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Solar Based Bi-Directional Electric Vehicle Charger

Sampathraja Natarajan, Dr.Ashok Kumar Loganathan and Jishnu Viswanathan
Department of Electrical and Electronics Engineering
PSG College of Technology, Peelamedu, Coimbatore – 641 004
Email : nsr.eee@psgtech.ac.in, lak.eee@psgtech.ac.in, jishnuviswanathan1997@gmail.com

Abstract- Electric vehicles are gaining popularity as a solution to the problems caused by vehicles that run on fossil fuels. The ability of an electric vehicle (EV) to adapt is determined by the charging infrastructure. This paper proposes the development of a solar-powered bidirectional electric vehicle charger that integrates the solar array directly into the charger's DC bus. A bidirectional AC-DC converter is followed by a bidirectional DC-DC converter in this two-stage charger. Solar power or grid power are both used to charge the EV battery. The solar or the battery power is also feed to the grid. The charger works in both G2V and V2G mode. In this charger both the converters shares a common DC link capacitor. In G2V mode, the bidirectional AC-DC converter acts as a rectifier, and in V2G mode, it acts as an inverter. In G2V mode, the DC-DC converter acts as a buck converter. During the V2G mode the DC-DC converter acts as a boost converter to raise the voltage of the battery to the sufficient DC link voltage. The bidirectional AC-DC converter is controlled using DQ control, while the bidirectional DC-DC converter is controlled using a PI controller. The charger is intended for use with a single phase 230 V, 50 Hz supply and a load of 300 V, 66 Ah. MATLAB simulink software was used to design and simulate the charger. The simulation results are used to validate the proposed charger's design and control.

Keywords: Electric vehicle, Bi-directional charger, solar array, G2V, V2G.

I. INTRODUCTION

The increase in population, shrinkage of resources like fossil fuels and the growing concern for reduce the environment pollution has made the automobile industries to think of an alternative approach of propulsion.As a result, electric vehicles are gaining popularity as a solution to the problems caused by vehicles that run on fossil fuels. The charging infrastructure determines how adaptable an electric vehicle (EV) is. However, charging an electric vehicle necessitates a significant amount of electricity. Most of the electrical energy comes from thermal power plants which use coal and gas. Thus electric vehicle can be a clean and green alternative way of transportation when the energy needed to charge the vehicle is derived from renewable sources. Renewable energies such as solar and wind based grid connected system can be used for charging the EVs. This requires revamping of transmission lines for carrying more power. A solar based energy generating station produces electric supply that can be used on-site. The benefit of this charging station is that the electricity is generated and consumed locally. When the cost of energy is high, the transmission line does not need to be upgraded for high power, and power does not need to be drawn from the grid to charge the vehicle. The used of solar based charging station minimizes the cost of charging and avoids overloading of grid. The solar PV power output is intermittent in nature and discontinuous. Energy storage devices like battery can be combined with solar panels to provide continuous power. The operation of Electric Vehicle and solar array reduces the impacts of solar generation. Electric Vehicles are parked for 90% of the time due to which their batteries store a large amount of energy. In V2G (Vehicle to Grid) mode, this energy can be used. The grid receives voltage support and reactive power compensation from the vehicle to grid mode.

The synchronous reference frame conversion is used to implement a current control for the bidirectional AC-DC converter. The active and reactive power outputs of the inverter are controlled in the dq reference frame with proportional integral (PI) controllers. The grid current and grid voltage are used to create an orthogonal signal pair using a Phase-Locked Loop. The PLL is used to align the injected grid current with the grid voltage.

"Mohamed O. Badawy, Y. Sozer" presents an optimal power flow technique for a solar battery powered Electric Vehicle (EV) charging station with the goal of lowering operational costs. The technique's goal is to aid power transmission from solar and battery systems to the grid. This also supports the growing demand for fast charging rates for electric vehicles. This can be accomplished by continuously lowering the system's operating costs while accounting for both battery degradation and grid traffic. The required constraints are formulated along with an optimization algorithm. The operating cost is calculated using a combination of battery degradation costs and grid prices. The cycle DOD, average SOC, and operating temperature are all taken into account in the battery degradation cost model. Particle Swarm Optimization (PSO) is a predictive optimization tool for setting the battery's SOC limits based on solar PV power, grid prices, and predicted load. [1].

“H.N. de Melo, J. P. F. Trovao, P. G. Pereirinha, H. M. Jorge” proposes a functional and a simple bidirectional plug-in electric vehicle charger topology which is capable of making interaction with an autonomous EMS (Energy Management System) in a residential setting. The EMS achieves potential benefits like energy exchange between the consumer and grid with the help of bidirectional electric vehicle charger. A suitable controller charger design is presented which includes the size of all passive elements and controllers. The charger can be adjusted for booth charging and discharging mode using the power level which is provided by the energy management system. The power of the charger is bidirectional and flexible, thus it allows charging and discharging operation at various power levels which is beneficial with integrating the power allocated and for scheduling the power among all the residential loads [2].

An electric vehicle (EV) charger that operates in all four quadrants of the reactive and active power (P-Q) plane is proposed by "Anjeet Verma, B. Singh." A full bridge AC-DC converter and a bi-directional DC-DC converter make up the charger. Grid to Vehicle (G2V) and Vehicle to Grid (V2G) charging modes are available. The bidirectional charger is capable of exchanging both reactive and active power. The batteries state of charge is also been preserved during the reactive power flow. The charger is designed to operate in a single phase 230 V, 50 Hz supply [3].

