Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, May : 2024

Grid Connected Off-Board EV Charger with V2G/G2V and V2V Capability

G.GAYATHRI YADAV[1], SHAIK WAZEED[2]

[1]PG Student, Dept of EEE, SITS, Kadapa.

[2]Assistant Professor, Dept of EEE, SITS, Kadapa.

Abstract –

Recent years have seen a dramatic increase in the usage of renewable energy sources in a variety of industries, including the automotive sector where it plays a role in charging the batteries of electric vehicles (EVs). An off-board charger for electric vehicles (EV) that can charge multiple EVs with grid power in "grid-to-vehicle" (G2V) mode and in "vehicle-to-vehicle" (V2V) mode. In addition, the proposed charger can feed power to the grid in "vehicle-to-grid" (V2G) mode. To maintain a constant charging and discharging current for EVs, a half-bridge bidirectional DC/DC converter is employed. Charging of EV battery from the grid increases its load demand. This leads to propose a photovoltaic (PV) array-based off-board EV battery charging system in this project. Irrespective of solar irradiations, the EV battery is to be charged constantly which is achieved by employing a backup battery bank in addition to the PV array. Here, we present a method for lightweight EVs that uses a solar energy power conversion with SEPIC and bidirectional interleaved DC-DC converter (BIDC) to charge their batteries from the grid instead of on-board. In order to test the effectiveness of the proposed charging method, a simulation was run in the MATLAB software using the Simulink application.

***Keywords* –** Electric vehicle, G2V/V2V, BIDC, SEPIC, PV system.

I. INTRODUCTION

Power quality (PQ) is a measure of the fitness of electrical power from the utility to the electrical customer. Low PQ is of concern because it can cause variations in voltage magnitude, issues with continuity of service from utilities, and transient voltages and currents. Harmonic distortion is a primary culprit in the causation of reduced power quality. Our research is focused on investigating three hypotheses. One, we hypothesized that, because EV charge controllers are nonlinear loads and because EVs demand a large amount of power, the PQ issues presented by EV charging could have an impact on distribution feeders. Two, we also hypothesized that the total harmonic distortion (THD) of the current drawn by an EV charge controller would change as a function of time as the charge controller moved through various phases of the charging cycle. And third, we hypothesized that the cumulative effects of multiple charge controllers on the same feeder would result in distortion greater than that of any one charge controller, thereby setting an upper bound on the maximum number of EV charging stations that could be connected to a single feeder.

The market for four-wheel electric vehicles is hindered by factors such as high cost, inadequate charging infrastructure, and safety concerns. The needs for EV charging infrastructure are largely dependent on vehicle type, battery capacity, power ratings, and charging methods. Conductive charging, also known as wired charging, is the prevalent charging technology. AC or DC conductive charging is possible. When using AC charging, the onboard charger of the EV receives AC power and converts it to DC. Bypassing the onboard charger, an offboard charger converts power externally and supplies DC power straight to the battery. DC charging, i.e., using an offboard charger, has the most benefits in terms of charging time, power capacity, and environmental impact. In general, grid connected offboard charger requires two converters AC/DC converter and DC/DC converter. On the AC conversion side, the present converters suffer from a low power factor, and the harmonic content of the input current is also high. To rectify this problem, many power electronic topologies were used. For a 5-kW system, a buck converter with advanced modulation technique was proposed, but the number of power electronic switches used in the converters is high, and harmonic distortion is greater than 5%. The system proposed consists of buck-type unity power factor rectifiers and their control strategies.

The system is not suited for low power applications like electric two-wheeler chargers. The buck-type matrix converter used in the project provides high THD, and switch stress is also high. Hence, the efficiency of the system becomes low. The proposed converter provides isolated AC-to-DC conversion. The filter design and closed-loop control of the system are complex. A rectifier is proposed for charging electric vehicles. The voltage stress on the power electronic switch is high, so the efficiency of the system is low. The study also focuses on rectifier efficiency. In this topology, coupled inductors and wide band gap devices are used to improve efficiency. But this concept is complex for low power applications, and control system design is tedious because of more number of power electronic switches. The study on Vienna rectifiers provides the detailed workings of the rectifier and efficiency improving methods. The control system is complex because the order of the system is high. The three-phase PWM rectifier has received the most attention among these various converters because it has a high-power factor and low harmonics.

The number of power electronic switches is low for both three-phase and single-phase configurations. The control system design is almost the same for high and lowpower applications. In addition to the above advantages, the PWM rectifiers provide bidirectional power flow. Based on the literature, a three-phase PWM rectifier is chosen as the front-end converter to convert AC to DC power. On the DC conversion side, for V2G and V2V operations, bidirectional DC/DC converters are preferred. A four-switch bidirectional DC/DC converter was proposed. It charges in buck mode and discharges in boost mode. Half-bridge and full-bridge interleaved DC/DC converters provide bidirectional power flow with low input ripple and high efficiency, but require more complex control and additional components. The bidirectional, non-isolated, low-cost converter proposed achieves high efficiency at rated power with fewer components and simple control logic. Based on research, a half-bridge bidirectional DCDC converter is selected for the second stage of the off-board charger.

Among various non-isolated bidirectional converter topologies, bidirectional interleaved DC–DC converter (BIDC) is preferred due to its advantages like improved efficiency in discontinuous conduction mode and minimal inductance value, reduced ripple current due to multiphase interleaving technique. Snubber capacitor across the switches reduces the turnoff losses and the inductor current parasitic ringing effect is also reduced by employing zero voltage resonant soft switching technique. These are the added advantages of this bidirectional converter. The system is an off-board EV battery charging system which charges the EV battery from PV array power through bidirectional DC–DC converter in stand-still condition and EV battery gets discharged to drive the dc load in the EV during the running condition. It has the drawback of charging EV battery only during sunshine hours. To overcome this disadvantage and to charge the EV battery without any interruption, the proposed charger is developed using PV array integrated with sepic converter, bidirectional DC–DC converter and backup battery bank for charging the battery of an EV.

