Grid to Vehicle and Vehicle to Grid Energy Transfer using Single-Phase Bidirectional AC-DC Converter and Bidirectional DC – DC converter

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ABSTRACT-

The energy storage is generally batteries whereas in FCEV the storage will be hydrogen gas stored in a tank. From this power storage (Battery) the power gets transferred to the controller. Controller acts as pipeline or gateway that propels the car. It modulates and keeps it and it decides how much power is used and acts as a converter. Motor converts the electric power to a physical form. The main function of control system is: (1) to maximize the fuel efficiency and (2) minimize the exhaust emissions. Sometimes the controller can be a converter. The converter converts the input signal to required output signal. In EV it is placed in between the storage unit and the motor. The storage unit is mostly a battery which gives DC output voltage but this voltage should be matched with motor input voltage for that boost converter is needed. The battery gets recharged due to regenerative braking and a buck converter is needed. So to have the advantages of both a bidirectional DC to DC converter is used [22].

KEYWORDS: Bidirectional dc-dc converter, Grid to vehicle, Vehicle to grid,

INTRODUCTION

The large number of automobiles in use around the world has caused and continues to cause serious problems of environment and human life. Air pollution, global warming, and the rapid depletion of the earth's petroleum resources are now serious problems. Electric Vehicles (EVs), Hybrid Electric Vehicles (HEVs) and Fuel Cell Electric Vehicles (FCEVs) have been typically proposed to replace conventional vehicles in the near future.[6]

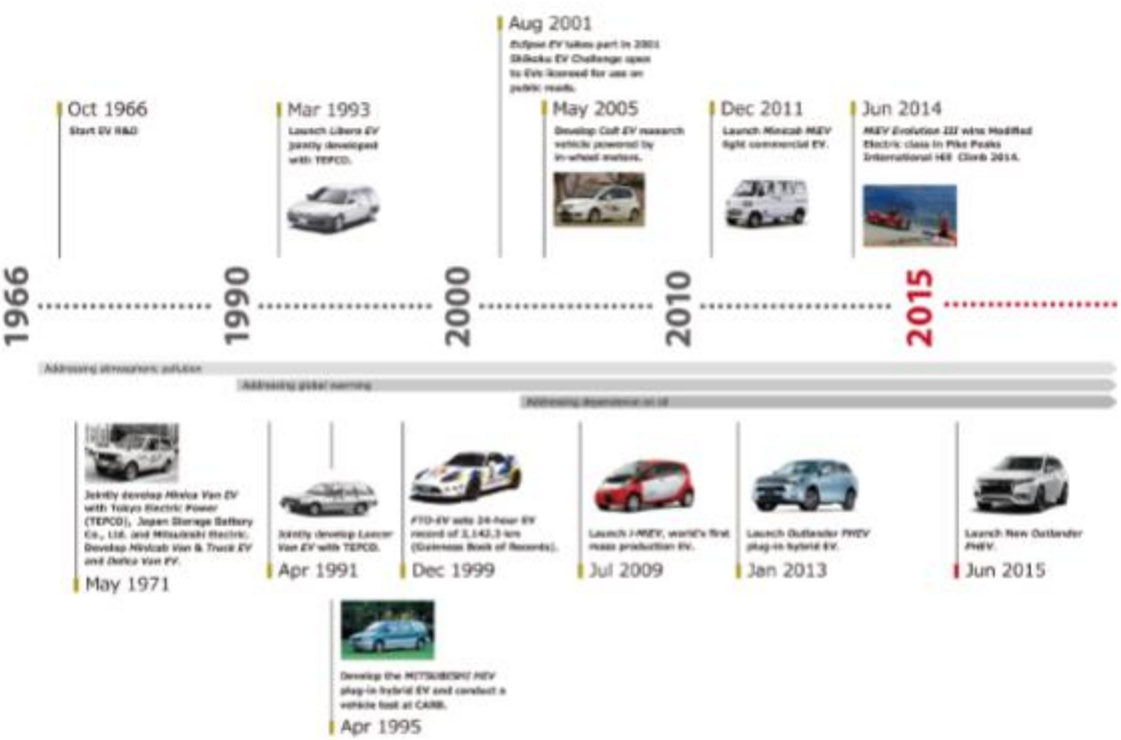


Figure1.1: The development in the electrical vehicles from 1966 to till date.