The design and control of a bidirectional DC-DC converter for electric vehicle charging applications is presented by "L. Albiol Tendillo, E. Vidal Idiarte, J.Maixé Altés, J.M. Bosque Moncus, H. Valderrama Blav." Sliding mode control is used in the DC-DC converter topology, which uses only one surface. The permanent magnet synchronous motor (PMSM) can function as a generator or a motor thanks to the converter's bidirectional operation.The current flows from the battery to the motor during motoring mode, and the converter acts as a boost converter. The current flows from the PMSM to the battery during braking mode, and the converter acts as a buck converter. In both the motoring and regenerative braking modes of the machine, the sliding mode surface successfully controls the DC-DC converter. [5].

"Liwen Pan, Chengning Zhang" present a SIC-based bidirectional AC-DC and DC-DC converter for electric vehicle charging applications with a high power density. The multifunctional on-board vehicle charger transfers energy between the battery and the electric traction system, as well as serving as an AC-DC battery charger.The converter control is designed for use in both the motor drive and battery charging systems. It is made up of a circuit that reduces power pulsation. In the battery charging mode, the improved control is designed to outperform the DCM control used in AC-DC converters [6].

Problem Statement

If the energy required for charging comes from renewable energy sources, the electric vehicle can be a clean and green alternative mode of transportation. The renewable energy based charger must be able to ransfer power in both V2G and G2V mode based on a power management strategy and must also aim in minimizing the utility grid dependency.

The rest of this paper is organized as follows. In Section II, system configuration is provided. In Section III explains the control algorithm of the proposed charger. Section IV explains the bidirectional AC-DC converter control for both grid to vehicle and vehicle to grid mode. Section V briefly explains the design of the proposed system.The proposed charger's MATLAB modelling is presented in Section VI. The simulation work's results are discussed in Section VII. Finally, Section VIII brings this paper to a close.

II. SYSTEM CONFIGURATION

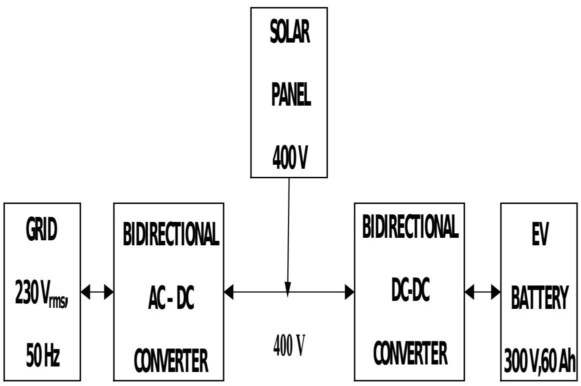

Fig.1 Block Diagram of the Solar Based EV Charger

Fig.1 shows the block diagram of proposed charger. The charger consists of a bidirectional AC-DC converter followed by a bidirectional DC-DC converter. The EV battery gets charged using the solar power or grid power. The solar or the battery power is also feed to the grid. The charger works in both G2V and V2G mode.

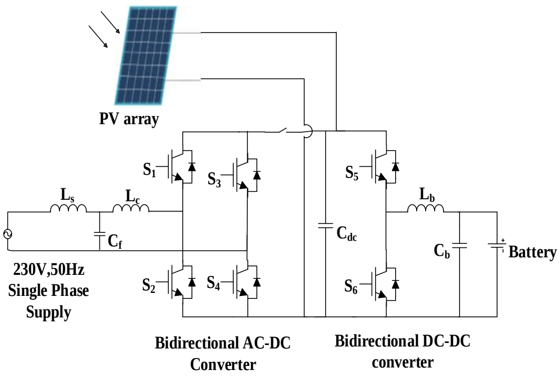

Fig.2 Circuit Topology of Solar Based Bi-Directional battery charger

Fig.2 shows the circuit diagram of the proposed charger. Two converters share a common DC capacitor in this proposed charger. One converter connects to the grid, while the other connects to the battery. During G2V mode the bidirectional AC-DC converter acts as a rectifier. It converts AC voltage into DC voltage for charging the battery. The power is transferred to the battery through the DC link capacitor. A bi-directional DC-DC converter is necessary to interface the battery. It acts as a buck converter for the control of charging voltage and current during grid-to-vehicle mode. The DC-DC converter acts as a boost converter in the V2G mode, raising the battery voltage to the required DC link voltage. As an inverter, the AC-DC converter is used. It converts DC voltage to AC voltage so that solar and battery power can be fed into the grid. The coupling inductor (L_c) is used to connect the charger to the grid. The coupling inductor eliminates the harmonics and smoothen the grid current.