II. POWER CONVERSION TECHNOLOGY

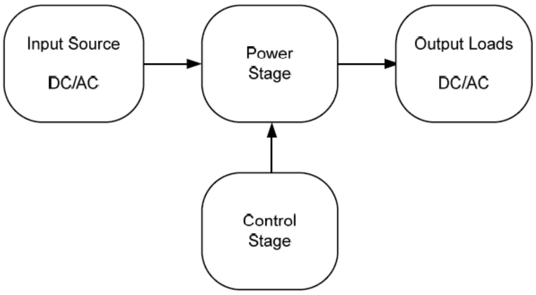


Fig:1 Power electronic conversion.

Power conversion process consists of two stages, power and control stages. As shown in Figure 1, the power stage is to convert the input power (AC or DC) and deliver it to the output side (AC or DC). The control stage is used for controlling the power converter to synthesis reference output power, by measuring input and output currents and voltages. Power conversion can be divided into four different categories according to the input and output power forms. In Figure 2, four different combinations of power converters can be used for power conversion of renewable energy sources.

- DC-DC converter.
- AC-DC converter (rectifier).
- DC-AC converter (inverter).
- AC-AC converter.

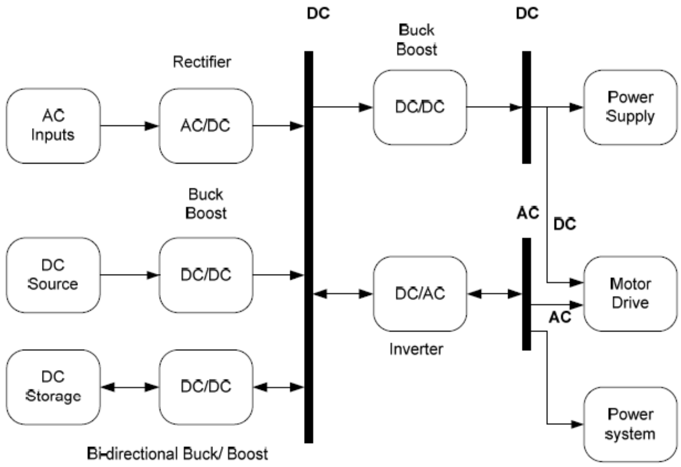


Fig:2 Energy conversion technologies based power converters.

III. PROPOSED SYSTEM

The proposed system consists of a three-phase grid and two EVs. Here, the grid and both the EVs can act as either sources or sinks. A three-phase PWM rectifier is used as the front-end converter that connects the grid to the common DC link. It is used in the first three modes to maintain constant DC link voltage, UPF at the grid side, and THD of grid current less than 5%. A half-bridge bidirectional DC/DC converter is used as the second stage converter for the off board charger. It connects the common DC link to the EV. When charging the EVs, the bidirectional DC/DC converter will function as a buck converter, and when discharging the EVs, it will function as a boost converter. It also maintains a constant charging and discharging current. A relay is used to connect EV2 directly to the common DC link by bypassing the bidirectional DC/DC converter in V2V mode alone. The block diagram of the proposed system is shown in Fig. 3.

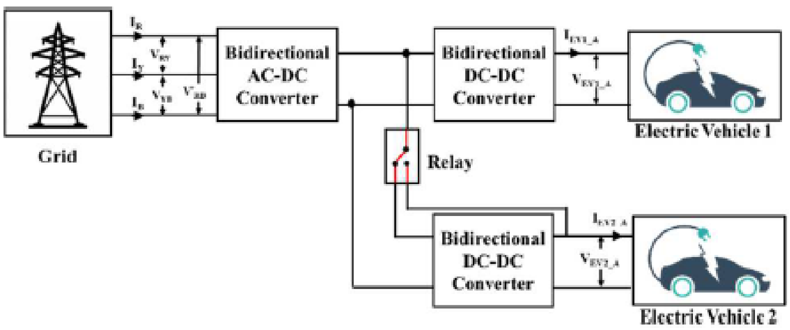


Fig. 3. Block Diagram of the Proposed System

The EV1 battery has a rating of 200 V and 100 Ah, while the EV2 battery has a rating of 400 V and 100 Ah. For a three-phase grid, the standard line-line voltage of 440 V with a frequency of 50 Hz is used. The proposed system operates in four modes. In G2V mode, both the EVs will be charged from the grid either individually or simultaneously. In this mode, the power flow is from the grid to the bidirectional converter. From the DC link, the power will be distributed to both EVs. The charging current for each EV will be decided by the controller. Based on the current reference value, the power will be shared among the EVs

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, May : 2024

connected to the system. The power flow for this mode is shown in Fig. 4. In V2G mode, both the EVs can deliver power to the grid either individually or simultaneously. The power flow for this mode is shown in Fig. 5. The power from the EVs is fed back into the grid. This is possible only when the converter connected to the system has the capability to allow the bidirectional current flow. The frequency and voltage of the power from the EVs are controlled by a PWM rectifier controller. In the combined G2V and V2V mode, one EV will be charged from grid power and another EV power simultaneously. By using this mode, the grid's power utilisation is lower because the load power is shared by one EV and the grid. The required current value by the charging EV will be decided by the controller, and based on the current value, the rectifier controller and another EV controller perform the current sharing process. The process for this mode is given in Fig. 6. In V2V mode, during the absence of the grid, one EV can charge another EV with the help of a bidirectional DC/DC converter. A relay is used to connect EV2 directly to the common DC link by bypassing the bidirectional DC/DC converter. Fig. 7 shows the power flow for V2V mode. The power flow for this mode is shown in Fig. 7. The current required by the EV that is charging is taken from another EV that is in discharge mode. This is possible only when the voltage provided by the discharging EV is equal to the charging EV voltage. It is the necessary condition for this mode; otherwise, V2V mode will not be achieved.