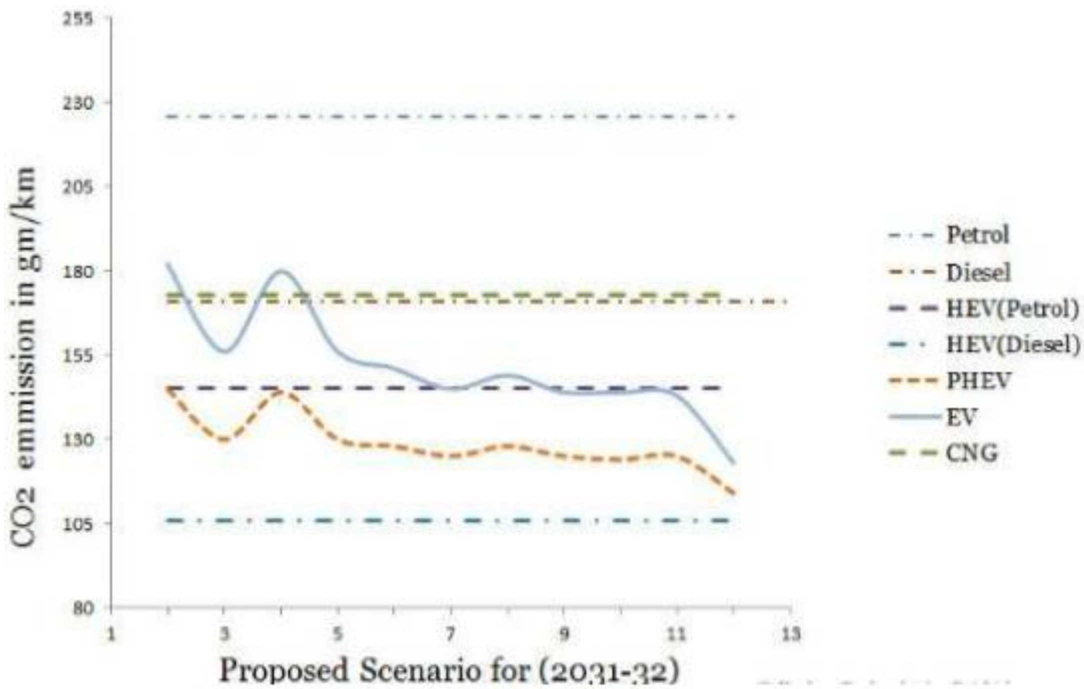


Figure 1.2: proposed scenario of electric vehicles

1.2 TYPES OF ELECTRICAL VEHICLES:[5]

1. Battery Electric Vehicles(BEV)

2. Fuel cell Electric Vehicle (FCEV)

3. Hybrid Electric Vehicle(HEV)

4. Plug-in Hybrid Electric Vehicle (PHEV)

The BEV and FCEV come under the category of pure EV while HEV and PHEV are HEV.

1.Battery Electric Vehicle: These have on board batteries that are charged from charging stations. These are also called as pure electric vehicles. These EV has no gasoline engine and longer electric driving ranges compared to PHEV and don‟t produce any dangerous gases. The Nissan LEAF, Fiat 500e and Tesla model S falls into this category.

2.Fuel Cell Electric Vehicle (FCEV): These use an electric motor like BEV but stores energy differently. These store Hydrogen gas in a tank. The fuel cell combines hydrogen with oxygen from the air to produce electricity. This powers the electric motor. The by product is water. These don‟t produce any harmful gases and there is no need for plug-in as their fuel cells are recharged by filling hydrogen gas which can take less than 5 minutes.

3.Hybrid Electric Vehicle: This is a combination of both gasoline engine with an electric motor and battery. They don‟t have the facility to charge the battery; the battery gets charged by trapping energy when braking using regenerative braking that transforms kinetic energy into electricity. This energy is generally wasted in conventional vehicles. Hybrid fuel saving technology can significantly increases the fuel economy.

4.Plug-in Hybrid Electric Vehicle: This is similar to HEV but in this the battery gets charged by plugging into an outlet as they are rechargeable batteries. These can substitute electricity from the grid for gasoline. These are also called as Extended Range Electric Vehicles. These have mile range expectation of 30 to 40 miles on electric power for shorter trips and a gasoline powered ICE for longer trips.

Electric vehicle Advantages:

• Cheaper Energy Cost

• Less Pollution

• Less Moving Parts/ Wear And Maintenance

• No Oil Changes

• No Waste Energy While Running

• Drivetrain Potentially Last Longer.

1.4 CONVERTER:[13]

Due to the advancement in power electronics it is known that each source and load has it's own specifications and could be connected by any means of converters. The basic fig for power flow in the electric circuit is given as follows:

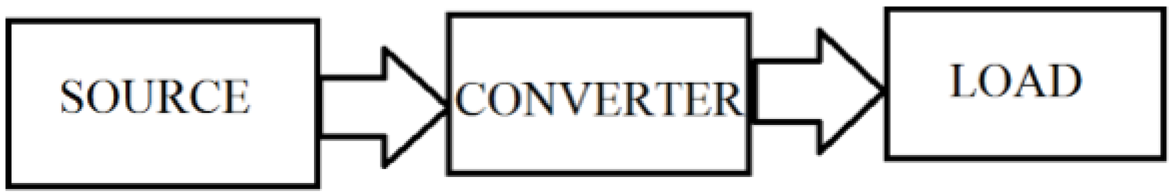


Fig 1.3: POWER FLOW IN THE BASIC ELECTRIC CIRCUIT

So now coming to the classification the source, converter and load, they could be classified as follows:

