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SOLAR PV FED DC LOAD EMPLOYING MPPT WITH ENERGY STORAGE SYSTEM INTEGRATION USING BIDIRECTIONAL DC/DC CONVERTER

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Abstract: An integrated system of Bidirectional DC/DC Converter with Solar PV module and DC load has been proposed in this paper. The main aim of this paper is to meet the load demand at every instant of time by keeping the DC bus voltage constant with the help of Bidirectional DC/DC Converter integrated with the Solar PV module. The Bidirectional DC/DC Converter helps in maintaining the power flow balance between the Solar PV module, the load and the Bidirectional DC/DC Converter. The PV module is operated at maximum power point (MPP) using MPPT technique. Perturb and Observe (P&O) method of MPPT has been used in this paper. Simulation of the proposed system is performed in MATLAB/SIMULINK and the results are found to be satisfactory.
Keywords: Bidirectional DC/DC Converter, Maximum Power Point Tracking (MPPT), DC/DC Boost Converter, Solar PV

1. INTRODUCTION

The bi-directional DC-DC converter in the system plays a role of transmitting energy in both directions i.e. it can conduct when the battery is to be charged as well as when the battery is to be discharged. These systems have simple structures and control units, and have the advantage of storing the residual energy from the solar cell [9]. It not only maintains the power flow balance in the circuit but it also helps in keeping the DC bus voltage constant. It operates in boost mode when the DC bus voltage is less than the reference voltage/desired voltage and in buck mode when the DC bus voltage is more than the reference voltage/desired voltage. In remote or isolated regions where power grid cannot extend to, stand-alone photovoltaic schemes have found a fairly wide application to meet the need for low but essential electric power consumption [4]. A PWM Generator is used to provide the desired duty cycle to the buck as well as boost switches of the Bidirectional DC/DC Converter to keep the DC bus voltage constant by comparing the DC error voltage between the DC bus voltage and the reference voltage with a saw vtooth pulse of desired frequency. A DC-DC boost converter is cascaded to the output terminal of PV array and duty cycle is maintained by MPPT to get the desired value of voltage so that the PV module can operate efficiently at maximum power point [2]. The energy storage system employs a battery which provides safe, flexible, low-cost and long-duration energy storage [7]. The loads integrated at the DC bus are simple resistors for the sake of easy analysis although RL loads, which are most common, could also have been used. Five resistors of different ohmic values are switched at an interval of 1 second to represent variable load.

2. SYSTEM OVERVIEW

Figure 1 shows the block diagram consisting of an energy storage system in the form of a battery combined with the Bidirectional DC/DC Converter which integrates it to the PV system and variable DC load. The purpose of Bidirectional DC/DC Converter is to help maintain the terminal load voltage constant, despite varying irradiance level, while employing MPPT. Perturb and Observe algorithm is used as the MPPT method. The Bidirectional DC/DC Converter can operate both as a buck converter as well as a boost converter, thereby managing the power flow between PV array, battery and load. In case of sufficient solar insulation level, PV arrays supply the load requirement and the surplus power is directed to the battery Through the Bidirectional DC/DC Converter to charge it and hence the converter operates in buck mode. If the solar insolation level is not high enough to fulfill the load requirement, for example during night or rainy season, then in that case, the energy stored in the battery must be delivered to the load through the Bidirectional DC/DC Converter, thereby operating in boost mode. Therefore, the dual mode DC/DC converter must be able to handle the energy flow in both the directions and hence operate in buck as well as boost mode according to the load requirement and the solar power available at that moment. A DC bus acts a point for integration of Bidirectional DC/DC Converter with the PV array and the load. The proposed architecture augments the charging capability which becomes fast and highly efficient as it consumes power directly from the PV module. Efficient delivery of power to the load by providing a constant voltage at the terminal of load is the primary function of the proposed system.