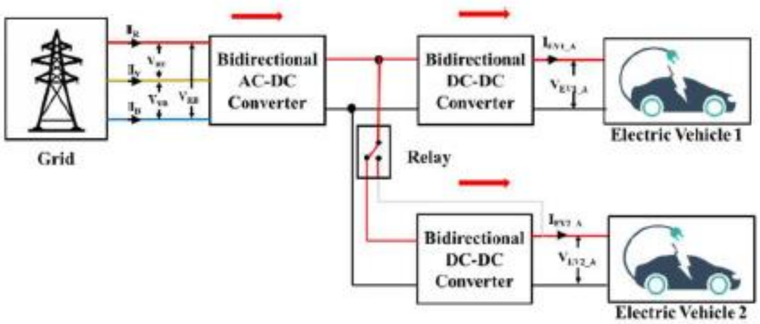


Fig. 4. G2V Mode of Operation

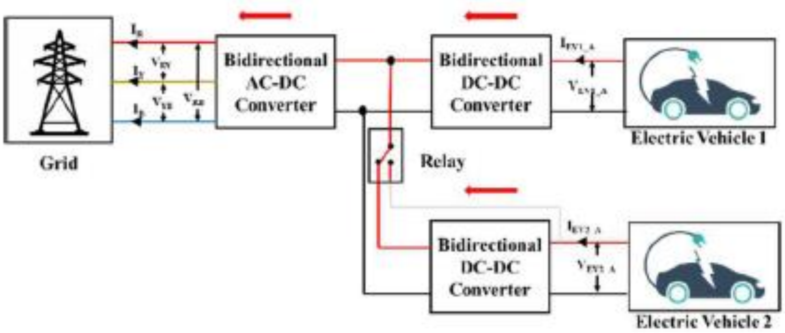


Fig. 5. V2G Mode of Operation

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, May : 2024

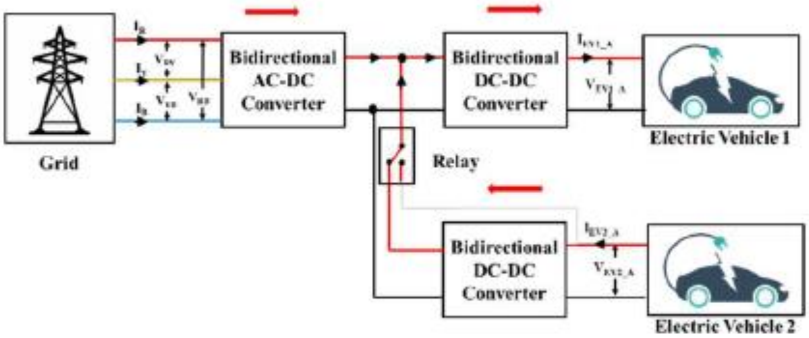


Fig. 6. G2V and V2V Mode of Operation

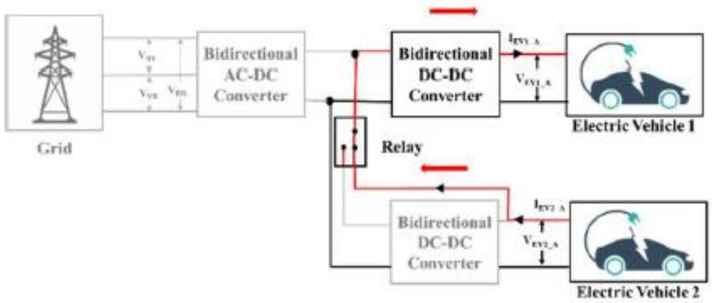


Fig. 7. V2V Mode of Operation

The three-phase PWM rectifier is controlled using hysteresis-band PWM, which is simple compared to current-based sinusoidal PWM and voltage oriented control. It controls the output voltage, grid current, and grid voltage. The reference DC link voltage and the actual DC link voltage are compared, and the difference is fed to the proportional integral (PI) controller as an error. The DC output voltage is maintained constant by this outer voltage loop. The output of the PI controller decides the magnitude of the source, which depends on the required reference DC voltage. A unit sine template is obtained from the grid voltage, which is multiplied by the required magnitude of the grid current to obtain the reference current for the grid. The hysteresis current controller method controls the actual current through the inductor, i.e., the actual grid current. The instantaneous value of the actual current is compared with the reference value. If it surpasses this threshold, the appropriate phase of the grid is immediately linked to the DC link voltage's negative node. If not, the DC link's positive node becomes the new grid phase. For the other two phases, the same procedure is followed simultaneously and independently.

IV. SIMULATION RESULTS

Using MATLAB/Simulink, the proposed system is simulated.