III. CONTROL ALGORITHM

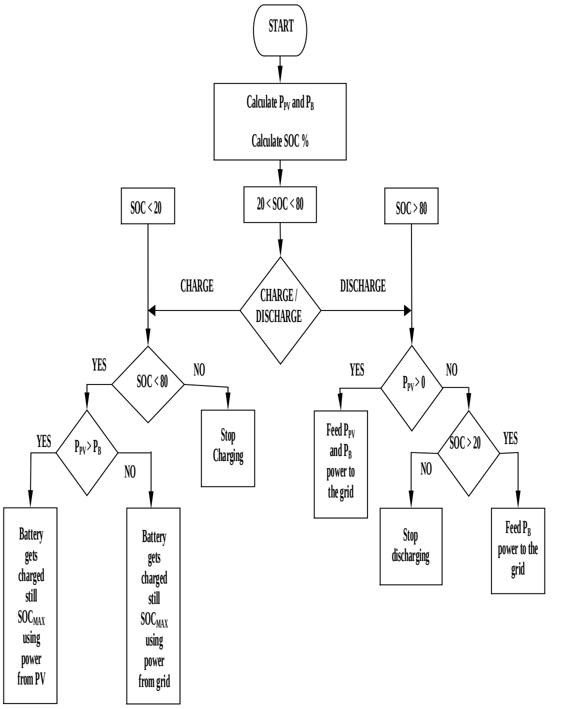

Fig.3 Control Algorithm

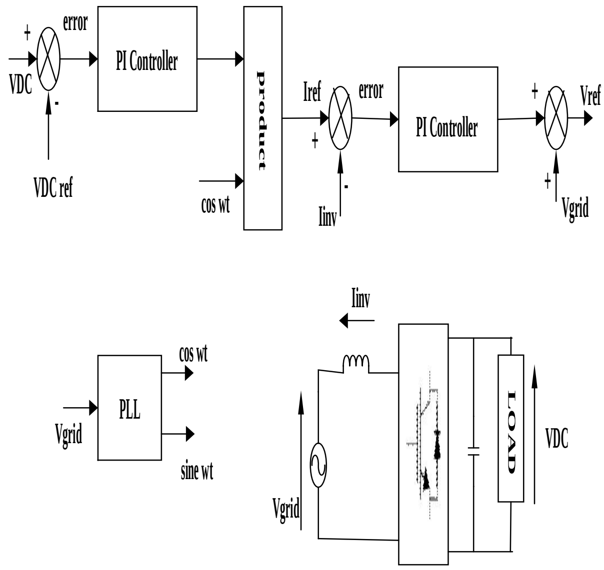

Fig.4 G2V Controller Block Diagram

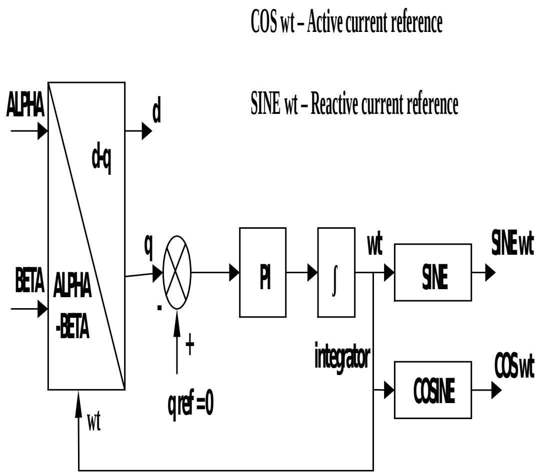

Fig.5 Phase Locked Loop (PLL) Block Diagram

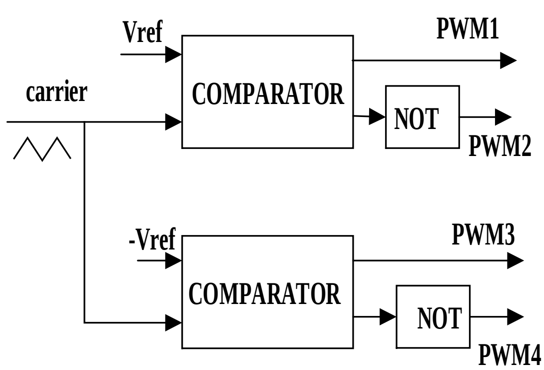

Fig.6 PWM Generation Block Diagram

The control Algorithm of the proposed charger is shown in figure 3.The solar-powered electric vehicle charger has two modes of operation. Grid to vehicle and vehicle to grid are the two modes of operation. Each mode of operation depends on the solar power generated and the state of charge (SOC) of the battery. When the SOC of the battery is less than 20 % the battery gets charged. The battery gets charged from the solar power when the PV power generated is greater than the battery power. When the PV power generated is less the battery gets charged from the grid power until the SOC of the battery reaches 80 %.

When the battery's SOC is greater than 80%, the charger switches to vehicle to grid mode. When the PV power generated exceeds zero, the solar and battery power are both fed into the grid. When no power is generated from the PV array only the battery power is fed to the grid. When the SOC of the battery reaches 20 % the battery stops discharging.

IV. BIDIRECTIONAL AC-DC CONVERTER CONTROL

Grid to Vehicle Mode

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Figure 4 depicts the grid to vehicle control block diagram. The bidirectional AC-DC converter acts as a rectifier in the G2V mode. The grid voltage, grid current, and output DC voltage are all sensed at the inverter side for this control. The error between the actual DC voltage and the reference voltage is found which is then fed to a PI controller.The value of reference current is calculated by multiplying the output of the PI controller by cos (wt). PLL generates a phase-aligned unit vector, Cos(wt), based on the grid voltage. A PLL is depicted in Figure 5 as a block diagram. The reference current is compared to the inverter current to determine the error. The error is then sent to a PI Controller. To obtain the reference voltage value, the output of the PI controller is multiplied by the grid voltage. The obtained reference voltage is fed to the PWM generation block. In the PWM generation block, the reference voltage is compared with triangular carrier waves to generate PWM pulses. The output of each comparator is inverted using NOT gate. The generated PWM is connected to the respective switches of the bidirectional converter. The PWM generation block diagram is given in figure 6.