Requirements of BDC:

• Less weight

• High efficiency

• Compact size

• High reliability

There would be four types of converter from source to load, they are:

1. Ac to ac converter: This type of converters is used if both the source and load are of ac. Eg: cyclo-converters, transformers.
2. Ac to dc converter: This type of converter is used when the source is of ac, and the load is of dc. Eg: rectifiers.
3. Dc to ac converter:This type of converter is used when the source is of dc, and the Load is of dc Eg: choppers.
4. Dc to dc converter:This type of converter is used when both the source and load are of dc.Eg: choppers.

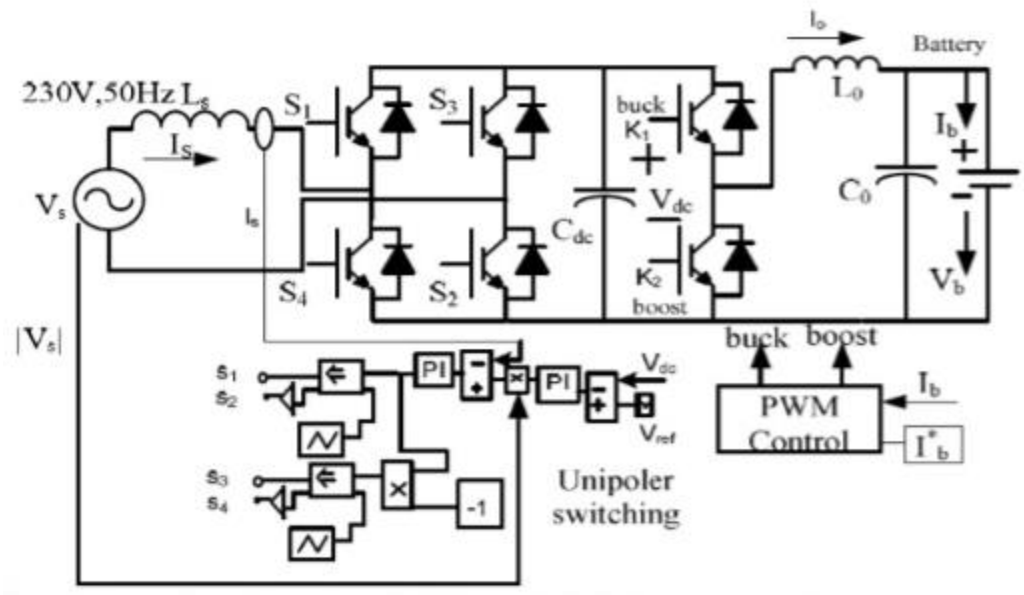
2.MODELLING AND ANALYSIS OF THE PROPOSED SYSTEM CONFIGURATION

2.1 Design of the proposed system:[18]

The design of various components of proposed system consists of charging and discharging modes in a single phase bidirectional AC-DC converter, a .bidirectional DC-DC boost converter, a battery energy storage system. The detailed design of each part is given in the following sections.

2.1.1Design of single-phase bidirectional AC-DC converter:

These types of converters are developed to meet the requirements of applications of bidirectional power flow in order to improve the power quality at grid. And it is designed for a 3kw.The below fig shows a circuit of this type of converter.



Proposed configuration for V2G and G2V Energy transfer

The fundamental converter voltage Vc is given as,

$$v_c = \frac{mv_{dc}}{\sqrt{2}}$$

Where, where m is modulation index, the value of m is considered as 0.9, and Vdc is the dc link voltage and it is taken as 380 V. Thevalue of Vc by using above equation is 241.86V. The relation between fundamental converter voltage andsource voltage is given as,

