MPPT Based Bi- Directional DC-DC Converter for Stand Alone Systems

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ABASTRACT

The Field Programmable Gate Array FPGA controlled solar photo voltaic (SPV) system is proposed in this paper. The Bi-Directional DC-DC Converter BDC is proposed for charging the battery during day hours and discharging of battery during night hours by operating in buck and boost modes respectively. For buck mode PID controller is preferred and TYPE 3 controller for boost mode of operation of BDC and implemented on FPGA. Besides the BDC, the maximum power point tracking MPPT charge controller is also designed with constant voltage maximum power point tracking CVMPPT and used in FPGA after conversion in digital domain form.

I. INTRODUCTION

In today life there is the rapid increase in the population growth and the need of energy is increasing tremendously. Due to which the demand of fossil fuels is also increasing and these fuels cause pollution at the time of electricity generation. Since they are limited in nature, so there excess use is reducing them rapidly. To avoid the pollution caused by fossil fuels clean sources of energy like wind and photo voltaic energy are generated. Further there are still some areas in the world like mountain areas where there is not access of any grid. For such reason stand alone system is becoming best choice for those OFF grid places and can be easily installed. These stand alone systems consist of solar PV modules, power conditioning systems, energy storage and connected loads. Since the energy conversion efficiency is low in photo voltaic cell, therefore maximum power point tracking MPPT is needed to be installed so that maximum power is extracted from the solar photo voltaic modules in order to increase its efficiency[1].

The type of energy generated from solar PV system needs to be stored so that it can be used during night hours and in cloudy conditions, when sun is not available. So for the storage of this generated DC power, DC-DC Converters are widely used [2,3]. The Bi-Directional DC-DC converters are more popularly used for this purpose because of their Bi-Directional flow. A good description of the original and fundamental buck ,boost, and buck boost switched mode DC-DC topologies appears in[4].Also in [4] the concept of two quadrant bilateral converter is introduced and its suitability to battery charging/discharging is discussed. In [5][6] techniques like high filter inductance and high output filter capacitance is used, due to which turn OFF losses and conduction losses which

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are harmful for switches are reduced. However they tend to increase the cost and also results for low power density. In [7] a new soft-switching technique for buck, boost and buck–boost converters has been proposed. This technique allows the main inductor current to operate in CCM with small ripple. The Bi-Directional DC-DC Converter in [8] used for energy storage is having more switches and is isolated. So the switch losses and production cost are more and reduces the efficiency of system.

From the above discussion, this paper has defined efficient MPPT based non isolated Bi- Directional DC-DC converter which features as high voltage gain, low power losses with reduced current ripples, CCM operation, simple in structure and less number of switches.

II. PROPOSED SYSTEM

The fig.1 shows the block diagram of our proposed system consisting of PV module , MPPT, charge controller, BDC and battery for storage of power. The output from charge controller will fed to load through DC bus as well as to battery at the time of requirement. The Bi-Directional DC-DC converter BDC interfaces battery to DC load bus and performs the charging and discharging of the battery as per the requirement.
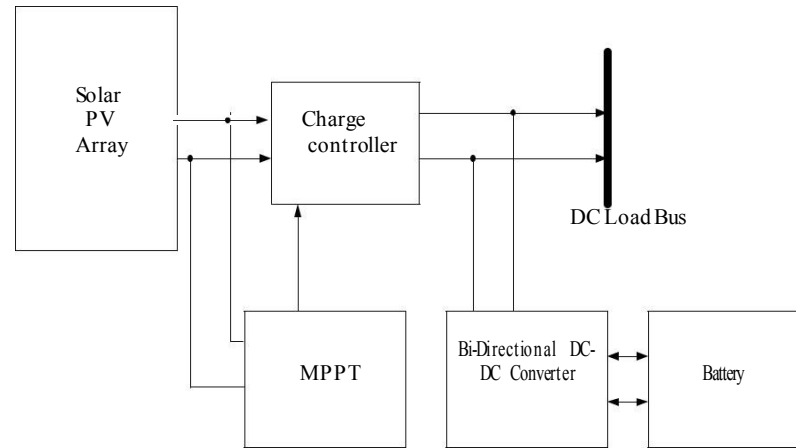

