC-link voltage quickly recovers after the transient. Additionally, both operating modes support reactive power compensation to mitigate grid voltage drops by independently regulating the reactive power reference (I_q) irrespective of active power transfer.

  The simulation generated several critical waveforms that validate the feasibility analysis:
- **Battery Waveforms (SOC, Voltage, Current)**: It shows the charging (increasing SOC/Voltage, negative Current) and discharging (decreasing SOC/Voltage, positive Current) characteristics. In the SOC & Battery Voltage Graphs, it is clear that in V2G mode, the SOC curve has a negative slope, and battery voltage decreases. In G2V mode, the SOC curve has a positive slope, and battery voltage increases.
- **Grid Waveforms**: It demonstrates that grid voltage and current are aligned in phase, confirming unity power factor and stable synchronization.
- **DC Link Voltage**: The system maintains consistent 800V tracking across both modes of operation, demonstrating the robustness of the Voltage-Oriented Control (VOC).
- **PWM Signals**: It verifies that the DC-DC converter correctly switches between Buck (G2V) and Boost (V2G) modes at a frequency of 10kHz.

VI. CONCLUSION

The system works well in both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes and can control the flow of both active and reactive power between the grid and the EV battery. The AC/DC converter's voltage-controlled approach successfully facilitates reactive power compensation, which is essential for addressing grid voltage drop problems caused by EV charging and other grid loads. It retained a steady, regulated DC link voltage and a steady State of Charge (SOC) for the EV battery in all situations. The system performs well under abrupt load variations and manages seamless transitions between G2V and V2G operating modes. In terms of controlling the battery current reference tracking (positive/negative), offering quicker dynamic performance, and guaranteeing a smooth transition between modes, the current control method was found to be superior.

The most effective way to regulate voltage is to use Voltage-Oriented Control (VOC) in conjunction with inner current-phase loops. VOC regulates the battery-side voltage or the DC-link voltage loop with inner loops controlling current or duty cycle.

Table 4 shows the features of G2V and V2G operation. G2V charges the EV battery from the grid, while V2G sends power back from the battery to support the grid. Active power flow reverses between the two modes, though both can provide reactive power for voltage regulation.

REFERENCES

[1] Cai, Aiguo, Yannan Yu, Liang Xu, Yunbo Niu, and Jichi Yan. "Review on reactive power compensation of electric vehicle charging piles." 22nd IEEE International Conference on Electrical Machines and Systems (ICEMS), Harbin, China, pp. 1-4 August, 2019.

[2] Ma Youjie, Chang Liu, Xuesong Zhou, and Zhiqiang Gaol. "Reactive Power Compensation Method for Distribution Network from Electric Vehicles." 37th IEEE Chinese Control Conference (CCC), Wuhan, China, pp. 8826-8830, July, 2018.

[3] Gallardo-Lozano, Javier, Enrique Romero-Cadaval, Victor Miñambres-Marcos, Dmitri Vinnikov, Tanel Jalakas, and Hardi Hõimoja. "Grid reactive power compensation by using electric vehicles in 9th international IEEE Electric Power Quality and Supply Reliability Conference (PQ 2014), Rakvere, Estonia pp. 19-24, June, 2014.

[4] Latifi, Mohammadshayan, Reza Sabzehgar, and Mohammad Rasouli. "Reactive power compensation using plugged-in electric vehicles for an AC power grid." 44th Annual IEEE Industrial Electronics Society Conference, IECON Washington, DC, USA, pp. 4986-4991, December, 2018.

[5] Lenka, Rajesh Kumar, Anup Kumar Panda, Ashish Ranjan Dash, Naik N. Venkataramana, and Nishit Tiwary. "Reactive Power Compensation using Vehicle-to-Grid enabled Bidirectional Off-Board EV Battery Charger." 1st IEEE International Conference on Power Electronics and Energy (ICPEE), Bhubaneswar, India, pp. 1-6. February,2021.

[6] Mojdehi Mohammad Nikkhah, and Prasanta Ghosh. "An on-demand compensation function for an EV as a reactive power service provider." IEEE Transactions on Vehicular Technology, Vol. 65, No. 6 pp. 4572-4583, 2016

[7] Kisacikoglu, Mithat C., Burak Ozpineci, and Leon M. Tolbert. "Examination of a PHEV bidirectional charger system for V2G reactive power compensation." Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), Palm Springs, CA, USA pp. 458-465, March, 2010.

[8] F. O. Igbinovia, G. Fandi, J. Švec, Z. Müller and J. Tlusty, "Comparative review of reactive power compensation technologies," 16th International Scientific Conference on Electric Power Engineering (EPE), Kouty nad Desnou, Czech Republic, pp. 2-7, May,2015.

[9] Fernão Pires, António Roque, Duarte M. Sousa, and Gil Marques. "Photovoltaic electric vehicle chargers as a support for reactive power compensation." IEEE International Conference on Renewable Energy Research and Applications (ICRERA), Nagasaki, Japan pp. 1-6, March, 2013.

[10] Falahi, Milad, Hung-Ming Chou, Mehrdad Ehsani, Le Xie, and Karen L. Butler-Purry. "Potential power quality benefits of electric vehicles." IEEE Transactions on Sustainable Energy Vol 4, No.4, pp. 1016-1023, October, 2013.

[11] Erb, Dylan C., Omer C. Onar, and Alireza Khaligh. "Bi-directional charging topologies for plug-in hybrid electric vehicles." Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), Palm Springs, CA, USA, pp. 2066-2072, March, 2010.