$$V_{c=\sqrt{(v^2{}_s+(i^2{}_s*X^2{}_l)}};$$

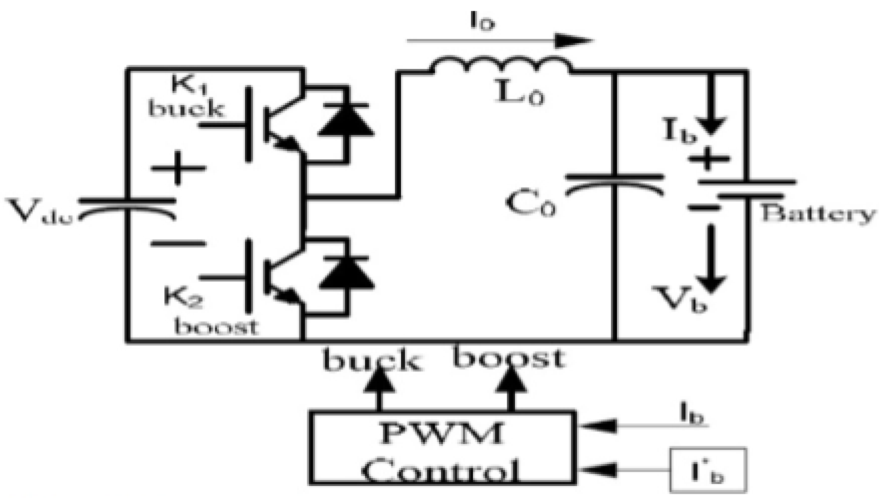
whereVs is rms grid voltage and the value of Vs is 230 V andIs is grid rms current. By using above equation the value of gridinductance is calculated as 2.1mH. The value of dc link capacitor is given as,

$$C_{dc}=\frac{I_{dc}}{2*\omega*V_{dcripple}}$$

whereIdc is the DC link current (Pdc/Vdc) and ω is angular frequency and dcripple v is 5% of Vdc. From above equation the calculated value of Cdc is 1mF .Detailed model parameters of the system are given

s.no	Parameter	Value
1.	K_{i1}	2
2	K_{p1}	0.1
3	l_s	2.3mh
4	K_{i2}	2
5	K_{p2}	0.85,3000w,230v rms
6	f_s	20khz

2.1.2. Design of Bidirectional Buck-Boost DC-DC Converter:



Bidirectional buck-boost DC-DC Converter

Above figure shows a bidirectional buck-boost dc-dc converter.The solid state switch K2 is used for boosting while the switchK1 is used for the buck mode. The relationship betweenswitching frequency f, inductance L, in buck–boost mode isgiven as,

$$f = \frac{1}{2 * P * L}\left(\frac{1}{\left(\frac{1}{V_{dc}}\right) + \left(\frac{1}{V_b}\right)}\right)$$

Where P is conversion power, Vdc is input voltage and Vbis output voltage and f is the switching frequency and its valueis 50 kHz. The value of P is 3 kW, Vdc input voltage 380V andVb is output voltage is 120 V. From above equation the value of L is: 1.9 mH [8, 9]. Detailed model parameters are given in below table

s.no	Parameter		Value
1.	Buck	K_{i1}	1
2.		K_{p1}	0.001
3.	Boost	K_{i2}	0.5
4		K_{p2}	0.001
5.	F_s		50khz
6.	L_o		1.9mh

2.2 control strategy :

The control algorithm for different blocks of proposed system is given in this section. It plays an important role in the operation of such system and is explained as follows.The average value of output voltage Vo can be controlled by using a control scheme.They are different types of controllers. And out of all pi controller is the most desired one.

2.2.1 Proportional Integral (PI) Controller:[16]

At present, the PI controller is most widely adopted in industrial application due to its simple structure, easy to design and low cost. Despite these advantages, the PI controller fails when the controlled object is highly nonlinear and uncertain.

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system.

Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller.

PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when

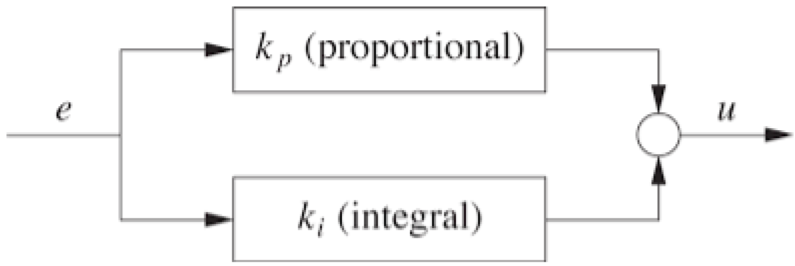
1. Fast response of the system is not required

2. Large disturbances and noise are present during operation of the process

3. There is only one energy storage in process (capacitive or inductive)

4. There are large transport delays in the system.

Therefore, we would like to keep the advantages of the PI controller. This leads to propose a PI controller shown in the fig. This controller uses of the proportional term while the integral term is kept, unchanged.