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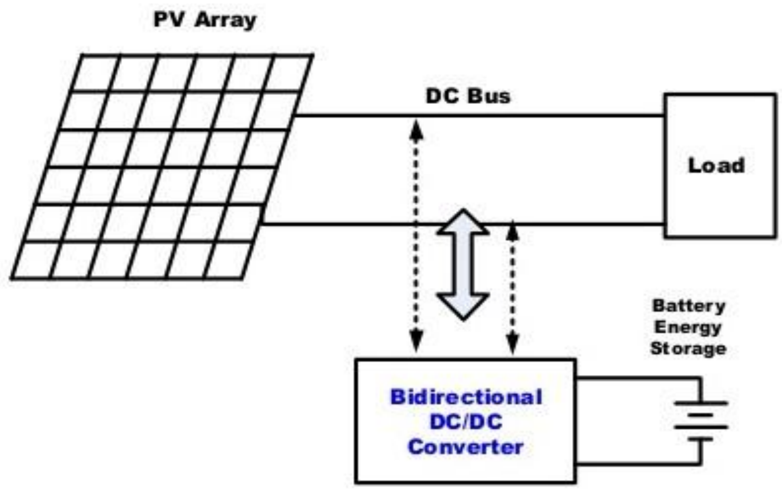

Fig. 1 Block diagram of Proposed System

2.1 Bidirectional DC/DC Converter

Bidirectional DC/DC converter is a converter which has the ability of conducting in both the directions between two DC points at different voltage levels. In order to provide power to the variable DC load continuously, and that too in an energy fluctuating natured renewable energy based system, energy storage systems such as batteries are coupled with this converter having bidirectional power flow capability to compensate this power fluctuation [10]. Therefore, a bidirectional DC/DC converter is simply an electronic circuit or electronic device that converts a source of direct current (DC) from one voltage level to another and is capable of handling power flow in both the directions [9]. Basically, it is a combination of both buck and boost converters and hence it is also called a dual mode or dual switch DC/DC converter. Switched-mode DC-to-DC converters convert one DC voltage level to another, which may be higher or lower, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. The storage may be in either magnetic field storage components (inductors, transformers) or electric field storage components (capacitors) [8]. Switching conversion is more power efficient (often 75% to 98%) than linear voltage regulation, which dissipates unwanted power as heat [10].

2.2 DC/DC Boost Converter

A switched mode DC/DC converter is connected in cascade to the output terminal of the PV panel and the duty cycle is set by MPPT to step up the voltage as desired [5]. The DC link capacitor connected across the boost converter regulates the output voltage and maintains it at a constant magnitude irrespective of the variation in the surrounding temperature or the solar irradiance level [1].

2.3 PWM Generator

A PWM Generator is used to provide the desired duty cycle to the Bidirectional DC/DC Converter switches. The duty cycle is generated by comparing the DC error voltage between the DC bus voltage and the reference voltage i.e. 500 V with a sawtooth pulse of desired frequency generated by a Pulse Generator. When the sawtooth voltage is greater than the DC error voltage, then the output of the PWM Generator is binary 1 whereas when it is less than the DC error voltage, the PWM Generator output is binary 0. This output of the PWM Generator is then fed to the buck/boost switches of the Bidirectional DC/DC Converter depending upon the voltage value of the DC bus, the control algorithm of which has been proposed next.

3. PROPOSED CONTROL ALGORITHM

In order to maintain the DC bus voltage at a constant value, which is chosen as 500 V in this proposed topology, and to ensure power flow balance in the circuit, the following algorithm has been proposed based on the different voltage level of the DC bus :

Case I : When $V_{DC\ Bus} > V_{Reference}$ i.e. $V_{DC\ Bus} > 500$ V

When the DC bus voltage is greater than 500 V, then the proposed control algorithm must act in such a way that it lowers the DC bus voltage value to 500 V. For this to happen, the bidirectional DC/DC converter must operate in buck mode. For buck mode, the output voltage is given as

$$V_O = DV_{in} \tag{1}$$

where V_{in} is input battery voltage and D is the duty cycle applied to the buck switch by the output of the PWM Generator. The difference between DC bus voltage and the reference voltage i.e. 500 V, is called the error voltage.