Fig.1 Proposed System

1.1 PV MODULE

The combination of PV cells in series or parallel sequence results in formation of PV module or solar panel. The fig.2 shows the single equivalent circuit diagram of PV module circuit. Current voltage relationship for the pv module is given below[9,10].

$$V_{pv} - V_D + I_{pv}R_s = 0 \qquad (1)$$

Where,
I_{LG} = Current due to solar radiations,   (2)
I_D = Current flowing in diode
V_D = voltage across the diode
I_{PV}= PV current
V_{PV} = PV voltage
R_{sh}= shunt resistance
R_s= series resistance.

I_{sat}=saturation current of PV module

$$\cdots - 1) - \frac{V_{pv} + I_{pv}R_s}{R_{sh}} \qquad (3)$$

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T = temperature of PV module (k)

k = Boltzmann constant (J/K) $(1.380{\times}10^{-23})$
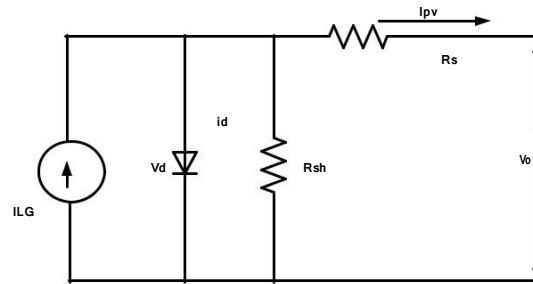
q = electron in charge (C) (-1.602×10^{-19})

Fig.2. solar PV cell equivalent circuit.

1.2 MPPT

The maximum power point tracking (MPPT) charge controller is a DC-DC converter circuit with MPPT algorithm. The MPPT algorithm decides the specific duty cycle for the switching operation of DC-DC converter, so that the operating point is close to MPP. There are many techniques available for MPPT algorithm development. But we are using constant voltage based maximum power point technique CVMPPT for extraction of maximum power. The relation between voltage at maximum power point and open circuit voltage "V_{MPP}" and "V_{OC}" is given by

$$V_{MPP} = KV_{OC}$$

Where constant K = 0.71 to 0.78[9]. Therefore voltage at MPP can be calculated by the use of above formula and is taken as reference voltage. The algorithm used in MPPT technique is shown in below fig.3
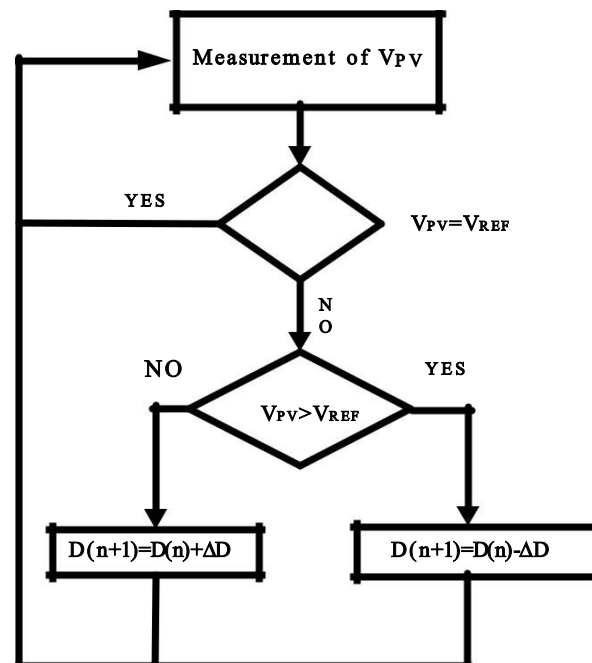
Fig.3. Algorithm of CVMPPT method

The output of boost converter (voltage and currents) which is a part of DC-DC converter is constant and creates a DC bus. This DC bus is connected to loads in order to supply power as shown in fig.1.

