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Bidirectional DC-DC Converter for Solar Battery Backup Applications

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ABSTRACT

In this paper Bidirectional DC-DC converter for solar battery backup applications is presented. The Bidirectional converters have received a lot of attention because of their high efficiency and uninterruptable power supplies. The proposed converter configuration has reduced number of switches compared to the existing converter topology having four switches. PV system is one among the most prominent renewable sources of energy where the generated solar power is converted into electricity with the help of solar PV cells. A solar PV system along with battery energy storage with the help of bidirectional DC-DC converter has been accomplished in this proposed work. Non-isolated bi-directional DC-DC converter is designed in this work, which has high efficiency in comparison with isolated bidirectional DC-DC converter. By using PI controllers the output across the load is maintained constant with controlled input. The simulations are carried out using MATLAB/SIMULINK platform. The simulation end result asserts the execution of PV system beneath standard conditions.

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KEYWORDS: *Bidirectional converter, Buck mode, Boost mode, Battery, Solar PV.*

I. INTRODUCTION

This Bidirectional DC/DC converters (BDCS) are widely used in power-electronic systems, such as standalone photovoltaic systems, fuel-cell hybrid electric vehicles and uninterrupted power supplies [1]. Non-isolated bidirectional converter topology is used and it has less component count and voltage stress with high voltage gain and soft switching is accomplished with great efficiency [2]. Bidirectional interleaved switched-capacitor DC-DC converter that features bidirectional power flow capability and a high-voltage conversion ratio. In addition, the interleaved configuration of the converter and its modular design enable both its current rating and voltage gain to be increased [3-4]. Soft-switching bidirectional dc-dc converter is introduced with coupled inductor and a voltage doubler cell for high step-up/step-down voltage conversion areas. The coupled inductor operates not only as a filter inductor of the buck-boost BDC, but also as a transformer of the DAHB converter [5-6]. An isolated bidirectional dc-dc converter is proposed for the high-voltage input power supply to low-voltage output energy storage systems. The wye-delta connection of the transformers is employed to reduce the voltage stress at the high side and the current stress at the low side of the transformers [7]. The inverter is incorporated which is connected to grid with single stage performance is used for energy storage system and it includes following merits like power conversion at one stage, lower dc-bus voltage. Hence it results in high efficiency and high life time [8-9]. The energy flow between battery and UC is free in this MIC, the proposed EMS not only regulates the state-of-charge of UC but also smooths the battery power profile by using a fuzzy logic controller and a rate limiter [10].

II. CONFIGURATION OF BIDIRECTIONAL CONVERTER

Bidirectional converters are employed to transfer the power among two DC sources in both directions. These converters are comprehensively used in diverse utilizations. It acts as a mandatory one for assembling the energy storage systems with PV. These converters serves the purpose of stepping up or stepping down and also same the voltage level transfer between its input and output along with the capability of power flow in both the directions. The Bidirectional DC-DC converter is widely used in various applications such as fuel storage areas, hybrid vehicles and uninterruptable power supplies. These systems are always backed up and supported by the sources which are rechargeable such as battery units. The bidirectional DC-DC converter is required to permit power flow in both the directions at the standardized level. In case of low DC bus voltage the bidirectional converter is used to transfer the solar energy power to the load. The circuit diagram of the proposed work is shown in the figure 1.

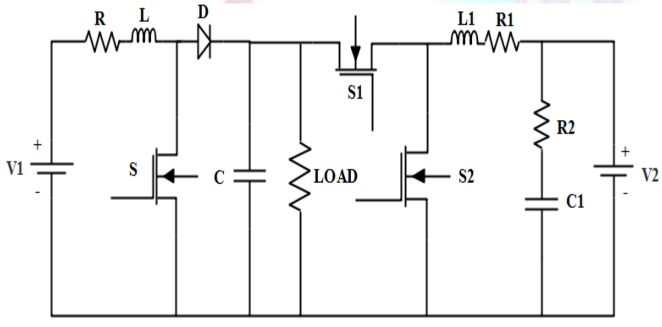

Fig. 1 Proposed circuit diagram

The first half of the circuit is the DC-DC boost converter design and the second half is the bidirectional DC-DC converter. The boost converter design is provided for the solar system.Any type of converters either Boost, Buck or Buck-boost is used to match the intrinsic impedance level of PV panels with the impedance of load. Hence maximum power transfer is possible. MPPT is obtained by manipulating the duty cycle ratio of DC-DC converter, hence PV panel operates at its maximum power point.