Existing method:-

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, May : 2024

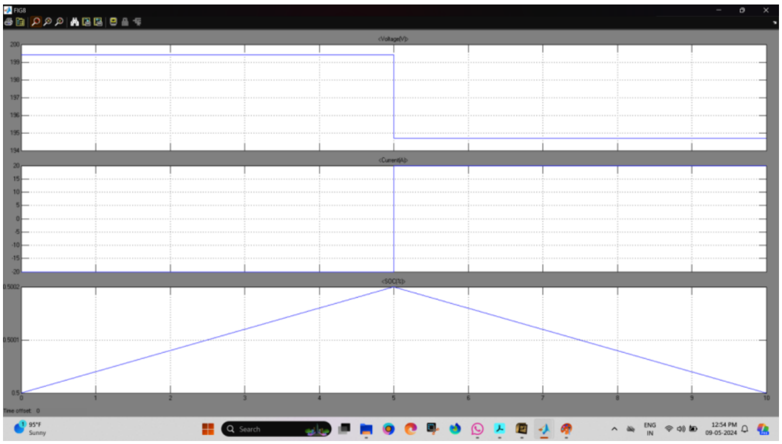


Fig. 8. EV1 Battery Voltage, Current and SOC in G2V and V2G

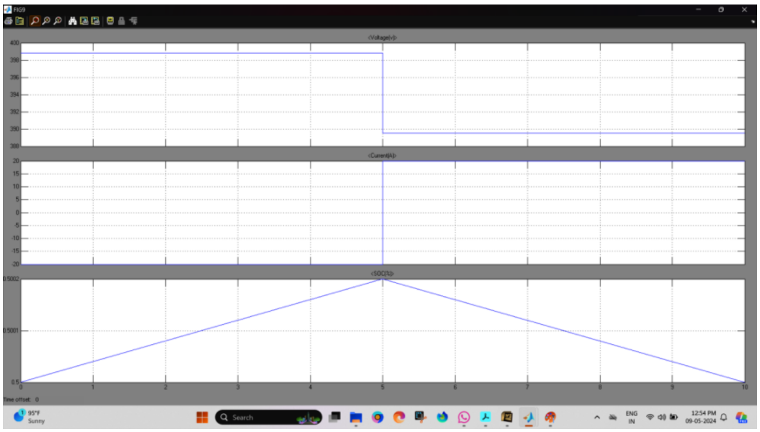


Fig. 9. EV2 Battery Voltage, Current and SOC in G2V and V2G

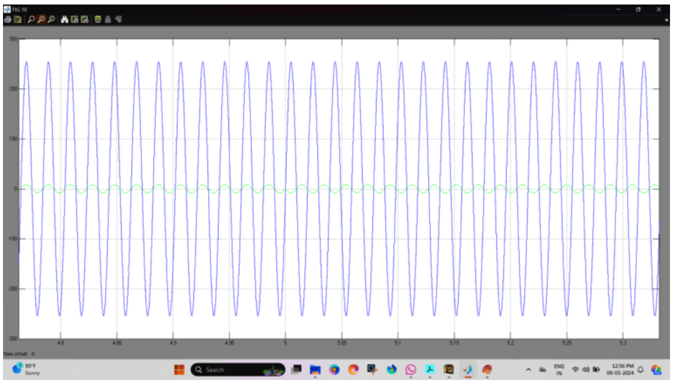


Fig. 10. R-phase Voltage and Current in G2V and V2G

The first two modes are operated in dynamic condition. The system operated in G2V mode for first 5 seconds and operated in V2G mode in the next 5 seconds. In G2V mode, the power from the grid is used to charge both the EVs. The EV1 is charged using 3.99 kW of grid power and EV2 is charged using 7.98 kW. Both the EVs are charged with a constant current of 20 A as shown in Fig. 8. and 9. In this mode the battery voltage of EV1 is maintained at 199.4 V as shown in Fig. 8 and of EV2 is maintained at 398.8 V. The positive

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, May : 2024

slope in the SOC graph in Fig. 8 and 9 shows that EV1 and EV2 is charged through grid power. The corresponding grid voltage and current are shown in Fig. 10. From Fig. 10, it can be noted that the grid voltage and current are in phase with UPF in G2V mode (t <= 5seconds). In V2G mode from 5 to 10 seconds, the power from both the EVs will be delivered to the grid. The EV1 delivered a power of 3.89 kW to the grid with a discharging current of 20 A and maintained a battery voltage of 194.7 V, as shown in Fig. 8. Similarly, EV2 delivered a power of 7.79 kW to the grid with a discharging current of 20 A and maintained a battery voltage of 389.5 V, as shown in Fig. 9. The negative slope in the SOC graph in Fig. 8 and 9 shows that the EV1 and EV2 are discharged. The corresponding grid voltage and current are shown in Fig. 10. From Fig. 10, it can be noted that the grid voltage and current are out of phase with UPF in V2G mode (t > 5 seconds).