1.3 BI-DIRECTIONAL DC-DC CONVERTER

Bi-Directional DC-DC Converter is used to transfer power between two voltage sides that is, it transfers power from low voltage side to high voltage side and from high voltage side to low voltage side. However we can use Boost and Buck converters individually but it will increase size, cost and losses of system and also reduces the efficiency of system. That is the reason we use Directional DC-DC Converter (BDC) for supplying the un interrupted power supply. The fig.4 shows the BDC with the controller for two modes of operation (Buck & Boost) by manipulation of switches.
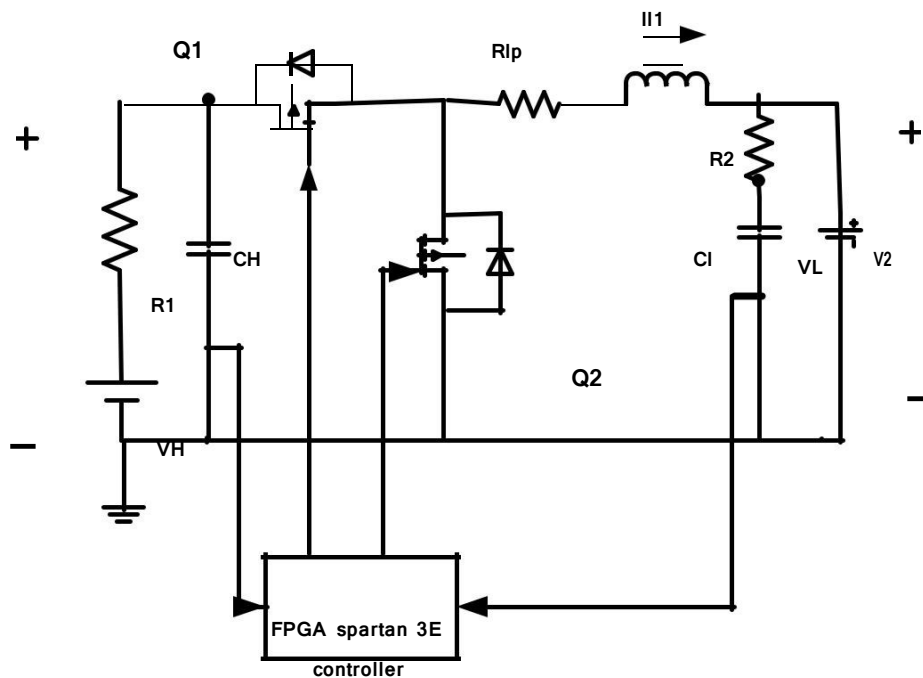

Fig. 4 BDC circuit with controller.

1.4 OPERATING PRINCIPLE

The equivalent circuit diagram shown in fig.4 represents two DC sources including low voltage side bus V_L and high voltage side bus V_H. the resistance R_l acts as internal resistance in charging and discharging mode on high voltage side or load during boost resistive applications. While R_2 acts as internal resistance on low voltage side during charging and discharging modes or load during buck applications. The capacitor bank is indicated by C_H and output capacitor at battery side is indicated by C_L capacitor. The switches Q_1 and Q_2 are controlled by providing complementary gate signals. Since there are two modes of operation i.e; Buck and Boost operations which are explained below.

1.4.1 BDC IN BUCK MODE

During the requirement of low voltage or during the charging BDC acts in Buck mode as shown in Fig.5. Current flowing through inductor changed for one cycle can analyse input voltage (V_{in})and output voltage (V_O). since we are not considering voltage drop across diode, so during the turn ON time.

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$$(\quad - \quad) \quad - = 0 \tag{4}$$

On solving the above equation, the gain is

$$\quad = \quad = \tag{5}$$

Therefore output voltage becomes $V_o = DV_{in}$

Fig.5 shows the BDC in the buck mode of operation.