Vehicle to Grid Mode

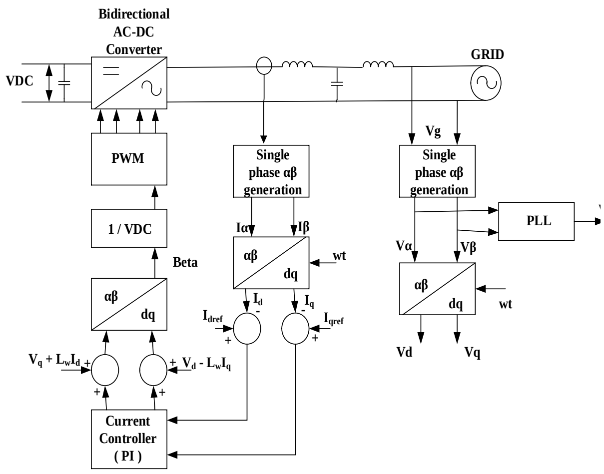

Fig.7 V2G Controller Block Diagram

The vehicle to grid control block diagram is given in figure 7. The bidirectional converter acts as an inverter in V2G mode. dq control is used to control the inverter's switching pulse. The grid voltage is sensed and it is transformed into αβ frame. The alpha (α) and beat (β) voltages is given to the PLL to get wt. The αβ voltages are converted into dq voltages. Similar to the grid voltage, the inverter current is also sensed and transformed into dq frame. The output is given to the PI controller after Id and Iq are compared to their reference values. The PI controller's output is combined with Vq+LwId and Vd-LwIq, respectively. The added values are then transformed back to the αβ frame. The beta voltage is multiplied with $1/V_{DC}$ and given to the PWM generation block [7].

V. DESIGN OF PROPOSED SYSTEM

The bidirectional AC-DC converter is designed for a power of 3 kW. The DC link voltage which is required for power transfer to the battery is 325 V. Therefore, for design of DC link capacitor a voltage of 400 V is considered.

$$C_{dc} = \frac{I_{dc}}{2 * \omega * \Delta V_{dc}} = \frac{P_{dc}/V_{dc}}{2 * \omega * \Delta V_{dc}}$$

$$= \frac{3000/400}{2 * 314 * 0.015 * 400} = 1990.4\ \mu F$$

The value of the DC link capacitor is rounded off and considered as 2000 µF.

The switching frequency considered for the design of the coupling inductor is 20 kHz. The fundamental supply current peak value is 20 A. 3% of the fundamental supply current is taken as the current ripple.

$$L_c = \frac{mV_{dc}}{6 * f_s * h * \Delta i_c}$$

$$= \frac{400}{6 * 20 * 10^3 * 1.2 * 20 * 0.03} = 4.62\ mH$$

The inductor value is rounded off to 5 mH for simulation. There will be harmonics injected from the grid. To prevent this inductive and capacitive filter is designed.

$$C_f = \frac{I_{peak}}{\omega_L V_{peak}} \tan(\theta)$$

$$= \frac{20\sqrt{2}/230}{314 * 230\sqrt{2}} \tan 1 = 318\ nF$$

A filter capacitor value of 330 nF

is considered.

The filter inductor is designed as

$$L_s = \frac{1}{2\pi f_s * \frac{I_g}{V_g} * \quad 1 - \frac{2\pi f_s{}^2}{2\pi f_{res}{}^2}} = 7.35\ \text{mH}$$

The filter inductor in the dc side is designed for a switching frequency of 10 kHz. The duty ratio is considered as 0.75.

$$L_b = \frac{V_{dc}k(1-k)}{f\Delta I_b}$$

$$= \frac{400 * 0.75 * 0.25}{32 * 1000 * 10 * 0.05} = 4.68\ \text{mH}$$

Thus, by rounding off the obtained value 5 mH is selected as the inductor value.

Table 1 AC-DC Converter Specification

S.NO	NAME	RATING
1	Supply Voltage	230 V
2	Supply Current	20 A
3	Switching Frequency	20 kHz
4	Output Voltage	400 V
5	Output Current	13 A
6	Filter Circuit Inductor	7.35 mH
7	Filter CircuitCapacitor	330 nF
8	Coupling Inductor	5 mH

Table 2 DC-DC Converter Specification

S.NO	NAME	RATING
1	Input Voltage	400 V
2	Switching Frequency	10 kHz
3	Output Voltage	325 V
4	Output Current	10 A
5	Modulation Index	0.8
6	DC Link Capacitor	2000 μF
7	Filter Inductor	5 mH
8	Filter Capacitor	700 μF

Table 3 Battery Specification

1	Battery Voltage	300 V
2	Rated Capacity	60 Ah
3	Type	li-ion

S.NO	NAME	RATING
1	No. Of Modules	60
2	Cell per Module	60
3	Open Circuit Voltage	36.3 V
4	Short Circuit Current	7.84 A
5	Output Current	13 A
6	Maximum Power	213 W
7	Output Voltage	400