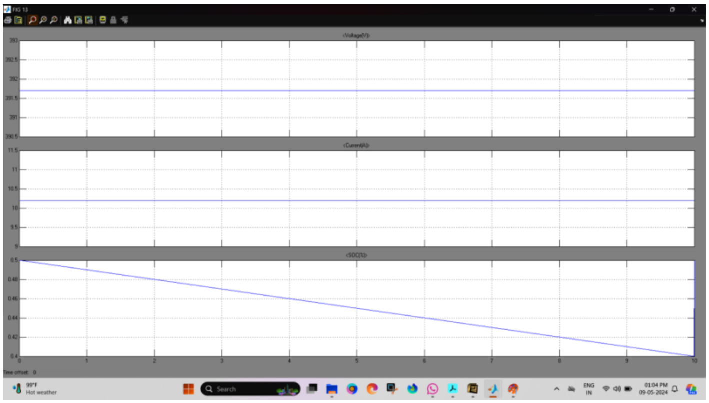


Fig. 11. EV2 Battery Voltage, Current and SOC in V2V

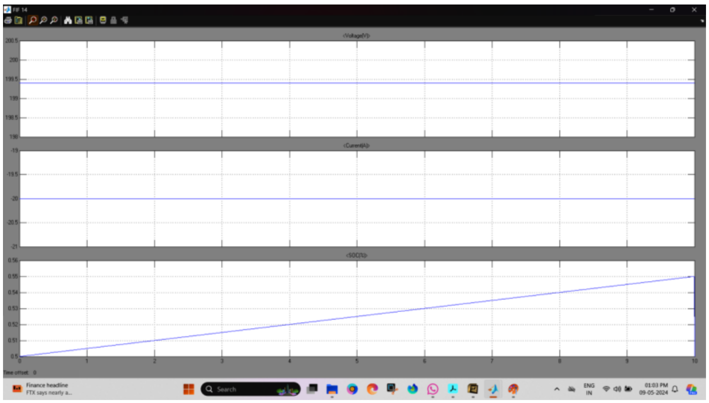


Fig. 12. EV1 Battery Voltage, Current and SOC in V2V

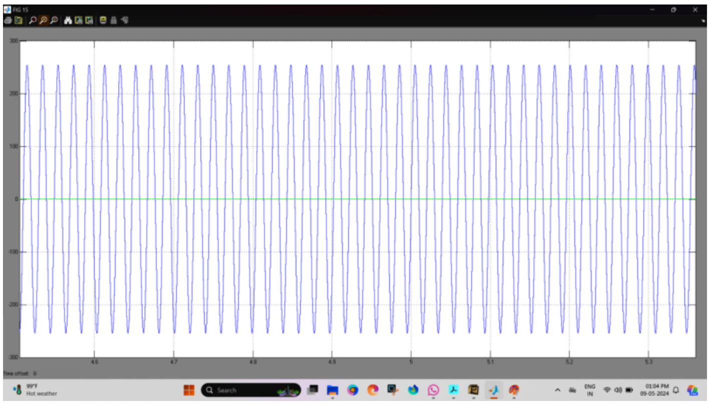


Fig. 13. R-phase Voltage and Current in V2V

In V2V mode, the power from EV2 is used to charge EV1 during the absence of the grid. EV2 delivered a power of 3.99 kW with a discharging current of 10.2 A at a battery voltage of 391.7 V, as shown in Fig. 11. The negative slope in the SOC graph in Fig. 11 shows that EV2 is discharged. EV1 is charged with a charging current of 20 A and a battery voltage of 199.4 V, i.e., a total power of 3.98 kW, as shown in Fig. 12. The positive slope of the SOC graph in Fig. 12 shows that the EV1 is in charging mode. Fig. 13 depicts the absence of a grid with zero grid current.

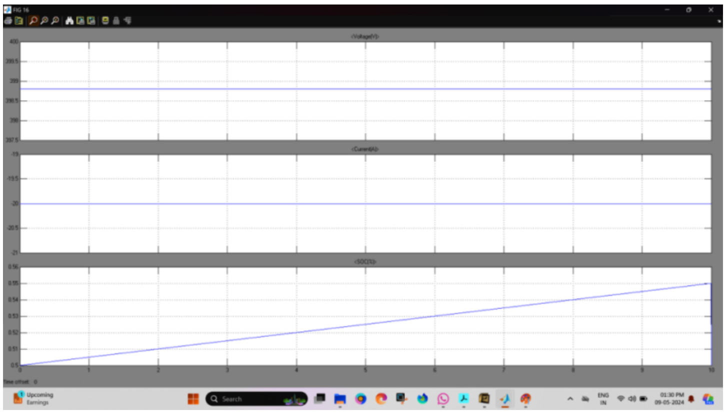
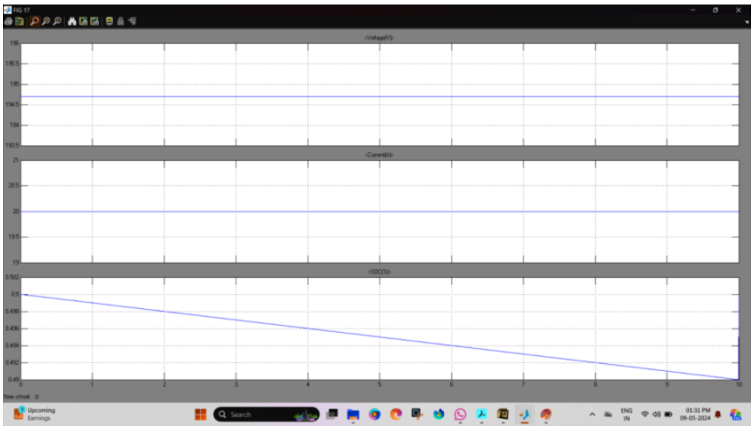


Fig. 14. EV2 Battery Voltage, Current and SOC in combined G2V & V2V



Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, May : 2024

Fig. 15. EV1 Battery Voltage, Current and SOC in combined G2V & V2V

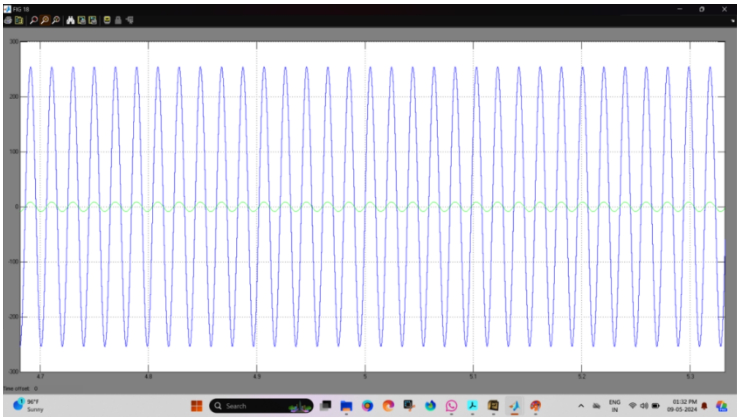
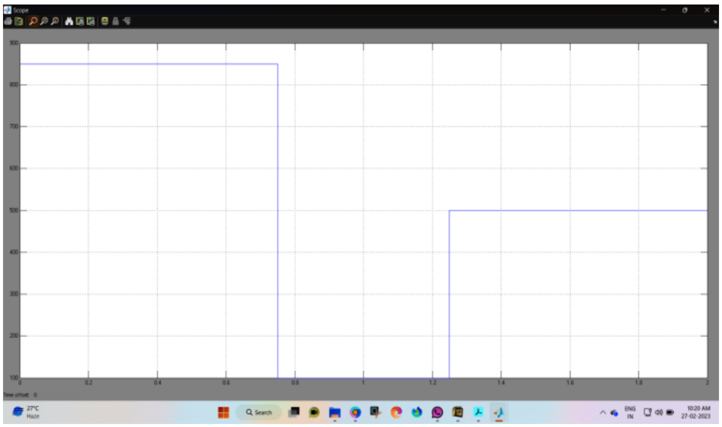