In our proposed work, we used boost converter which connects PV array with load. MPPT algorithm modifies the duty ratio such that PV array is operated at voltage corresponding to maximum power point. Generally, in areas other than Solar PV, input to boost converter is constant voltage source. In those circuits duty ratio is measured based on the required amplification and circuit parameters are found based on allowable range of ripple. But, in case of photovoltaic applications the input is PV array which is a non-linear dependent current source.

First we should design the boost converter considering required output voltage for load. The functioning of boost converter is checked based on the constant power level by changing the load. By altering the load voltage and current changes accordingly but output power and input power for boost converter must be same. If any difference occurs, it indicates the losses. The next stage is bidirectional DC-DC converter which operates in forward and reverse directions. It is described below in detailed manner.

A. Bidirectional converter circuit

The bidirectional DC-DC converter is one of renowned types of DC-DC converter. It performs both buck and boost operations and it has the ability to reverse the current flow direction and also the power transfer between two DC sources. It acts as buck mode when it charges the battery and it acts as boost mode when the battery discharges power to load. This topology incorporates a non-isolated bidirectional converter for a battery charging and discharging areas. The bidirectional power flow for battery charging and discharging is carried out by using two switches. Here, MOSFET is used as switch.

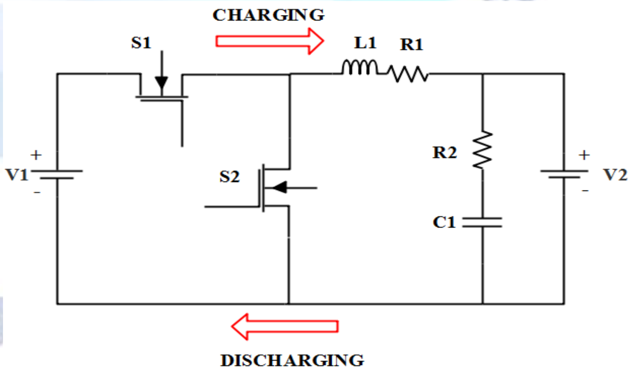

Fig. 2 Bidirectional converter circuit

In the proposed circuit given above, there are two DC sources which are represented as V1 and V2. Where V1 is the solar PV panel and V2 is the battery. Since, the PV system output power is mainly depend on weather conditions, sometime PV produces more power than the load requirement and hence the excess power will be stored in the Battery using bidirectional switches, which can be later used during night time and incase of seasonal modifications in weather.These converters are habitually used in variety of applications, like hybrid power networks, and battery storage systems.

The bidirectional conversion is carried out by two switches, and are regulated with the help of controllers. During boost mode the switch S1 is ON and switch S2 is OFF. At buck mode the switch S2 is ON and switch S1 is OFF. Cross conduction issues will not persists, since the switching operations are carried out based on the provided dead time appropriately. Due to the availability of compensation source, the output will be provided continuously to the DC load based on the requirement without any interruption.The main aim of this proposed system is to provide uninterruptable supply with the help of bidirectional topology. The merits of this propose work are it requires less components, it does not require transformer, low cost, and provides high efficiency.

There are two different operating modes. They are buck mode and boost mode.

Mode- 1

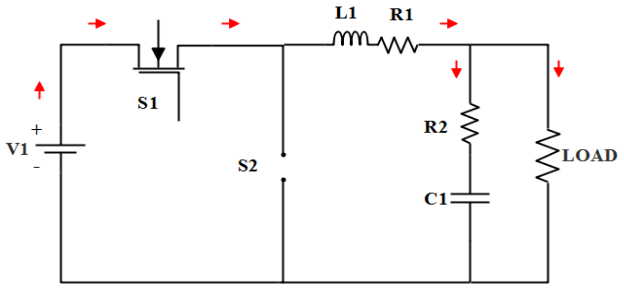

Fig. 3Mode 1

The function of Mode 1 is represented in the figure 3. The buck mode is the first operating mode and is also called as forward power flow mode. This mode comes into act, when the generated solar power is greater than the load requirement and when the battery does not have full charge. At this mode switch S1 will be turned on and switch S2 will be turned off. Through S1 the power from the solar panel will be supplied to the battery for charging purpose.When switch S1 is ON, the input current rises and flows through S1 and L. When S1 is OFF, the inductor current falls until the next cycle. The energy stored in inductor L is supplied for charging the battery. At this mode the PV panels supplies power to the load and as well as charge the battery through the excess power generated by PV. At this mode the battery is charged through buck mode.