Table 4 PV Module Specification

VI. MATLAB MODELING

MATLAB Block – Grid to Vehicle Mode

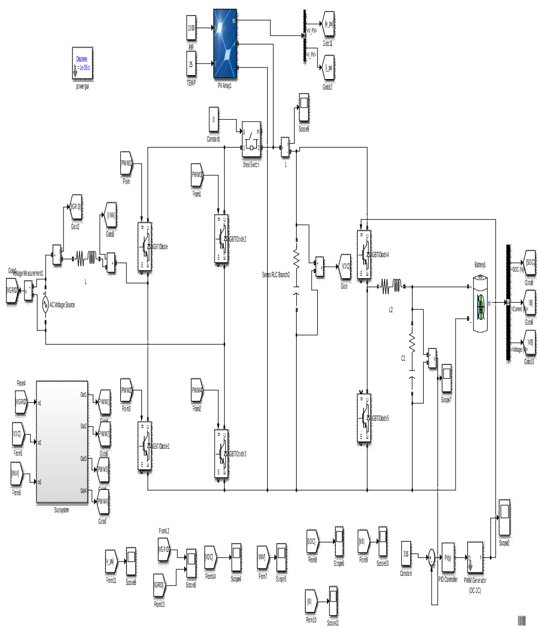

Fig. 8 Grid to Vehicle Mode

In figure 8 the electric vehicle charger is simulated in grid to vehicle mode. An AC supply of 325 V is given at the supply. The bidirectional AC - DC

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converter is controlled using dq control. The AC supply is converted to DC source and a DC voltage of 400 V is obtained across the DC link capacitor. A solar panel is connected after the bidirectional AC – DC converter. A voltage of 400 V is obtained from the solar panel. The DC – DC converter acts as a buck converter in grid to vehicle mode. The 400 V DC supply is reduced to 300 V. A battery of 300 V, 66 Ah is connected at the load. The battery gets charged during this mode.

MATLAB Block – Grid to Vehicle Control

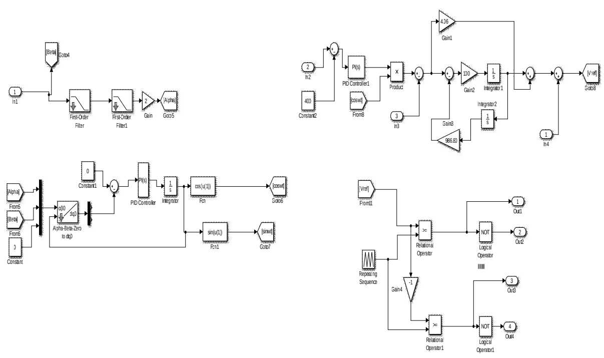

Fig. 9 Grid to Vehicle Control

The grid to vehicle control simulation block is shown in figure 9. The grid voltage is sensed and is converted from alpha beta to dq frame. The difference between the actual DC voltage and the reference voltage is determined, and the result is sent to a PI controller. The value of reference current is obtained by multiplying the PI controller's output with cos(wt). The error between the actual and the reference current is fed to the PI controller. The controller output is then given to the pulse generation block.

MATLAB Block – Vehicle to Grid Mode

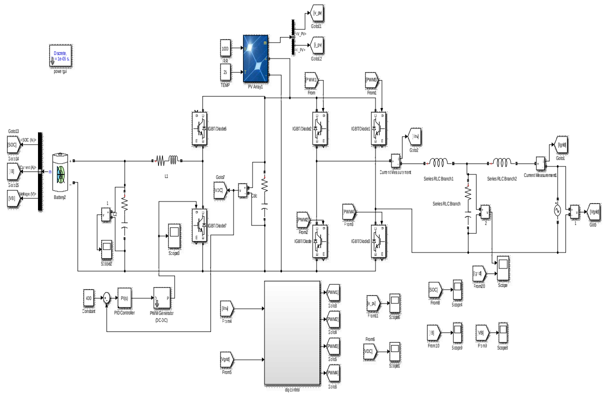

Fig. 10 Vehicle to Grid Mode

In figure 10 the electric vehicle charger is simulated in vehicle to grid mode. A battery of 300 V, 66 Ah is connected at the supply. In this mode, the bidirectional DC–DC converter acts as a boost converter.The 316 V battery voltage is converted to 400 V. A solar panel is connected after the bidirectional AC – DC converter. A voltage of 400 V is obtained from the solar panel. The bidirectional AC - DC converter is controlled using dq control. The DC supply is converted to AC source and an AC voltage of 240 V and 10 A current is obtained at the output of the converter.

MATLAB Block – Vehicle to Grid Control

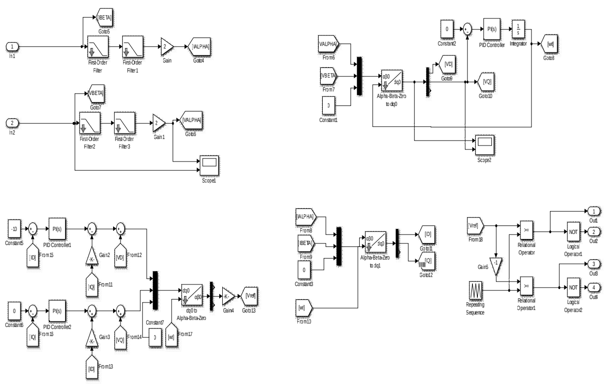

Fig. 11 Vehicle to Grid Control

The vehicle to grid control simulation block is shown in figure 11.The grid voltage and current is sensed and transformed form alpha beta to dq frame. The Id and Iq are compared to their respective reference values before being

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sent to the PI controller. The PI controller's output is converted to an alpha beta frame. The beta voltage is given to the PWM generation block.