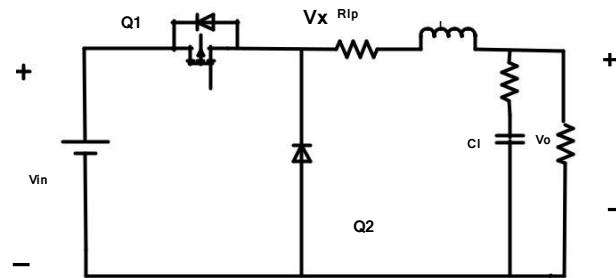Fig.5. Buck mode of bidirectional DC DC converter.

1.4.2 BDC IN BOOST MODE

BDC acts as boost converter during the discharging of battery or during conversion of voltage from low voltage to high voltage side DC. The diode is forward biased during the switch Q_2 is ON. At that time energy across $V_x = V_{in}$. During its turn OFF, voltage from inductor and input is drawn to output side. Zero value of inductor is taken for steady state analysis.

$$+ (\quad - \quad) \quad = 0 \tag{6}$$

On solving the above equation .

$$\quad = \quad = \frac{1}{1-} \tag{7}$$

Therefore output voltage becomes

$$= \frac{}{1-} \tag{8}$$

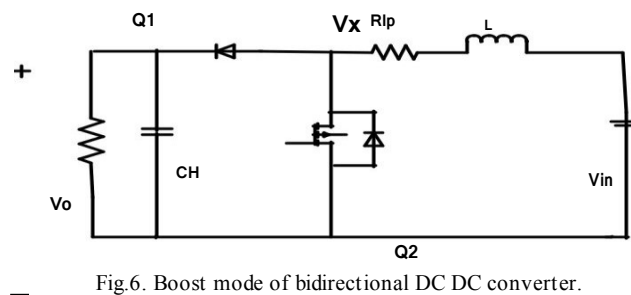The fig.6 shows the Bi-Directional DC-DC converter in Boost mode of operation.

Fig.6. Boost mode of bidirectional DC DC converter.

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1.5 FPGA

It is a field programmable gate array and is an integrated circuit which is programmed according to the requirement. It can be easily programmed for the design of pulse width modulation PWM in control applications. The steps involved in the programming of FPGA is given in a below fig.7
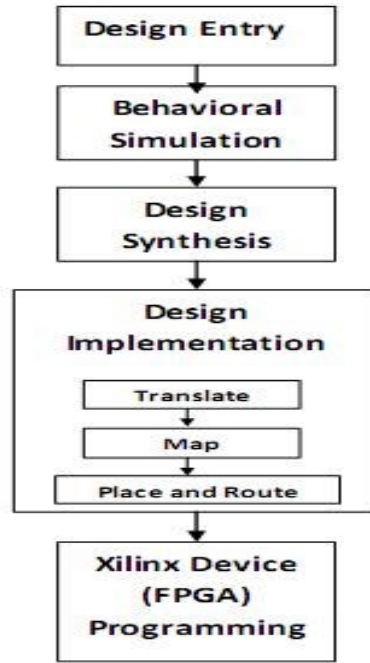
Fig.7 Steps in Design FPGA.

FPGA is used for generating pulses for Bi-Directional DC-DC converter. They are fast in execution of program and can measure million of instruction per second.