$V_{error} = (V_{DC\ Bus} - 500)$ (2)

Thus if the DC bus voltage increases, the error voltage also increases and becomes more positive. As a result, the duty cycle reduces according to the logic of the PWM Generator due to which the output voltage of the Bidirectional DC/DC Converter which is the DC bus voltage itself decreases. It can also be seen from the above equation (1) according to which the output voltage is proportional to the duty cycle.

Case II : When $V_{DC\ Bus} = V_{Reference}$ i.e. $V_{DC\ Bus} = 500$ V

When the DC bus voltage is equal to 500 V, the duty cycle is 0 as can be seen from the PWM Generator logic. As a result the Bidirectional DC/DC Converter circuit is cut off from the solar PV array circuit which is also necessary as it is not required to change the DC bus voltage to any value other than 500 V.

Case III : When $V_{DC\ Bus} < V_{Reference}$ i.e. $V_{DC\ Bus} < 500$ V

When the DC bus voltage is less than 500 V, then the proposed control algorithm must act in such a way that it ups the DC bus voltage value to 500 V. For this to happen, the Bidirectional DC/DC Converter must operate in boost mode. For boost mode, the output voltage is given as

$V_o = [\ D/(1-D)\ ]V_{in}$ (3)

where V_{in} is input battery voltage and D is the duty cycle applied to the boost switch by the output of the PWM Generator. The difference between DC bus voltage and the reference voltage i.e. 500 V, is called the error voltage.

$V_{error} = (V_{DC\ Bus} - 500)$ ……..…………. (4) Thus if the DC bus voltage decreases, the error voltage also decreases and becomes more negative. As a result, the duty cycle increases according to the logic of the PWM Generator due to which the output voltage of the Bidirectional DC/DC Converter which is the DC bus voltage itself increases. It can also be seen from the above equation (3) according to which the output voltage increases if the duty cycle increases.

4. SIMULATION RESULTS

The simulation of the proposed system is carried out in MATLAB/SIMULINK software.

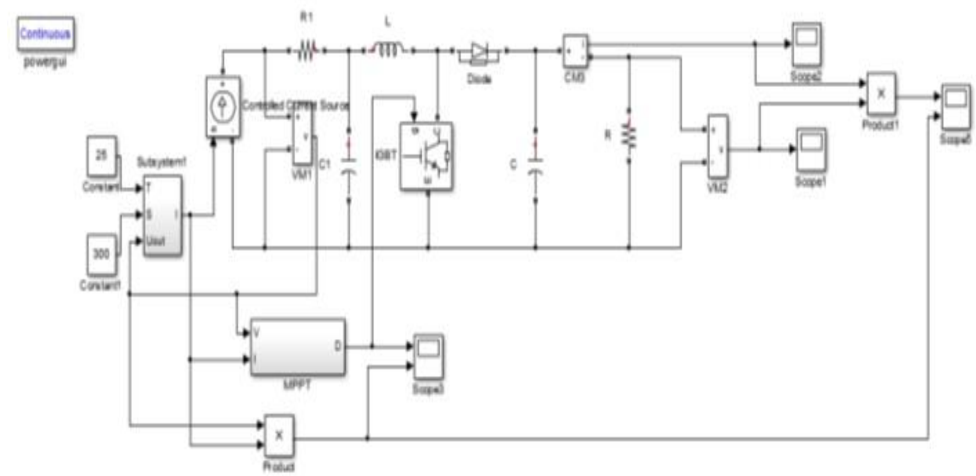

Fig. 2 Simulation circuit of MPPT

Figure 2 shows the equivalent circuit of PV panel in which fixed temperature of 25^o C has been taken and varying irradiance level is taken as 300 W/m^2 and $500W/m^2$. Current and voltage is taken as an input to the MPPT sub circuit which are then evaluated according to MPPT algorithm and the desired gating signal is fed to the boost converter. Figure 3 shows the gating sub circuit of MPPT. The current and voltage are changed into discrete values, the present and past values of current and voltage are multiplied respectively to obtain the present and past values of power. Then (P_n-P_b) and (V_n-V_b) is calculated where P_n and P_b are new and previous power and V_n and V_b are new and previous voltage values. The difference of voltage and power are multiplied, if the product is positive i.e. either both are positive or both are negative then the output voltage is increased and if the product is negative i.e. either difference in voltage is negative or difference in power is negative the output voltage is increased in order to maximize the power output of solar panel in accordance to perturb and observe algorithm.