VII RESULTS AND DISCUSSION

Grid to Vehicle Mode

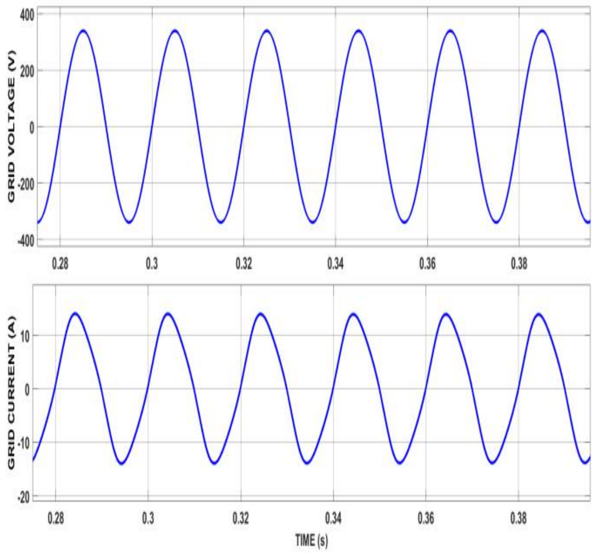

Fig.12 Input Grid Voltage and Current

Figure 12 depicts the grid voltage and current. The converter is supplied with a grid voltage of 325 V and a frequency of 50 Hz. The grid current is rated at 10 amps.

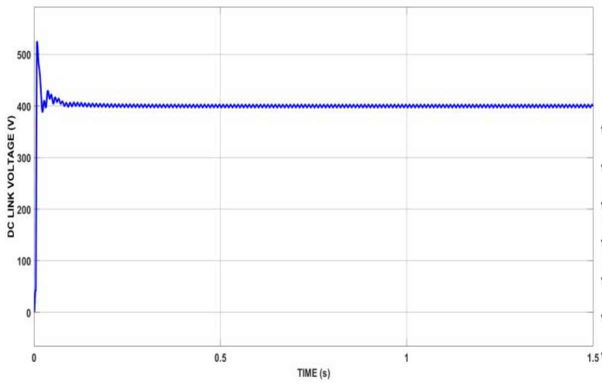

Fig.13 DC link voltage

Figure 13 depicts the bidirectional AC-DC converter's output DC voltage. The voltage is boosted 1.5 times the input supply voltage by the DC link capacitor. The DC voltage obtained is 400 V.

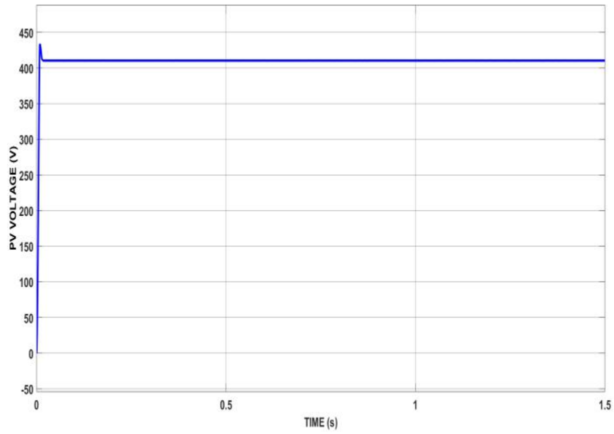

Fig.14 Solar PV Output Voltage

The output DC voltage of the solar panel is shown in figure 14. The DC voltage of 425 V is obtained from the PV array.

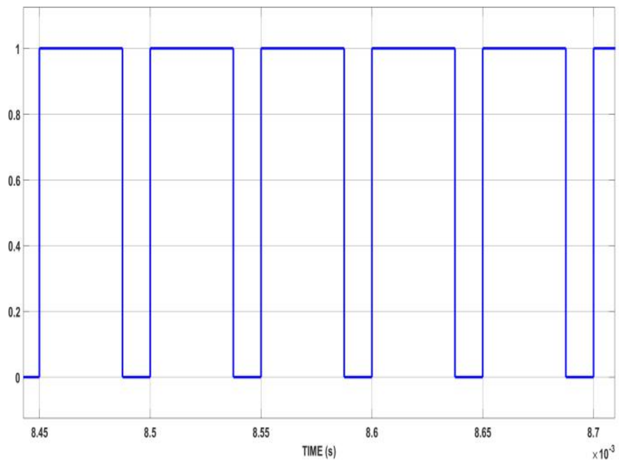

Fig.15 PWM Pulse to the Bidirectional DC – DC Converter

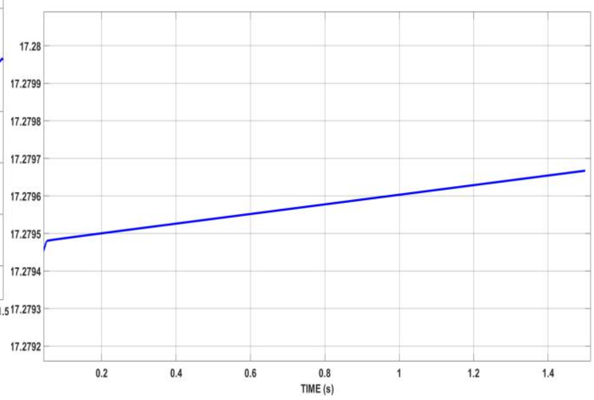

Fig.16 Battery SOC

Figure 15 depicts the PWM pulses applied to the DC – DC converter's switch 1. 10 kHz is the switching frequency. The battery state of charge is shown in figure 16. The SOC % increases as the battery is getting charged.