1.6 CONTROLLING METHODOLOGY

For the controlled operation of BDC the voltage mode control method is implemented. Using this method voltage at output side is sensed and is compared to reference voltage (V_r) and produces error in voltage. This error is corrected by controller and sends controlled signal to modulator for its modulation. On comparing with saw tooth wave form of constant amplitude, the pulse width modulated voltage signal (V_m) of required duty cycle is generated. The control value decides the duty ratio of generated PWM signal. Fig.8 shows the block diagram of DC-DC converter with the close loop feedback system i.e; shows the voltage pulse width modulation scheme for DC-DC converter.
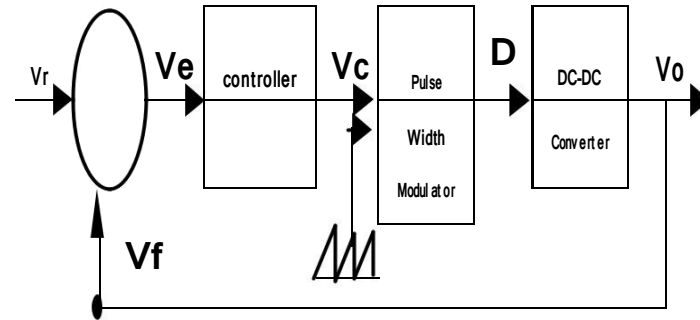
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Fig.8. Voltage control scheme for DC-DC converter

1.7 SIMMULATION RESULTS

The simulation results are presented with the help of simulation block diagram of proposed system in MATLAB. The output of PV array changes with the change in the temperature and irradiance. Under these conditions the voltage supplied to load should be constant. To design the system, temperature and irriadiance should be taken in consideration. The variation in temperature and irradiance is shown in the fig. 9 and fig.10. Fig. 11 shows the output voltage of PV module which is later on increased to 200 by boot converter.
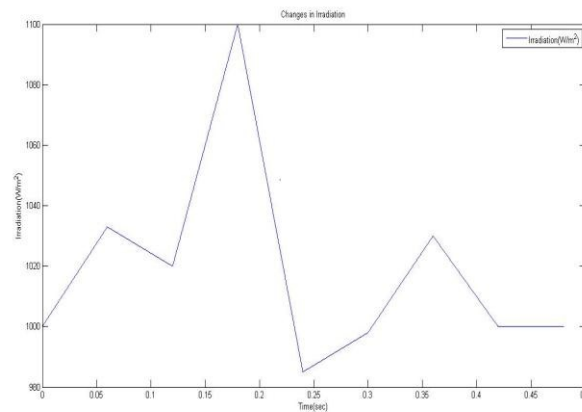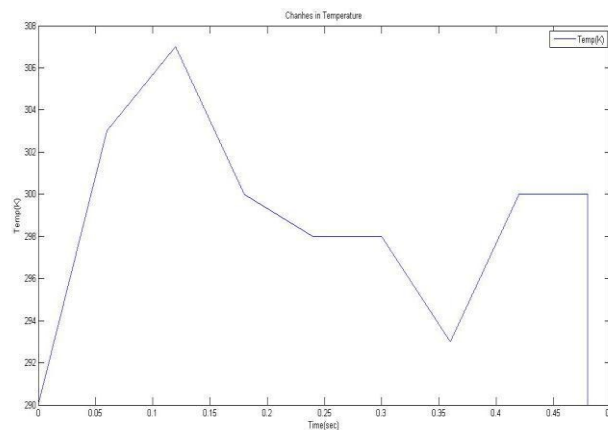

Figure.9 Changes in Irradiation

Figure-10 Changes in Temperature

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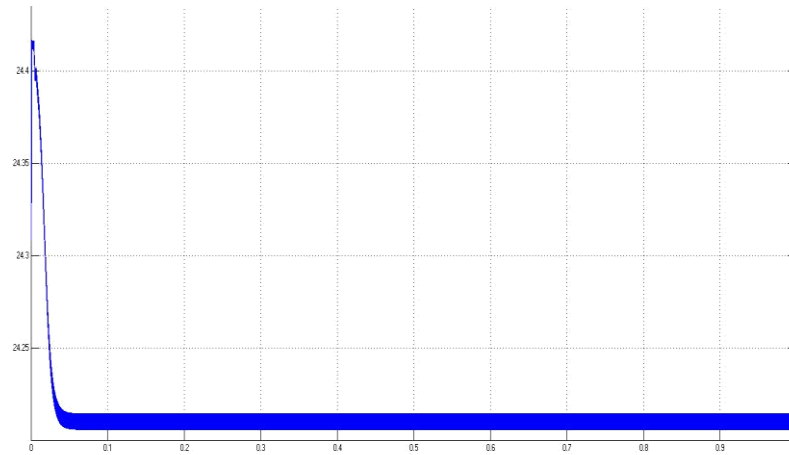p-ISSN: 2348-795X
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Fig.11 Output Voltage of the PV module.