Mode- 2

The function of Mode 2 is represented in the figure 4. The boost mode is the second operating mode and is also called as reverse power flow mode. This mode comes into act, when the generated solar power is lesser than the load requirement, but the battery will have full charge, hence it will provide compensation and supply the power to load. At this mode switch S2 will be turned on and switch S1 will be turned off

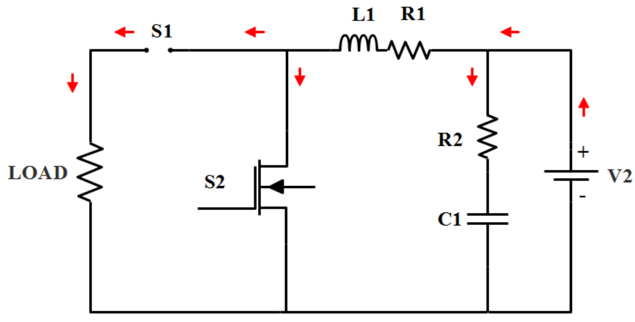

Fig. 4 Mode 2

Through S2, the power from the battery will be supplied to the load by discharging the battery.When switch S2 is ON, the input current rises through inductor L and S2.When S2 is OFF, the inductor current falls until the next cycle. The energy stored in inductor L flows through the load. At this mode the battery provides compensation until it discharges fully. The PV panels also supplies the power to load with the hep of PI controller and boost converter associated with it. Hence, in this mode the battery provides power to load through boost mode.

III. SIMULATION RESULTS

Simulation of this proposed work is carried out with the help of MATLAB software. In order to get the desired output, the simulation circuit has been designed in MATLAB software by using the respective components that is present in the MATLAB Simulink. Solar panel and battery are the two DC sources used in the system. Where solar panel is designed by using the series connection of solar cells. The battery is already available on Simulink model. The bidirectional DC-DC converter is designed using two MOSFET, one inductor and one capacitor. This converter performs operation in both forward and reverse directions. When S1 functions, the buck mode of operation is carried out for charging the battery and when S2 functions boost mode of operation is carried out for discharging the battery.

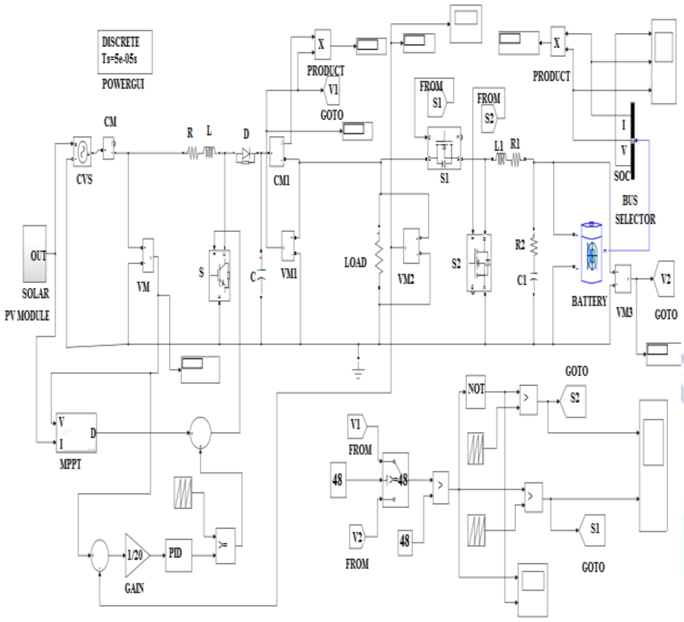

Fig. 5 Simulation diagram

Closed loop operation is carried out in order to maintain the load voltage constant even when the load capacity varies. The PI controller is carried out to perform the closed loop operation. In this closed loop circuit also we have to make the switching frequency has varying one so we have to follow the same method used in the variable frequency method as same in that we have to convert the formulas into blocks. Here the frequency is not directly converted into pulse first the frequency is converter into gain by using the designed formula and then the gain is converter into delay. Then this delay is compared to the variable frequency sawtooth generator to create a pulse for the S1 switch then it is subtracted from the delay for getting the S2 pulse and also the switching frequency must be within resonant frequency range. The simulation results are maintained constant due to function of closed loop operation.