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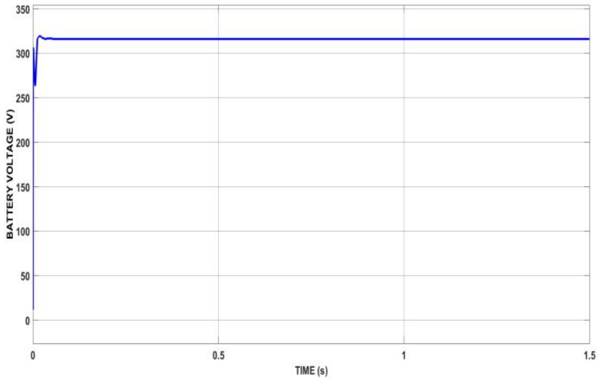

Fig.17 Battery Voltage

The waveform in figure 17 shows the battery voltage when it is getting charged. The battery voltage obtained is 316 V.

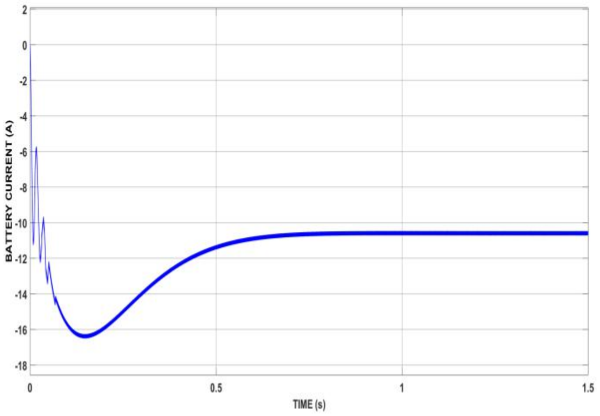

Fig.18 Battery Current

The waveform in figure 18 shows the battery current. The battery current obtained is -10 A. The obtained current is in negative polarity as the battery is getting charged.

Vehicle to Grid Mode

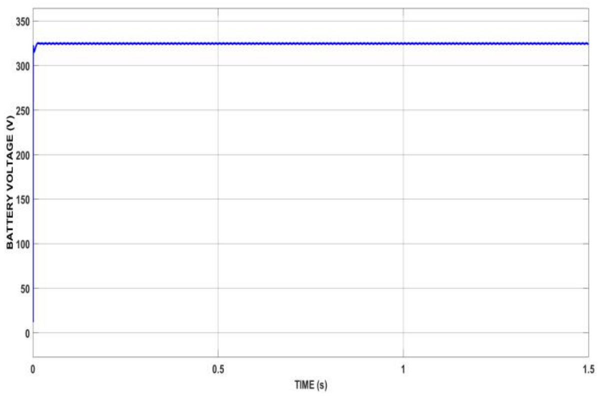

Fig.19 Battery Voltage

This waveform shown in figure 19 is the battery voltage when it is getting discharged. The battery voltage obtained is 316 V.

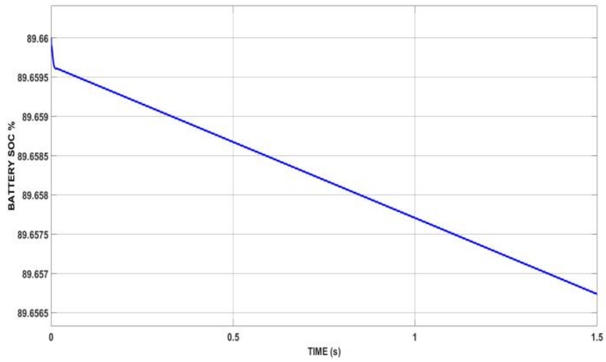

Fig.20 Battery SOC %

The battery state of charge is shown in figure 20. The SOC % decreases as the battery is getting discharged.

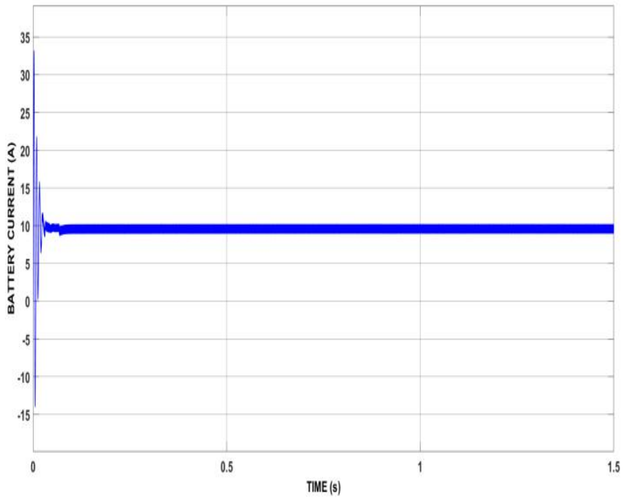

Fig.21 Battery Current

The battery current waveform is shown in figure 21. The battery current obtained when the battery is getting discharged is 10 A.