Fig. 16. R-phase Voltage and Current in combined G2V & V2V

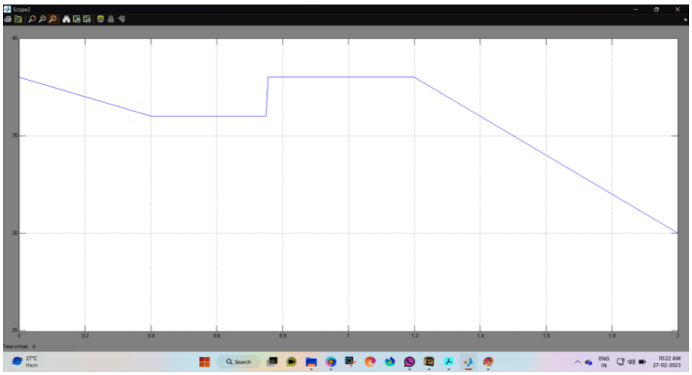
In the combined G2V and V2V mode, the power from the grid is used to charge EV2, while EV1 also delivers power to EV2 simultaneously. EV2 is charged with a constant current of 20 A and a battery voltage of 398.8 V, as shown in Fig. 14. The positive slope of the SOC graph in Fig. 14 shows that EV2 is in charging mode. EV1 delivers a power with a discharging current of 20 A and a battery voltage of 194.7 V, as shown in Fig. 15. The negative slope of the SOC graph in Fig. 15 shows that EV1 is in discharge mode. The corresponding grid current and voltage are shown in Fig. 16. This shows the grid provides less power compared with G2V mode. Hence, the load on the grid can be reduced using this mode. The grid current and voltage are in phase with UPF.

Proposed system:-

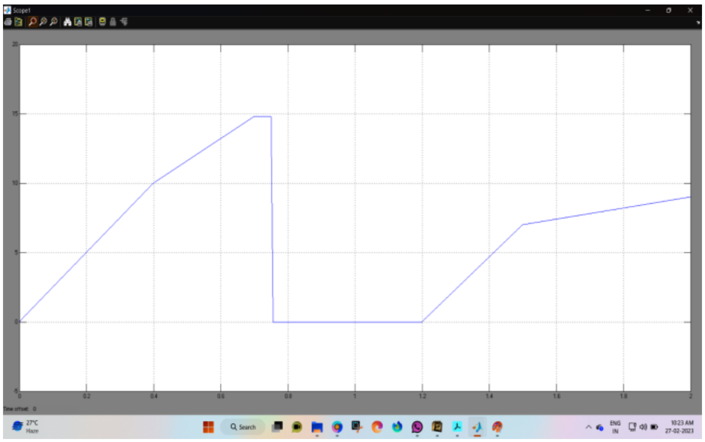


Irradiance

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, May : 2024

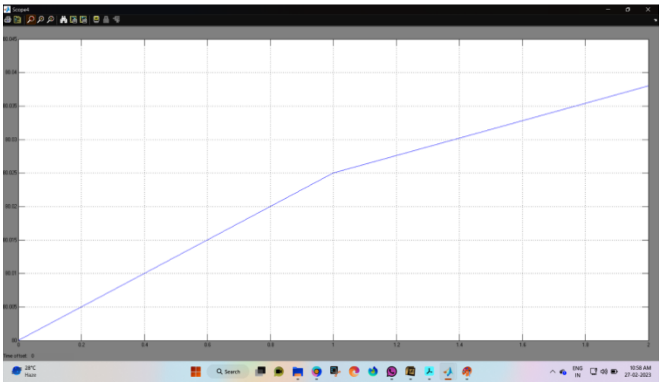


PV Array voltage (Vpv)



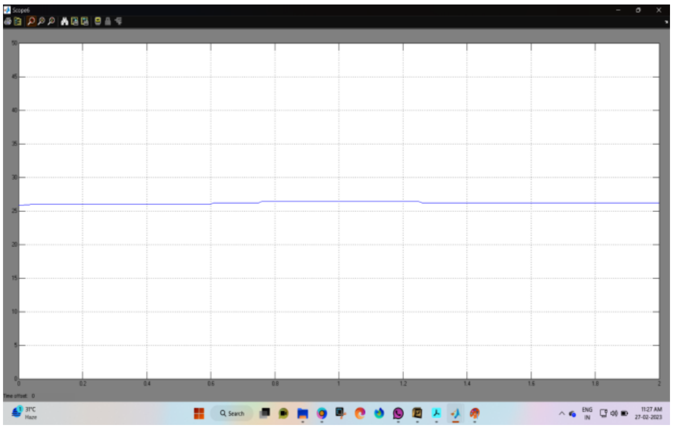
PV Array Current (Ipv)

Fig:(a) simulation waveforms of PV array

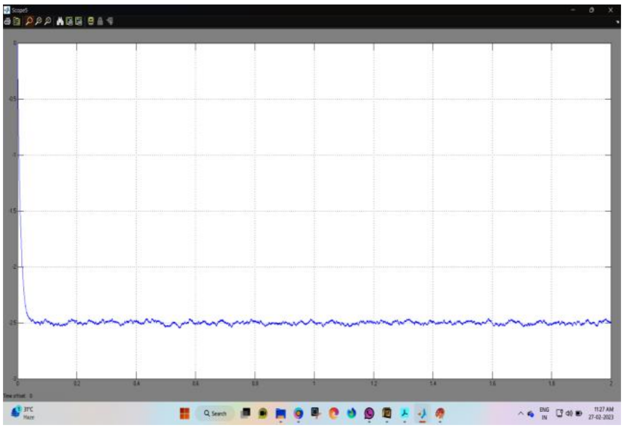


SOC of EV Battery

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, May : 2024

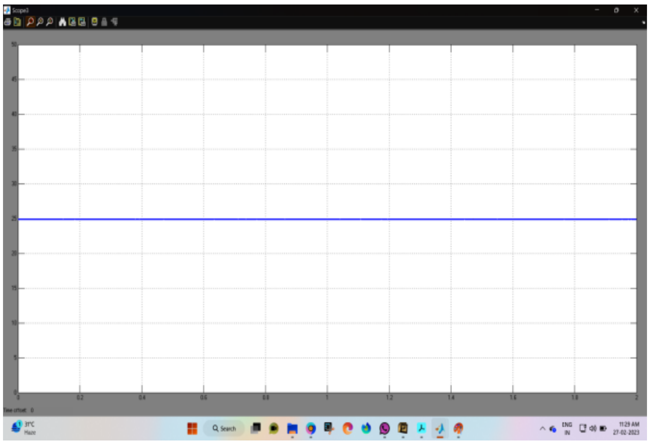


EV battery voltage (Vb)