2.2.2 control of single phase bi-directional ac-dc converter:

In the control of single-phase bidirectional AC-DC converter, a unipolar switching scheme is used, in which the triangular carrier waveform is compared with two reference signals

which are positive and negative signals. The output voltage varies between 0 and Vdc, or between 0 and –Vdc. The PI (proportional integral) voltage controller closely tracks the reference voltage (Vref) and gives a control signal (Ip) tominimize the voltage error Ve (k) which is calculated from thereference voltage Vref (k) and a sensed voltage Vdc(k) at kthinstant of time as,

$$V_e(k) = V_{ref}(k) - V_{dc}(k).$$

The output of the controller Ip(k) at kth instant is given as,

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

whereKpv and Kiv are the proportional and integral gains ofthe voltage controller.The PI current controller closely tracks the reference current$Ip*(k)$ and gives a control signal Vcs to minimize the current error $Ie(k)$ which is calculated from the reference input $Ip*(k)$. and a sensed current Ip(k) at kth instant of time as,

$$I_e(k)=I_p^*(k)\text{-}I_p(k).$$

This current error is amplified using the proportionalcontroller by gain "K," and which is given as, $Vcs=k.(k)$

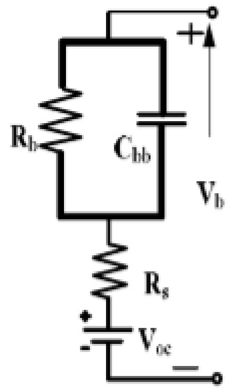
This amplified signal is compared with fixed-frequency (10kHz) triangular carrier wave in unipolar PWM switchingsignals for the IGBTs of single-phase bidirectional AC-DC converter.

2.2.3 control of bi-directional buck-boost dc-dc converter:[15]

In order to get the desired operation of charging anddischarging of the battery using a bidirectional buck-boostconverter, a PWM control technique is used here. A PIcontroller is used to control the battery output current (Ib).The PI voltage controller closely tracks the reference dc linkcurrent and gives a control signal (Vct) to minimize thecurrent error Iet(k) which is calculated from the reference dc link current $I{*}b(k)$ and a sensed dc link current $Ib(k)$at the kthinstant of time as, $Iet(k)$=$I{*}b(k)$-$Ib(k)$ The output of the PI controller $Ic(k)$ at kthinstant is given as,

$$V_t(k) = V_t(k-1) + K_{pv}\big(I_{et}(k) - I_{et}(k-1)\big) + K_{iv} I_{et}(k)$$

whereKpv and Kiv are the proportional and integral gains ofthe voltage controller [7]. This scheme is applicable for buckas well as boost mode. The output of the controller VT(k) at kthinstant is compared with fixed frequency (fs) saw-tooth carrierwaveform to get the switching signals for the MOSFETs ofthe bidirectional buck-boost converter.



2.3 matlab based modeling of the proposed system:

The simulation model of the proposed energy transfer from the vehicle to grid and grid to vehicle is shown in below fig developed in MATLAB. It consists of modeling of single phase bidirectional AC-DC converter. This single phase bidirectional AC-DC converter is designed for a power of a 3kW. The bidirectional DC-DC buck-boost converter is used for charging and discharging of the battery of PHEV. The detailed parameters of bidirectional buck-boost converter aregiven in Appendix A. A battery energy storage system is considered for 1.20 kW for 12 Hours peaking capacity with in the variation in voltage of 106 V to 136V. Detailed parameters of storage battery are given in below table.

s.no	Parameter	Value
1	r_b	10000 ohm
2	r_s	0.01 ohm
3	v_{oc}	120v

3.SIMULATION, RESULTS AND FUTURE SCOPE

3.1 Simulation Platform MATLAB has been used as the simulation platform for the Electric Vehicle modelling and PSIM has been used for the analysis of the converters. MATLAB, MATrixLaboratory is a multi-paradigm numerical programming language. It is a fourth generation programming language. MATLAB allows matrix manipulations and it is also acts like a graphical interface. 5.2 Simulation Model: Here the simulation of grid to vehicle and vehicle to grid energy transfer using single-phase bidirectional ac-dc and bidirectional dc-dc converter