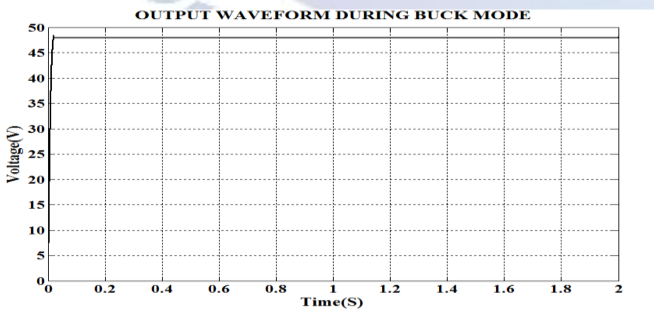

Fig. 6 Output waveform during buck mode

The dc output waveform of the proposed system during buck mode is shown in the above figure 6. Here, the input is obtained from the solar PV module and its range is 48V. The solar module supplies the load constantly and the remaining power is supplied to the battery as a backup source which will be used later during unavailability of solar. Hence, we obtain 48V as output at load constantly. This constant range is maintained by the closed loop function.

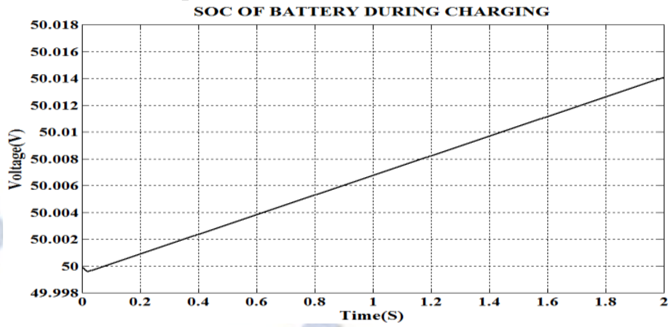

Fig. 7 SOC of battery during charging

The SOC of the battery is shown in the above figure 7. Where, SOC denotes the state of charge of the battery. In the waveform shown in the figure, the voltage level is increasing, which denotes the charging condition of the battery.

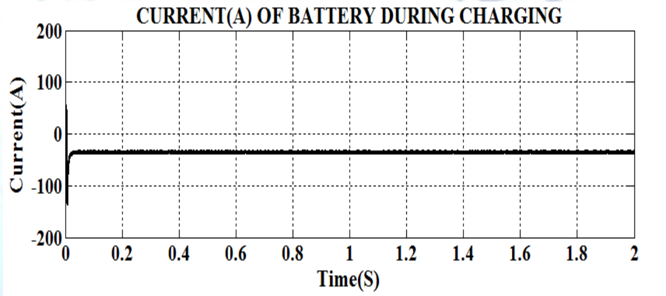

Fig. 8 Current (A) of battery during charging

The waveform of the current of the battery during charging mode is shown in the above figure 8. Here, the current is decreasing, and reaches a negative value, which denotes that when the solar panel charges the battery, the current value will be in negative as it is in charging mode. In this case the current decreases as the voltage increases.

The waveform of the voltage of the battery during charging mode is shown in the above figure 9. Here, during charging the voltage value increases steadily until it reaches fully charged state.When the solar power is generated higher than the load requirement, the battery will be charged from the solar power. When the solar power is insufficient, the battery will act as a source and discharge the power to load.

Where the nominal voltage denotes the end of linear zone of discharge characteristics. The rated capacity of the battery is the minimum capacity of the battery. SOC represents the initial state of charge of battery, where 100% indicates a fully charged battery and 0% indicates the empty battery. Fully charged voltage is given for the minimum discharge current

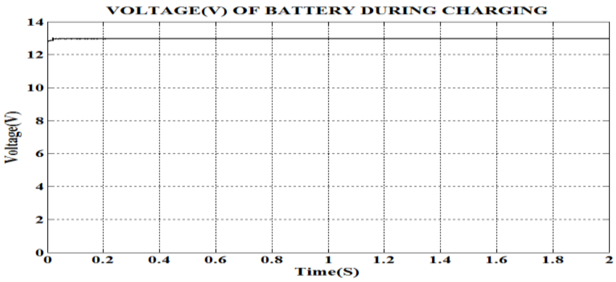

Fig. 9 Voltage (V) of battery during charging

The dc output waveform obtained during boost mode at this proposed work is indicated in the figure 10. In this mode the input is obtained from 12V battery. We obtain 48V as output at load constantly, which is provided by the boost mode of the bidirectional converter. In this method since, the solar irradiance level is lower, the battery will provide compensation through boost mode. The compensation is provided by the battery through the boost converter of the bidirectional buck-boost converter. This will make the system to provide stable operation and satisfy the load requirement.