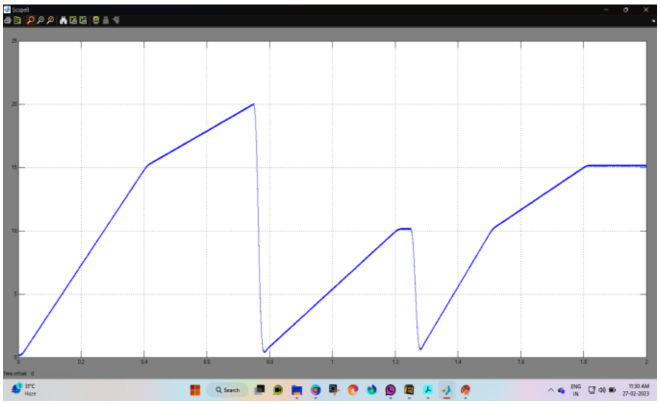


EV battery current (Ib)

Fig:(b) simulation waveforms of EV battery

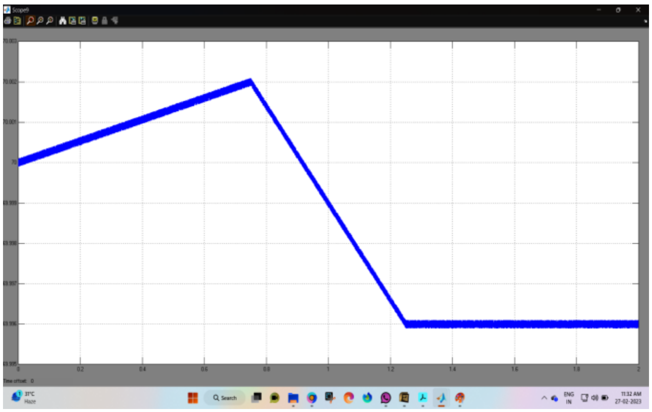


Vdc

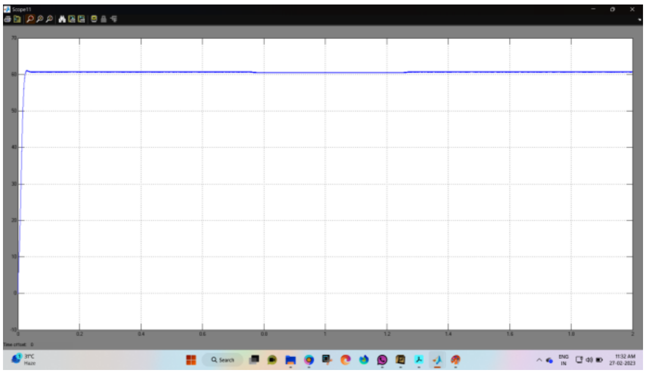


Idc

Fig:(c) simulation waveforms of DC link.

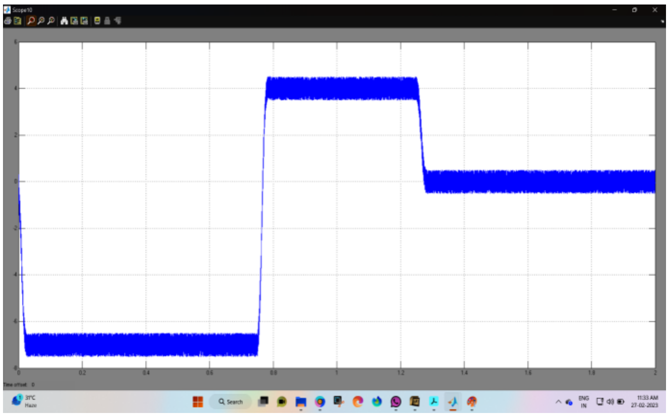


SOC battery



Battery voltage (Vbatt)

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, May : 2024



Battery current (Ibatt)

Fig:(d) simulation waveforms of battery.

Fig.17: waveforms of proposed system

Dynamic patterns of the PV array, dc link, EV battery, and backup battery were shown for different irradiation values in Fig. 17. Using the sepic converter, the 33.3 V PV array voltage (VPV) is reduced to the 28 V dc link voltage (Vdc) in mode 1. This is seen in Figs. 17a and b. Fig. 17b shows that when the EV battery's state of charge (SOC) rises, the negative current flowing through it increases. During this mode, the BIDC acts as a boost converter in the forward direction, increasing the dc link voltage, Vdc, from 28 to 60.6 V in order to charge the backup battery while maintaining a constant SOC (see Fig. 17d). Figure.17a shows the voltage and current waveforms of a PV array in mode 2 (during non-sunny hours and low irradiation circumstances), with VPV increasing to its open circuit voltage of 37.25 V and IPV being 0 A. As can be seen in Fig. 17b, the BIDC switches into buck mode in the opposite direction at this time, reducing the voltage from the secondary battery to 27.32 V in order to charge the EV's battery. Fig. 17d shows that the backup battery is being depleted by a positive current and a falling SOC. As shown in Fig. 17d, the voltage of the backup battery drops from 60.6 V to 55.2 V when this mode concludes. Figures 17a and 17c depict how the PV array voltage, VPV, is reduced to the dc link voltage, Vdc, of 27.6 V in mode 3 to charge the EV battery. Even in this mode, the EV battery's state of charge (SOC) is rising and the current is negative, showing that the battery is being charged. As illustrated in Fig. 17d, the backup battery's voltage stays at 55.2 V even if its current drops to zero while in mode 3, which occurs when the battery is disconnected from the charging system. In all three modes depicted in Fig. 17b, the EV battery is continually being charged, either by the PV array or the backup battery, while the SOC of the EV battery rises and the current decreases.