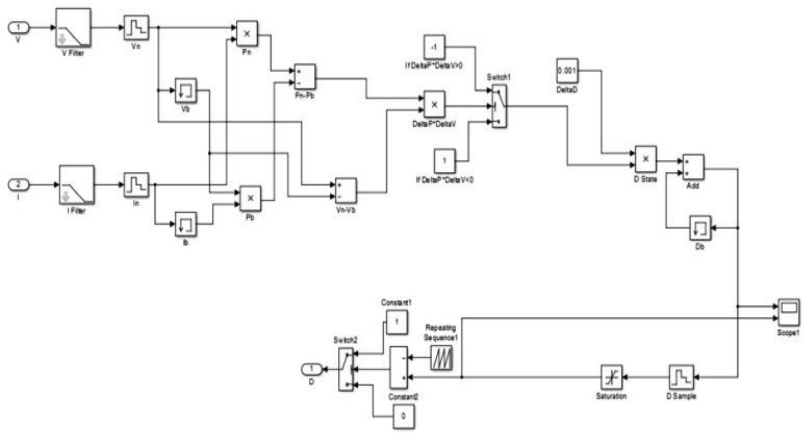

Fig. 3 MPPT Sub circuit

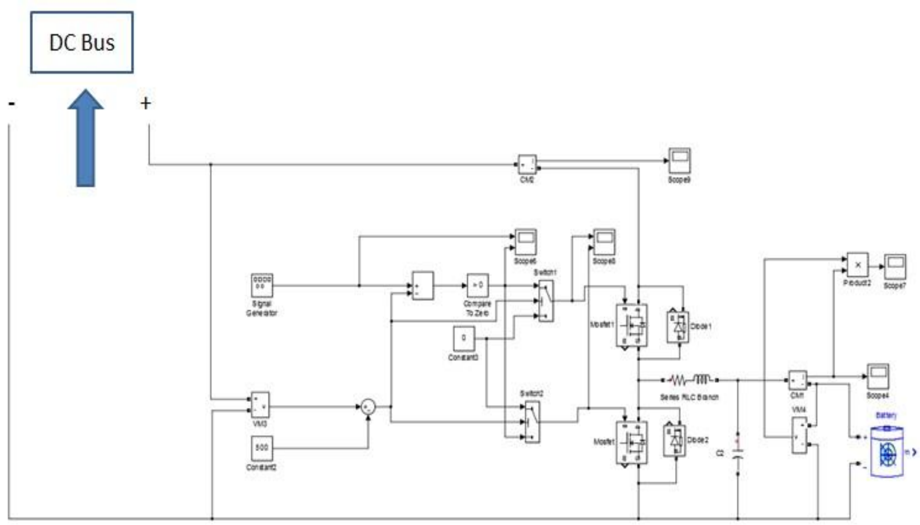

Fig. 4 Bidirectional DC/DC Converter

Figure 4 shows the simulation circuit of Bidirectional DC/DC Converter in which there are 2 MOSFET switches – MOSFET1 and MOSFET2. By appropriate gating of these switches we can control their operation in buck and boost mode. In the control mechanism the reference voltage has been taken as 500V and the switching occurs at 25 kHz. When switch 1 operates the power is transferred from dc bus to battery otherwise when switch 2 operates the power is transferred from battery to load.