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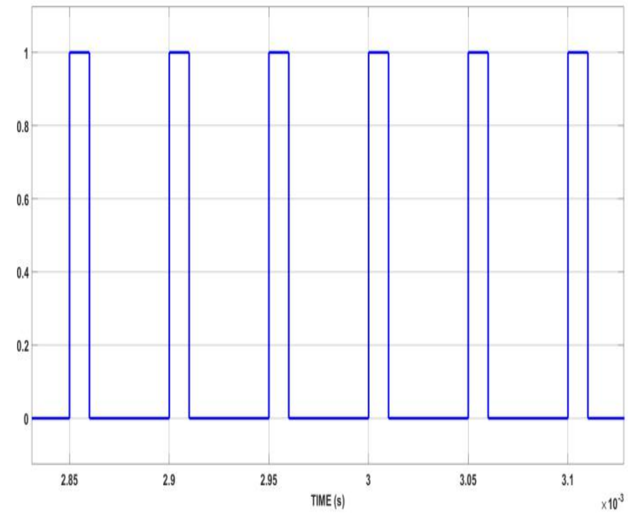

Fig.22 Gate Pulse

Figure 22 depicts the PWM pulses applied to the DC – DC converter's switch 2. 10 kHz is the switching frequency.

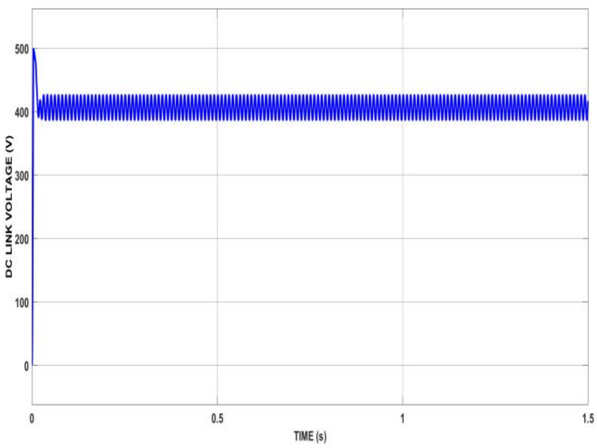

Fig.23 Output Voltage of DC-DC Converter

The output DC voltage of the bidirectional DC-DC converter is shown in figure 23. The DC-DC converter act as a boost converter and a voltage of 425 V is obtained.

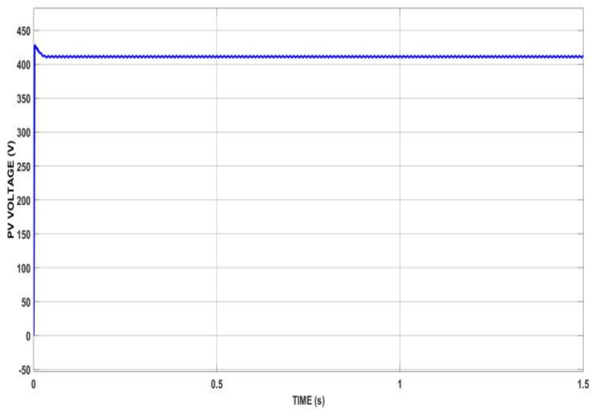

Fig.24 Solar Panel Voltage

The output DC voltage of the solar panel is shown in figure 24. The DC voltage of 425 V is obtained from the PV array.

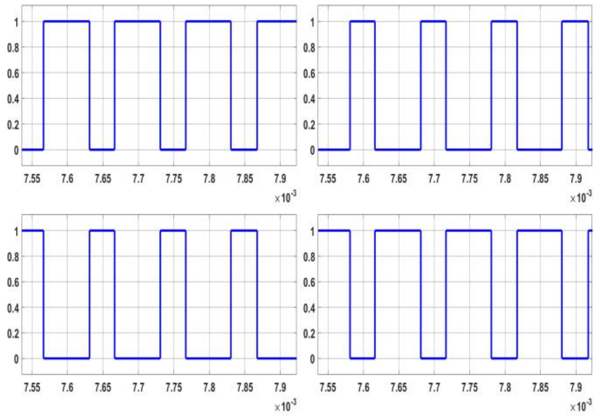

Fig.25 PWM Pulse to the AC – DC Converter

PWM pulses given to the switches of the bidirectional AC – DC converter is shown in figure 25. The switching frequency is 20 kHz.

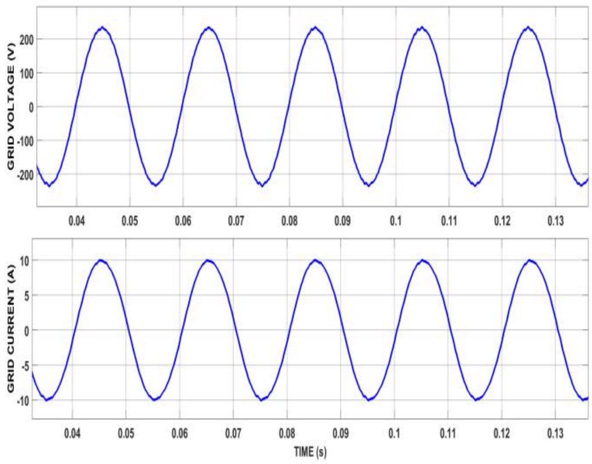

Fig.26 Output AC Voltage and Current

The obtained AC voltage and current is shown in figure 26. AC voltage of 240 V and 10 A current is obtained at the output of the converter.

I. CONCLUSION

A solar-powered electric vehicle charger with a bidirectional AC–DC converter and a bidirectional DC–DC converter, as well as a solar panel, was designed and simulated in this paper. Both grid to vehicle and vehicle to grid charging are possible with the electric vehicle charger. The charger is controlled based on the control algorithm. The proposed system is modelled and simulated using MATLAB software. The simulation results obtained indicates that the operation of the charger is achieved as per the control algorithm in both the

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modes. The proposed system also minimizes the utility grid dependency.

II. REFERENCES

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