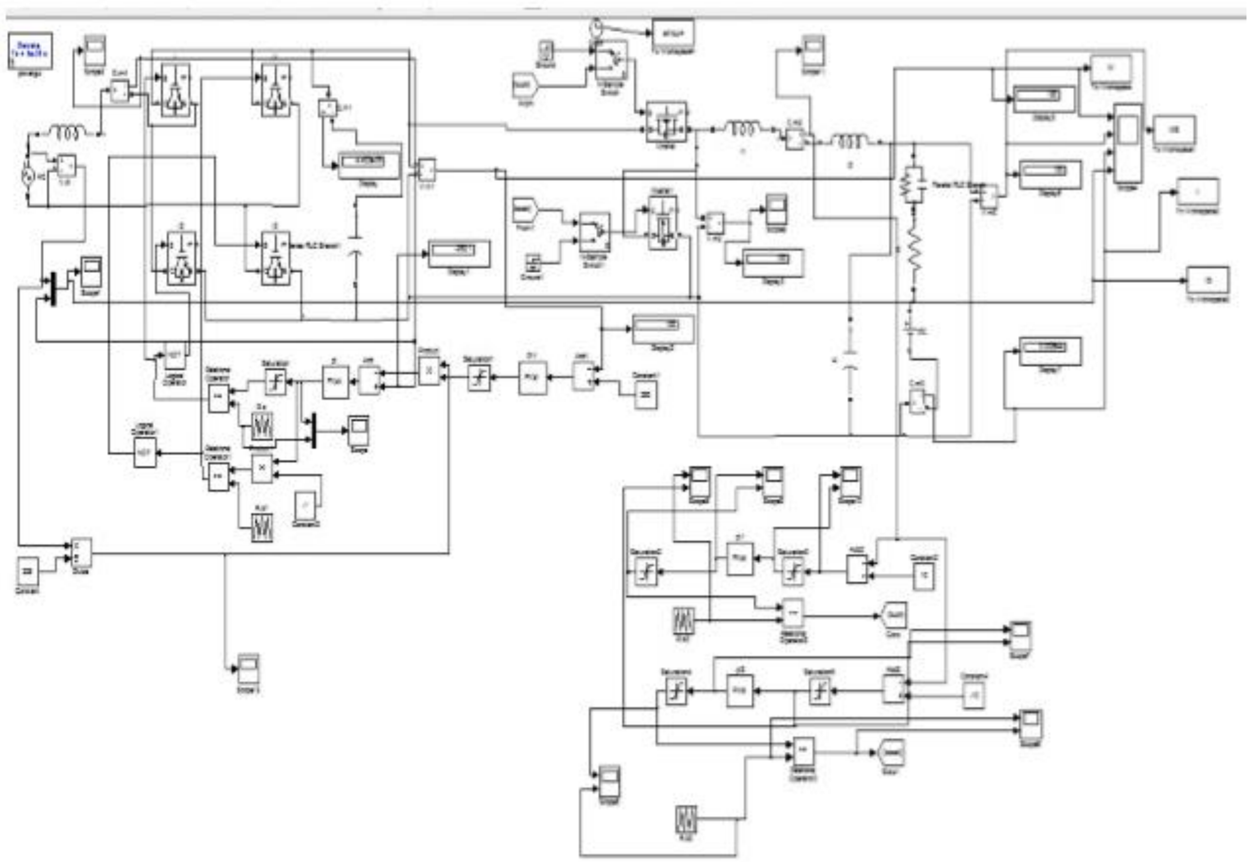


Figure:3.1closed loop simulink model of single phase bi-directional ac to dc and dc to ac converter.

The simulated results from the above plug-in mode are shown in the below figures.

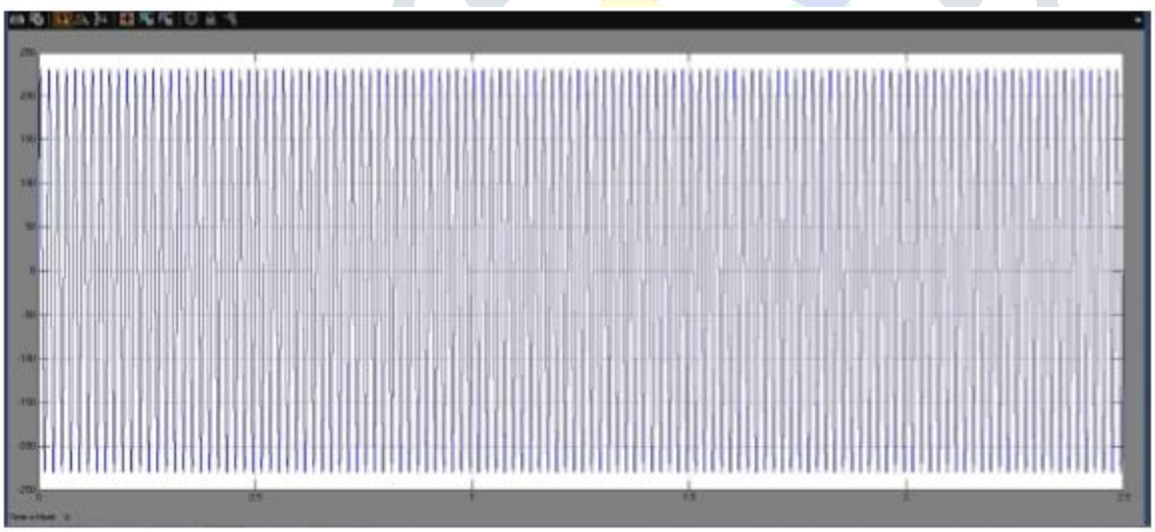


Figure 3.2.1 source voltage of the proposed system.