[12] Aboudrar, Imad, Soumia El Hani, Khadija El Harouri, João Martins, and Ricardo Jardim Goncalves. "Reactive Power Compensation by ADRC in Vehicle to Grid Application during Grid Fault Conditions." IEEE International Conference on Electrical and Information Technologies (ICEIT), Rabat, Morocco, pp. 1-6, June, 2020.

[13] Choi, Wooyoung, Woongkul Lee, and Bulent Sarlioglu. "Reactive power control of grid-connected inverter in vehicle-to-grid application for voltage regulation." IEEE Transportation Electrification Conference and Expo (ITEC), Dearborn, MI, USA, pp. 1-7, June, 2016.

[14] Udaya K. Madawala, and Duleepa J. Thrimawithana. "A bidirectional inductive power interface for electric vehicles in V2G systems." IEEE Transactions on Industrial Electronics, Vol 58, No. 10, pp. 4789-4796, 2011.

[15] Zhou, Xiaohu, Srdjan Lukic, Subhashish Bhattacharya, and Alex Huang. "Design and control of grid-connected converter in bi-directional battery charger for plug-in hybrid electric vehicle application." IEEE Vehicle Power and Propulsion Conference, Dearborn, MI, USA, pp. 1716-1721, October, 2009.

[16] Ajeet Verma, and Bhim Singh. "Three-phase off-board bi-directional charger for EV with V2G functionality." 7th IEEE International Conference on Power Systems (ICPS), Pune, India, pp. 145-150, June, 2017.

[17] Abeywardana, Damith Buddika Wickramasinghe, Pablo Acuna, Branislav Hredzak, Ricardo P. Aguilera, and Vassilios G. Agelidis. "Single-phase boost inverter-based electric vehicle charger with an integrated vehicle to grid reactive power compensation." IEEE Transactions on Power Electronics, Vol 33, No. 4, pp. 3462-3471, 2018

[18] Niels Leemput, Frederik Geth, Juan Van Roy, Jeroen Büscher, and Johan Driesen. "Reactive power support in residential LV distribution grids through electric vehicle charging." Sustainable Energy, Grids, and Networks Vol.3, pp. 24-35, July,2015.

[19] Sovacool, Benjamin K., and Richard F. Hirsh. "Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition." Energy Policy, Blacksburg, USA, Vol.37, No. 3, pp. 1095-1103, December, 2009

[20] U. C. Chukwu and S. M. Mahajan, "The Prospects of V2G for Reactive Power Compensation in Electric Distribution Networks," IEEE Power & Energy Society General Meeting (PESGM), Atlanta, GA, USA, pp. 1-5, January,2020

[21] A. Noorul Ameen and S. Suresh, "Design of Bi-Directional Power Converter for Vehicle-to-Grid Capability of Reactive Power Compensation," 2nd International Conference on Trends in Electronics and Informatics (ICOEI), Tirunelveli, India, pp.1336-1340, December 2018

[22] K. Sinjari, J. Kim and J. Mitra, "Single-phase and Three-phase Reactive Power Support for Microgrids by Grid-connected Electric Vehicle," 52nd North American Power Symposium (NAPS), Tempe, AZ, USA, pp. 1-6, June, 2021.

[23] H. Cheng, H. Chen and Q. Wang, "An Integrated Drive Power Converter Topology for Plug-in Hybrid Electric Vehicle with G2V, V2G, and V2H Functions," 22nd International Conference on Electrical Machines and Systems (ICEMS), Harbin, China, pp. 1-6, December, 2019.

[24] Tingting He, Dylan Dah-Chuan Lu, Mingli Wu, Qinyao Yang, Teng Li, and Qiujiang Liu. "Four-Quadrant Operations of Bidirectional Chargers for Electric Vehicles in Smart Car Parks: G2V, V2G, and V4G". Energies Vol.14, No. 1, pp -181. December, 2020.

[25] Yong, Jia Ying, Vigna K. Ramachandaramurthy, Kang Miao Tan, and N. Mithulananthan. "Bi-directional electric vehicle fast charging station with novel reactive power compensation for voltage regulation." International Journal of Electrical Power & Energy Systems, Vol.64, pp. 300-310, January, 2015.

[26] Monfared, Kourosh Khalaj, Hossein Iman-Eini, and Reza Razi. "Control of single-phase bidirectional PEV/EV charger based on FCS-MPC method for V2G reactive power operation." 10th IEEE International Power Electronics, Drive Systems and Technologies Conference (PEDSTC), Shiraz, Iran, pp. 641-646, April, 2019.

[27] M. Kesler, M. C. Kisacikoglu and L. M. Tolbert, "Vehicle-to-Grid Reactive Power Operation Using Plug-In Electric Vehicle Bidirectional Offboard Charger," IEEE Transactions on Industrial Electronics, Vol. 61, No. 12, pp. 6778-6784, 2014.

[28] S. Kulkarni, A. R. Thorat, and I. Korachagaon, "Bidirectional converter for the vehicle to grid (V2G) reactive power operation," International Conference on Circuit, Power and Computing Technologies (ICCPCT), Kollam, India, pp. 1-6, October, 2017

[29] B. Xu, H. Wang, H. Sun and Y. Wang, "Design of a bidirectional power converter for charging pile based on V2G", IEEE International Conference on Industrial Technology (ICIT), Toronto, Canada, pp. 527-531, May, 2017

[30] K. M. Tan, V. K. Rama Chandra Murthy and J. Y. Yong, "Bidirectional battery charger for an electric vehicle," IEEE Innovative Smart Grid Technologies, Kuala Lumpur, Malaysia, pp. 406-411, May, 2014