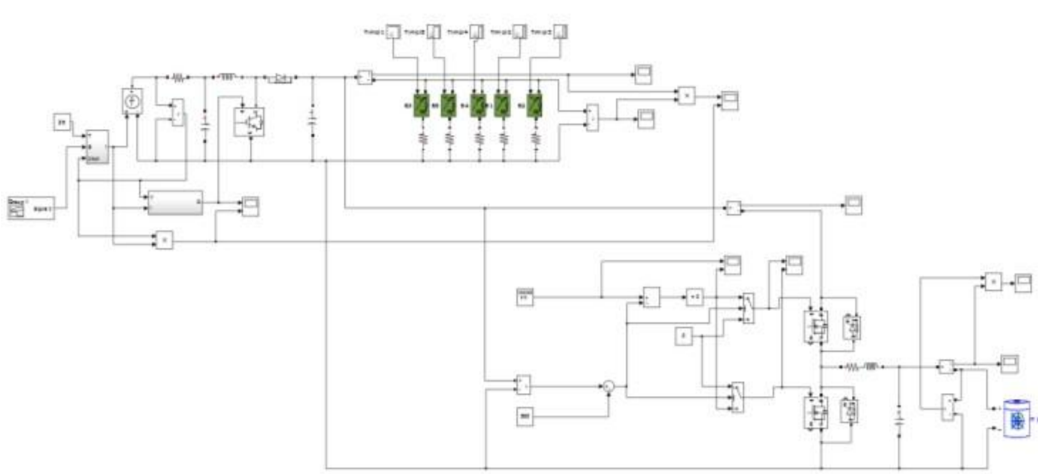

Fig. 5 Integrated System of Solar PV with MPPT and Bidirectional DC/DC Converter

Figure 5 shows the integrated circuit which has been used to obtain the required results. It consists of solar PV module, boost converter, Bidirectional DC/DC Converter and battery which are connected to load. The load is increased at an interval of 1 second during simulation by choosing different resistors. Due to the variation in the level of solar irradiation the output of the solar PV module changes. To convert the wide range of DC output voltage into a steady voltage on DC bus, a DC link capacitor is used in the system. Similarly, the charging and discharging of battery may be readily realized by controlling the converter. In the simulation circuit there are 2 modes of operation :

1. First when the load power is supplied only by solar PV module in case of sufficient solar power and surplus power is directed to the battery.
2. Second when power is supplied by combination of battery and solar power in case of insufficient solar power supply.