The fig.12 shows the output voltage from the Boost converter or Charge controller as shown in proposed system. This voltage directly fed to the DC load bus and also to storage system through BDC.
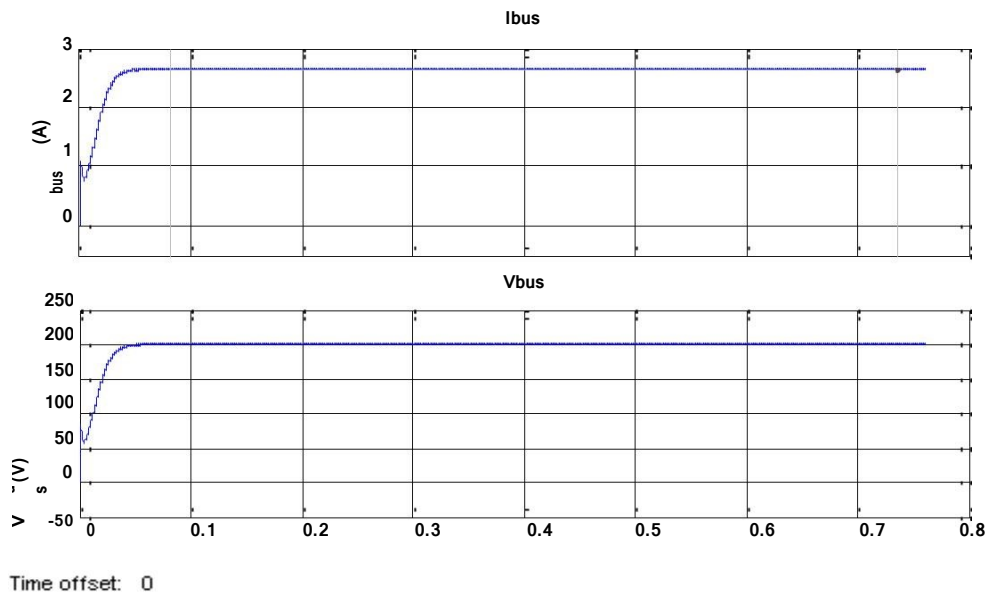

Fig. 13 Boost Converter output current and voltage.

The feasibility of the proposed system is verufied in real time implementation results and have been verified with the help of Xilinx system interfaced MATLAB Simulink as shown in fig.13 to fig.17.
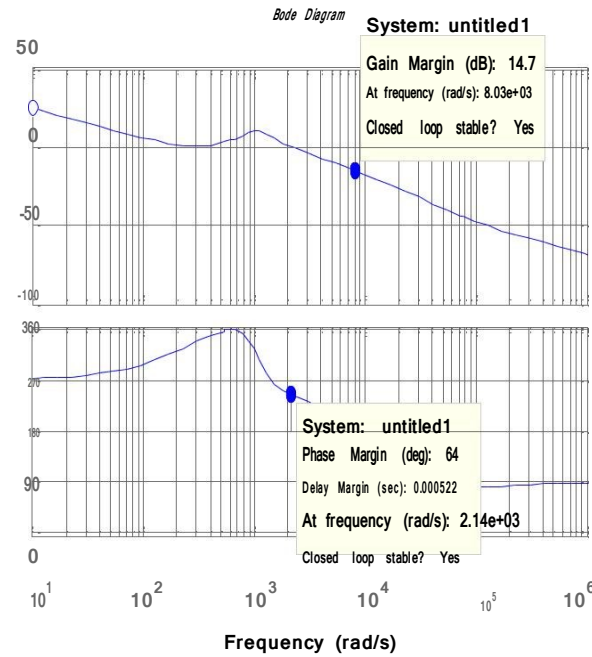
Fig.13. Bode plot of Boost converter loop gain with type-3 controller