V. CONCLUSION

A grid connected off-board charger is proposed in this project. The proposed system can charge the EV with grid power in G2V mode and from another EV in V2V mode. Further, it allows EVs to deliver power to the grid in V2G mode. Since the proposed system includes two EVs, one can use both grid and EV power to charge another EV in the combined

G2V and V2V mode. The grid voltage and current are maintained at UPF. Each of the four modes is simulated, and the results are validated using the system's power balance. This project proposes a PV-module-fed, SEPIC-and-BIDC-equipped off-board EV battery charging system for lightweight EVs. Examining the current state, most recent deployment, and difficult difficulties in implementing EV infrastructure, charging power levels, in conjunction with numerous charging power topologies, this article also examines the societal consequences and future prospects of EVs. As charging infrastructure and charger characteristics continue to evolve, so too must the parameters for evaluating battery performance in electric vehicles. This project explains how the system may be adjusted to both charge the EV's battery while the vehicle is idling and drive the motor while the vehicle is in motion. Simulink, a component of MATLAB, is used for both system design and simulation.

REFERENCES

[1] NITI Aayog, State Energy & Climate Index Round-I, April 2022.

[2] IVC Association, EY Parthenon, "Electrifying Indian Mobility", 2022

[3] NITI Aayog, Handbook of Electric Vehicle Charging Infrastructure Implementation Version-I.

[4] M. Yilmaz and P. T. Krein, ''Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles,'' IEEE Trans. Power Electron., vol. 28, no. 5, pp. 2151–2169, May 2013.

[5] Kabus, M.; Nolting, L.; Mortimer, B.J.; Koj, J.C.; Kuckshinrichs, W.; De Doncker, R.W.; Praktiknjo, A. Environmental Impacts of Charging Concepts for Battery Electric Vehicles: A Comparison of On-Board and Off-Board Charging Systems Based on a Life Cycle Assessment. *Energies* 2020, *13*, 6508.

[6] M. Safayatullah, M. T. Elrais, S. Ghosh, R. Rezaii and I. Batarseh, "A Comprehensive Review of Power Converter Topologies and Control Methods for Electric Vehicle Fast Charging Applications," in IEEE Access, vol. 10, pp. 40753-40793, 2022.

[7] T. Nussbaumer and J. W. Kolar, ''Improving mains current quality for three-phase three-switch buck-type PWM rectifiers,'' IEEE Trans. Power Electron., vol. 21, no. 4, pp. 967–973, Jul. 2006.

[8] M. Baumann and J. W. Kolar, "A novel control concept for reliable operation of a three-phase three-switch buck-type unity power factor rectifier with integrated boost output stage under heavily unbalanced mains condition," IEEE 34th Annual Conference on Power Electronics Specialist, 2003. PESC '03., 2003, pp. 3-10 vol.1.

[9] J. Afsharian, D. Xu, B. Wu, B. Gong, and Z. Yang, ''A new PWM and commutation scheme for one phase loss operation of three-phase isolated buck matrix-type rectifier,'' IEEE Trans. Power Electron., vol. 33, no. 11, pp. 9854–9865, Nov. 2018.

[10] Y. Jang, M. M. Jovanović and J. M. Ruiz, "Three-level TAIPEI rectifier," 2014 IEEE Applied Power Electronics Conference and Exposition - APEC 2014, 2014, pp. 943-950.

[11] T. B. Soeiro, T. Friedli, and J. W. Kolar, ‘‘Swiss rectifier—A novel three phase buck-type PFC topology for electric vehicle battery charging,’’ in Proc. 27th Annu. IEEE Appl. Power Electron. Conf. Expo. (APEC), Feb. 2012, pp. 2617–2624.
[12] L. Schrittwieser, M. Leibl, M. Haider, F. Thony, J. W. Kolar, and T. B. Soeiro, ‘‘99.3% efficient three-phase buck-type all-SiC Swiss rectifier for DC distribution systems,’’ IEEE Trans. Power Electron., vol. 34, no. 1, pp. 126–140, Jan. 2019.
[13] J. Halbig, ‘‘15 kW bidirectional VIENNA PFC,’’ presented at the STMicroelectronics APEC, Aug. 2020.
[14] T. Song, P. Wang, Y. Zhang, F. Gao, Y. Tang and S. Pholboon, "Suppression Method of Current Harmonic for Three-Phase PWM Rectifier in EV Charging System," in IEEE Transactions on Vehicular Technology, vol. 69, no. 9, pp. 9634-9642, Sept. 2020.
[15] S. Chaurasiya and B. Singh, "A G2V/V2G Off-Board Fast Charger for Charging of Lithium-ion Based Electric Vehicles," 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe (EEEIC /I&CPS Europe), Genova, Italy, 2019, pp. 1-6.
[16] Yang, Min-Kwon et al. “High-efficiency soft-switching PWM DC-DC converter for electric vehicle battery chargers.” 2013 IEEE Energy Conversion Congress and Exposition (2013): 1092-1095.
[17] Y. Du, X. Zhou, S. Bai, S. Lukic and A. Huang, "Review of non-isolated bi-directional DC-DC converters for plug-in hybrid electric vehicle charge station application at municipal parking decks," 2010 Twenty- Fifth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), Palm Springs, CA, USA, 2010, pp. 1145-1151.
[18] R. M. Schupbach and J. C. Balda, "Comparing DC-DC converters for power management in hybrid electric vehicles," IEEE International Electric Machines and Drives Conference, 2003. IEMDC'03., Madison, WI, USA, 2003, pp. 1369-1374 vol.3.
[19] V. Vaideeswaran, N. Sankar, (2018) “Control Technique of Three Phase PWM Rectifiers”, International Journal of Engineering and Advanced Technology (IJEAT), Volume 8, ISSN: 2249-8958, December.
[20] M. H. Rashid, “Power Electronics-Circuits, Devices and Applications,” 3rd Edition, Pearson Education, Upper Saddle River, 2003.