The obtained voltage is about 230v, since the grid is of 230v, 50hz, the source voltage obtained is of same value and is of sinusoidal input. The maximum voltage could be represented as:

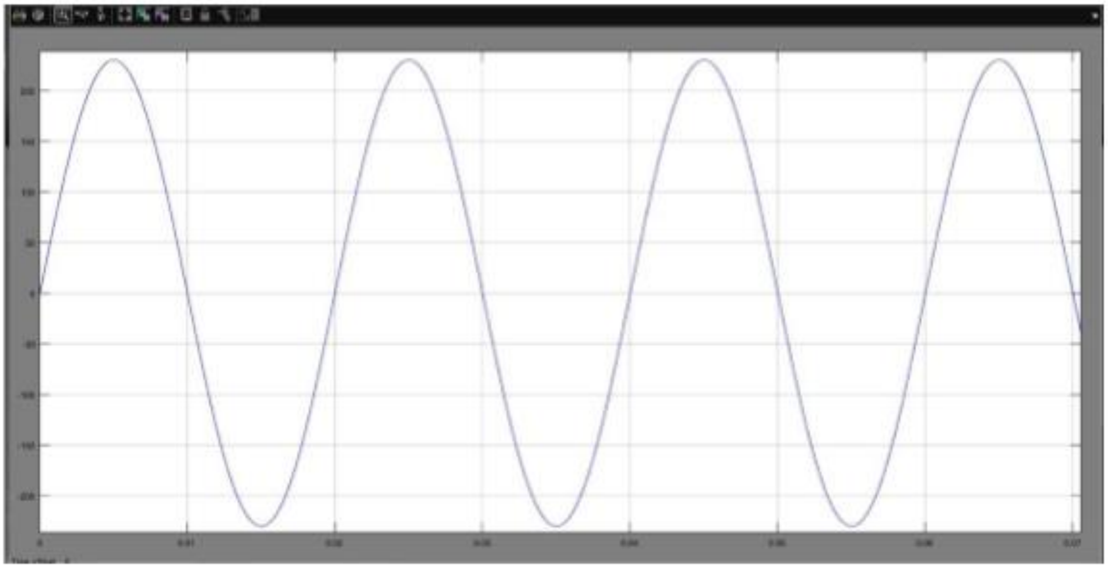


Figure 3.2.2 maximum source voltage of the proposed system

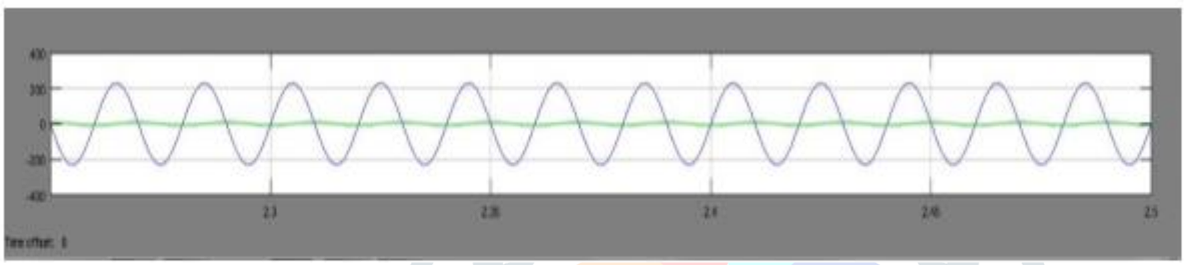


Figure3.3 source voltage and current profile in the proposed system.

The current delivered to and from the grid is shown to be sinusoidal and in phase with the grid voltage. This eliminates current harmonics and maintains unity power factor. When delivering power to the grid, the injected current is in the reverse direction of the grid voltage, which can be seen from 180 degree phase difference. In this case, zero crossing of the grid voltage and injecting current are still matching each other. Now, we need to concentrate on the voltage across the capacitor and it could be shown as follows:

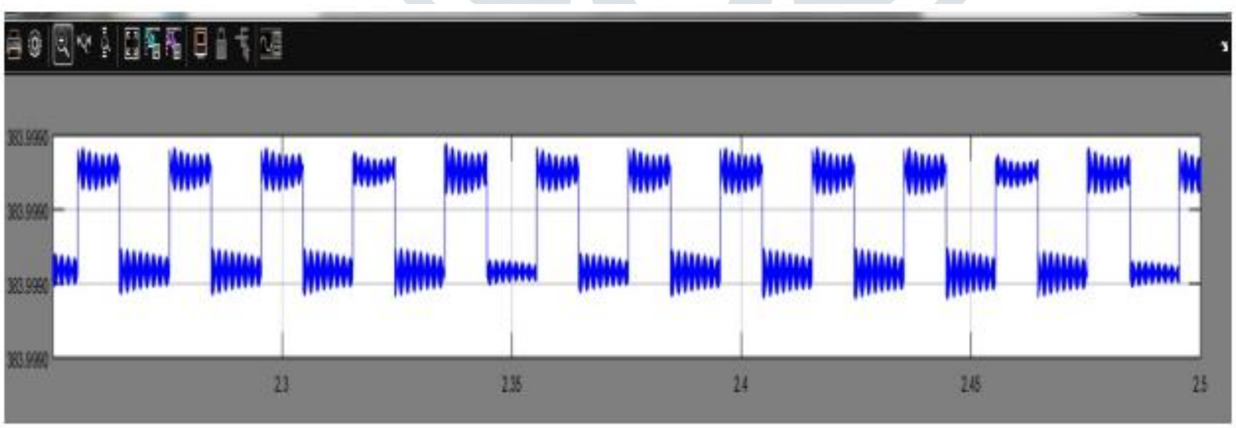


Figure 3.4: voltage across the capacitor.