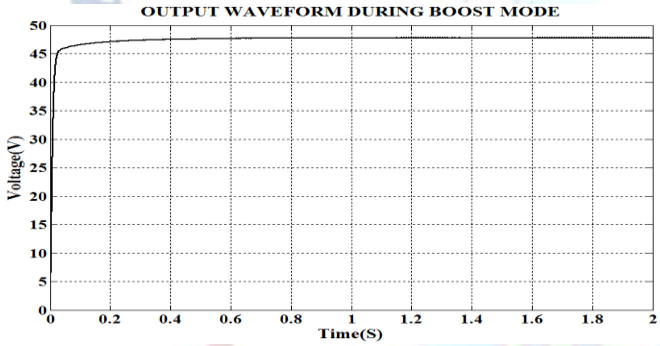

Fig. 10 Output waveform during boost mode

The SOC of the battery is shown in the figure 11. where, SOC indicates the state of charge of the battery. The voltage level of the waveform shown in the figure is decreasing, which denotes the discharging condition of the battery. In this case, the battery backup will act as a source and provide the power required for load.

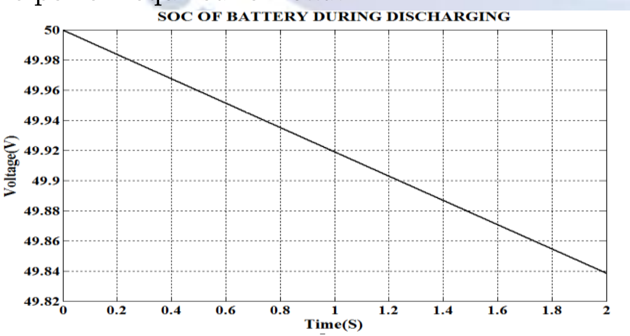

Fig. 11 SOC of battery during discharging

The waveform of the current of the battery during discharging mode is shown in the figure 12. Here, the current is increasing, here the current will be increasing positively as the voltage decreases, which denotes that the battery level is discharged and act as a source to provide power. The closed loop operation is provided in order to obtain the constant output voltage. It is carried out by using the Proportional-Integral controllers. Based on the threshold values provided, the bidirectional conversion process is automatically carried out. The switches performs based on these controllers and decide power flow based on the power availability and also the requirement of the load.

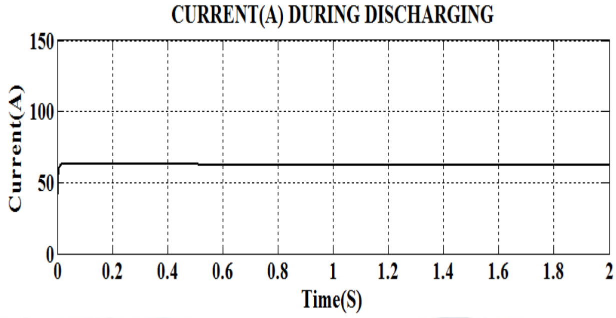

Fig. 12 Current (A) of battery during discharging

The waveform of the voltage of the battery during discharging mode is shown in the figure 13. Here the voltage value decreases, which denotes that in this case the battery acts as a source to provide power for load, since there is variation in the irradiation level of PV array.

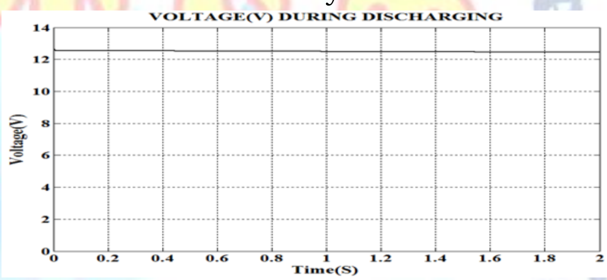

Fig. 13Voltage (V) of battery during discharging

IV. CONCLUSION

In this proposed system, Stand-alone solar photovoltaic systems with battery backup is achieved by using Non-isolated Bidirectional DC-DC converter. The isolated method has demerits like transformer core loss, saturation loss, etc. These are overcome by using non-isolated converters. The proposed work has less component count, provides uninterruptable power supply at both directions, high stability. PV system assisted with the energy storage system such as battery is carried out using bidirectional topology and is simulated in this proposed method. The boost converter assisted with PV is used to step up the PV output voltage, and the MPPT is also used to track the maximum power from panel. The simulation is carried out in closed loop with the help of appropriate PI controllers. In this proposed work, a bidirectional DC-DC converter is designed and simulated to facilitate the energy storage. For the bus voltage of 48 V and battery voltage of 12 V, the bidirectional converter is simulated by boost mode and buck mode of operations. The topology provides bidirectional power flow from solar to battery. Eventually, the entire design has been simulated in MATLAB Simulink and sufficient results have also been acquired.

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