Fig.14. Firing pulses to BDC in boost mode

The fig.15 shows the battery and bus side voltages. The battery side voltage is obtained by the step down action of BDC and DC bus side can also be obtained by step up action of BDC.
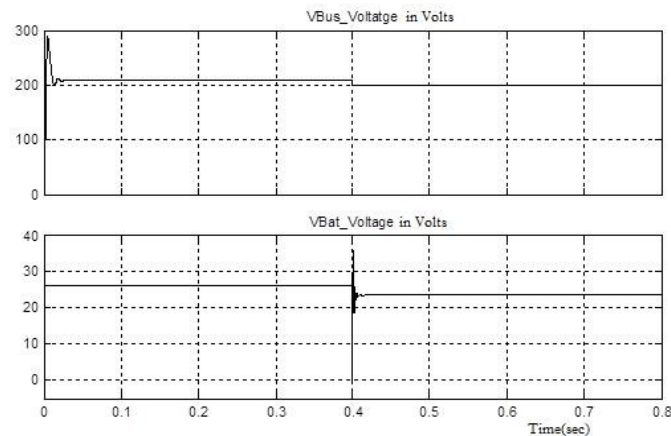

Fig.15. Voltage waveforms of BDC either sides(Bus side and battery side)

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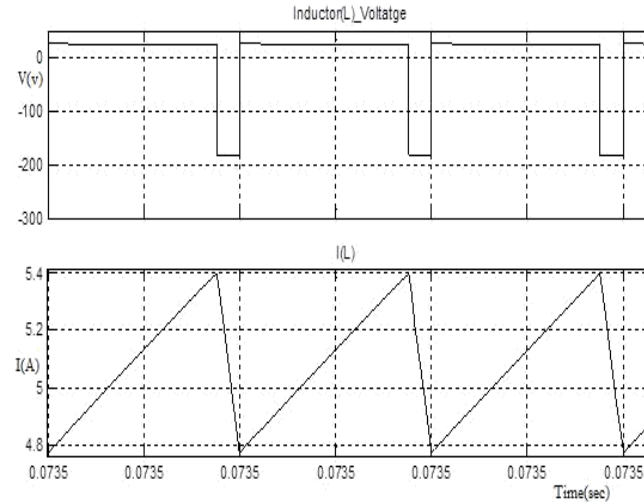p-ISSN: 2348-795X
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Fig.16. Inductor voltages and currents of BDC

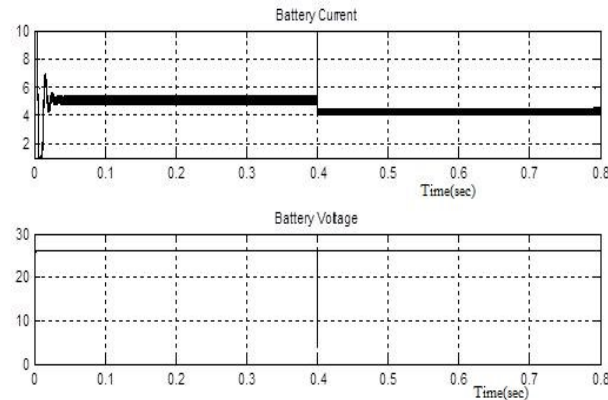Fig.17 shows the voltage and current waveforms on the battery side.

Fig.17. Battery side voltage and current

1.8 CONCLUSION

The study presents the SPV system in which the BDC of 8.33 voltage gain is designed and also the complete analysis of DC-Dc boost converter is presented. With the specifications of PM and GM, it is verified that the DC-DC Boost converter and BDC are both controlled and stable for any type of line load variation. After performing the simulation in MATLAB simulink and XILINX, it is concluded that battery charging and discharging is taking place with low ripple content.

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