It is observed that the voltage across the capacitor is found to be 383.999v. But as per the simulation it has to be and per the modeling of the system it has to be 380 v. That small variation in the voltage value might because of the gain that is the values of pi controller. And also as the conversion of voltage from ac to dc takes place usually rectifiers are employed and there is a slight increase than the usual value. That is 230v a.c is converted to 380v d.c. and that voltage is fed to the converter for buck operation.

Now we need to go through the battery side that is the voltage and current of the battery are to be measured:

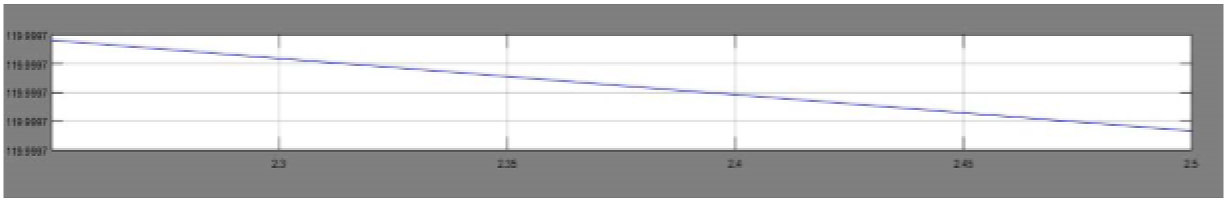


Figure 3.5 voltages across the battery.

The obtained voltage is 119.999v across the battery, it almost near to the required value that is 120v at the battery side, the voltage across the capacitor that is 383 v dc is stepped down to 120v dc because of the operation of dc-dc converter. Which operates as buck converter

and reduces the voltage? It is not mandatory to have 120 v at the battery but the voltage of the limit 106v to 136v is appreciable. Now the current across the battery is:

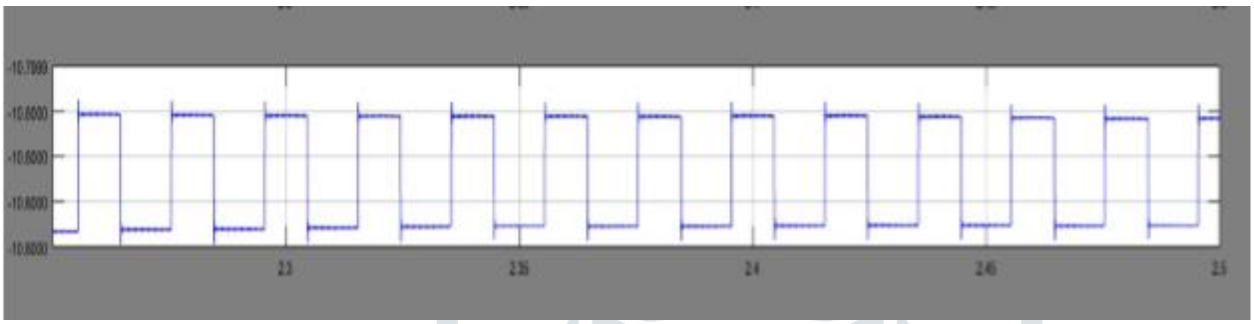


Figure 3.6 current across the battery.

The obtained current is about -10.8 A, that is for the discharging time, if at all for charging it would be 10A and the required limit for the current is about 10A to -10A. So the obtained current is apt for the given propulsion system. The obtained values could be tabulated as follows

s.no:	Parameter	Actual value	Obtained value
1	Source voltage	230v	230v
2	Source current	10A	10A
3	Battery voltage	120v	119.999v
4	Battery current	10A to -10A	10.8A to -10.8A
5	Capacitor voltage	380v	383v

4 Conclusion and future scope:

The proposed converter has delivered the ac current to/and from the grid at unity power factor and at very low current harmonics which ultimately prolongs the life of the converter and the battery and minimizes the possibility of distorting the grid voltage. It also enables V2G interactions which could be utilized to improve the efficiency of the grid. Here we have done the simulation for single phase bi-directional ac-dc and dc-dc converters and the results are also found to be approximately equal to the designed values.

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