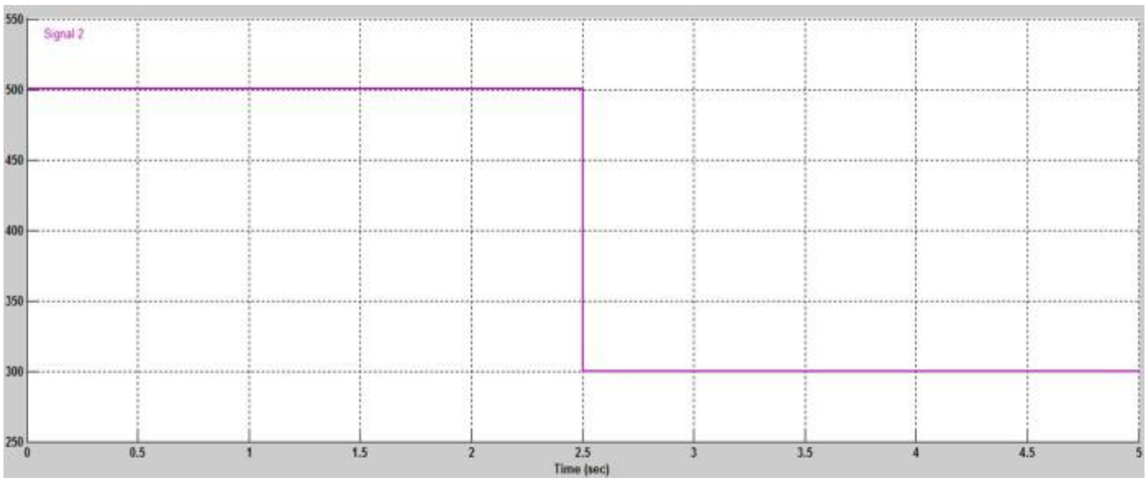

Fig. 6 Solar Irradiance Level

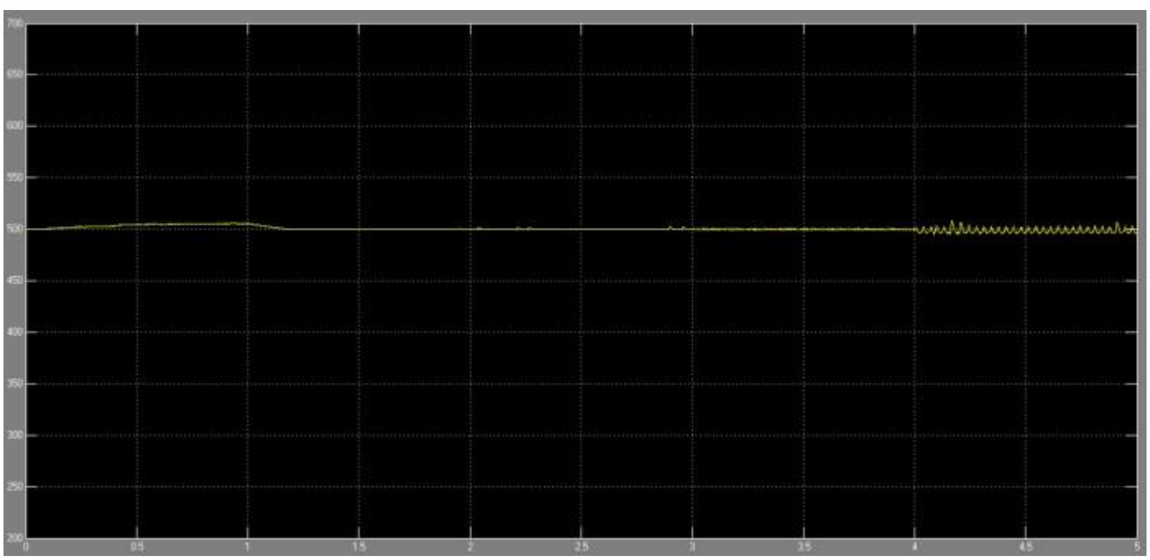

Fig. 7 Load Voltage Profile

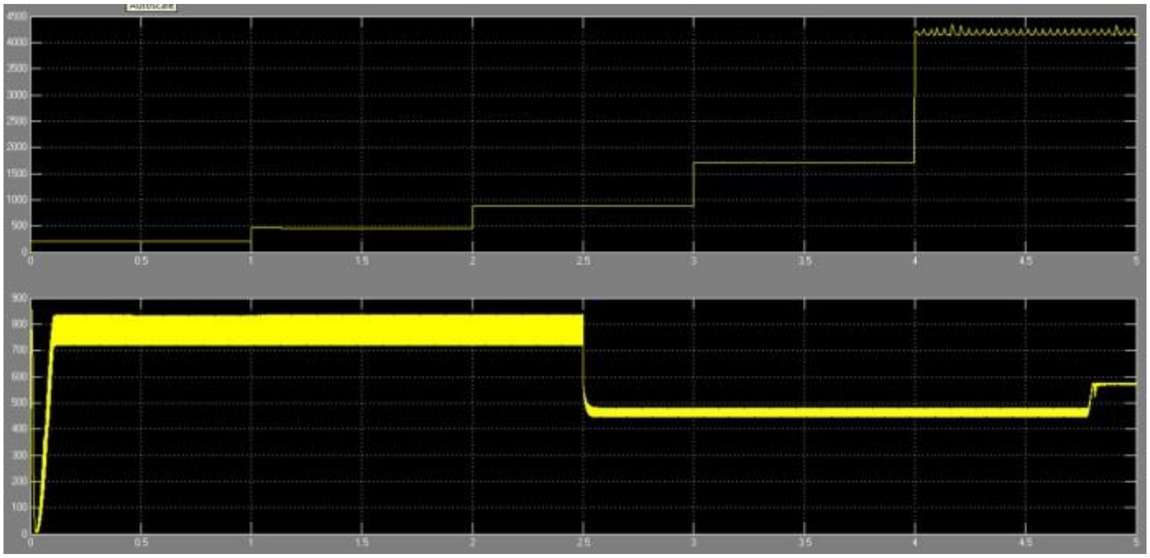

Fig. 8 Load Power and Solar Power

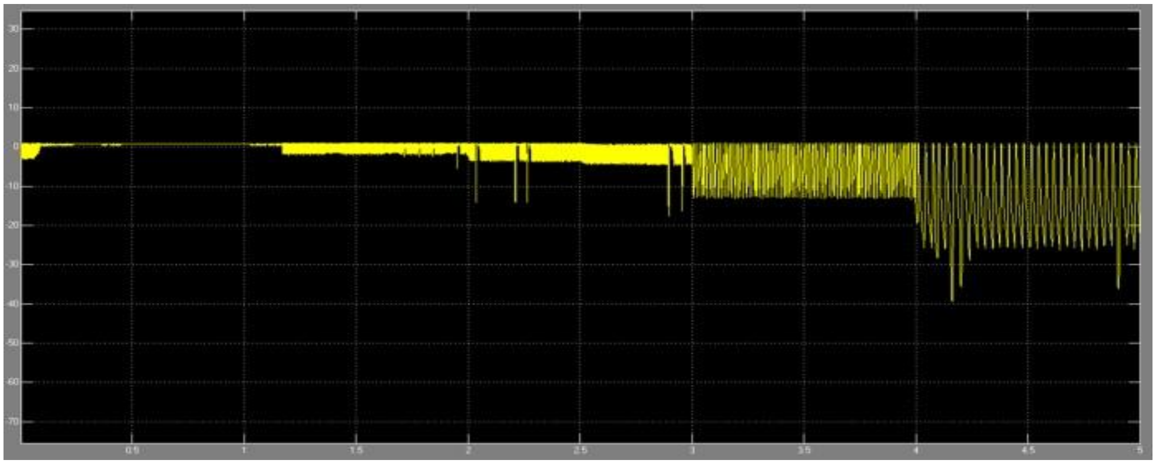

Fig. 9 Battery Current

Figure 6 shows the irradiance level which shows 500W/m^2 irradiance level up to 2.5 seconds and then 300 W/m^2 up to 5 seconds. Figure 7 shows the DC bus voltage which is kept constant at 500 Volts at different irradiance level and load requirement with the help of Bidirectional DC/DC Converter. Figure 8 shows the load power at 500 V and solar power at different irradiance level. Figure 9 shows the battery current. As the load requirement is low and solar power is sufficient to supply the load, the battery current is positive i.e. solar power supplies the load as well as charges the battery but as the load requirement increases, the solar power is not able to supply the load, so the battery also supplies the power to the load. As the load requirement goes on increasing after every 1 second, the battery current is seen to be going more and more negative i.e. the battery supplies more and more power.

Table I. Simulation Setup Parameters

S.No.	Components	Specifications
1	Bidirectional Switching Frequency	25 kHz
2	Boost Switching Frequency	250 Hz
3	Battery Voltage	250 V
4	Solar PV Power	800 W
5	DC Link Capacitor	10 mF
6	Boost Inductor	10 mH
7	Bidirectional Inductor	40 mH
8	Bidirectional Capacitor	4 mH

5. CONCLUSION

The main objective of this paper is to develop the control circuit of Bidirectional DC/DC Converter with MPPT controller for photovoltaic system to analyze its performance. The simulation study is done on MATLAB/SIMULINK. The simulation results clearly show that the MPPT tracks the maximum power point effectively. The result shows that during charging, the power is effectively transferred to the battery and similarly during discharging, the power is transferred back to the supply. The result shows that the battery and PV system is meeting the load demand at all times. Overall results are encouraging and indicate the trends towards a reliable system. The designed scheme may help in achieving accurate and fast response in stand-alone and grid connected PV energy conversion. It can also be applied to the fast changing solar irradiation areas where solar PV is used [6].

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