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A Study of Suitable Bi-Directional DC-DC Converter Topology Essential For Battery Charge Regulation In Photovoltaic Applications

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Abstract: *The Bidirectional DC-DC Converter along with a dedicated energy storage device is considered to be the convenient option for the Renewable Energy related as well as Hybrid Electric Vehicular Applications. Improving the Efficiency of the Renewable Energy Systems is of major concern now-a-days. Keeping in view about the fast extinction of fossil fuels in nearby future, it is of utmost important to design a reliable and flexible Energy Storage System by ensuring better charge control of battery. As far as Renewable Energy related Systems are concerned, the Power Management is an essential aspect in order to meet the Load Demand. So, Choosing a Suitable Bidirectional DC-DC Converter which facilitates the proper functioning of the Battery Charge Controlling as well as harvesting the energy to the maximum extent from a PV Array is required. The Bidirectional DC-DC Converter along with Solar Photovoltaic Array, Battery and Load is modeled and simulated in MATLAB/SIMULINK Environment. The Battery Terminal Voltage, the State of Charge and current flowing in Battery along with Charging and Discharging waveforms are presented in this paper.*
Keywords: *Bidirectional dc-dc converter, battery charge regulation, efficiency, energy storage, State of charge.*

I. Introduction

The Standalone photovoltaic (PV) systems and hybrid vehicular applications necessarily require a battery storage option [1,2] in order to save electrical energy if it is generated more than the load demand. Many researchers [2,3,4,5] have already been examined the importance of studying the battery characteristics and about the best suited bidirectional dc-dc converter circuit [6,7] which supports the proper functioning of entire standalone PV system as well as battery charge control. This shows that, this research area has got huge potential to explore further. The basic idea of this paper is to observe the battery state of charge (soc) and especially the two modes of dc-dc converter operation ie. buck and boost modes. The buck mode basically explains about the charging phenomenon where as boost mode tells about the discharging process that happens because of converter operation. Section I is all about a brief introduction regarding importance of dc-dc bidirectional converter and necessity of incorporating a battery into a standalone PV system. Section II describes about the different bidirectional dc-dc converter circuits suitable for PV systems and choosing the better circuit topology among them. Section III explains about the block diagram of standalone system. Section IV tells about the single diode PV array model. Section V gives a brief note on battery circuit model. Section VI deals with the simulation results and followed by conclusion.

II. Bidirectional DC-DC Converter Topology

It is well known fact that, the bidirectional dc–dc converter (BDC) allows the bidirectional power flow [6,7]. It especially smoothen the process of battery charging and discharging. The converter also plays a prominent role in extracting the maximum power from PV array [8,9] and effectively managing the power flow among PV source, battery and load. In Fig. 1, the different topologies of bidirectional converters are shown. The topologies shown in Fig 1(a), 1(b) and 1(c) have their own merits and demerits. But according to authors in [6,7], the topology represented in Fig. 2 is having more advantages when compared to other circuits referred in [10-12] respectively.

The unique feature of BDC shown in Fig. 2 is that, it supports both the function of Maximum Power Point Tracking (MPPT) and battery regulation in order to supply power to load continuously without any interruptions. The converter is considered to be the heart of the block diagram as shown in Fig. 3.

The BDC shown in Fig. 2 works as both buck as well as boost converter and provides an option of battery charging and discharging. The Fig 1(a), 1(b) represents the non-isolated type of BDC. But Fig 1(c) shows the isolated type of BDC. In Fig. 1(a) it can be observed that, there exist two converters namely basic non-isolated boos converter in series with load and a BDC connected in parallel across the load making the circuit a little bit complicated and losses can be increased since there are '3' switches in circuit.

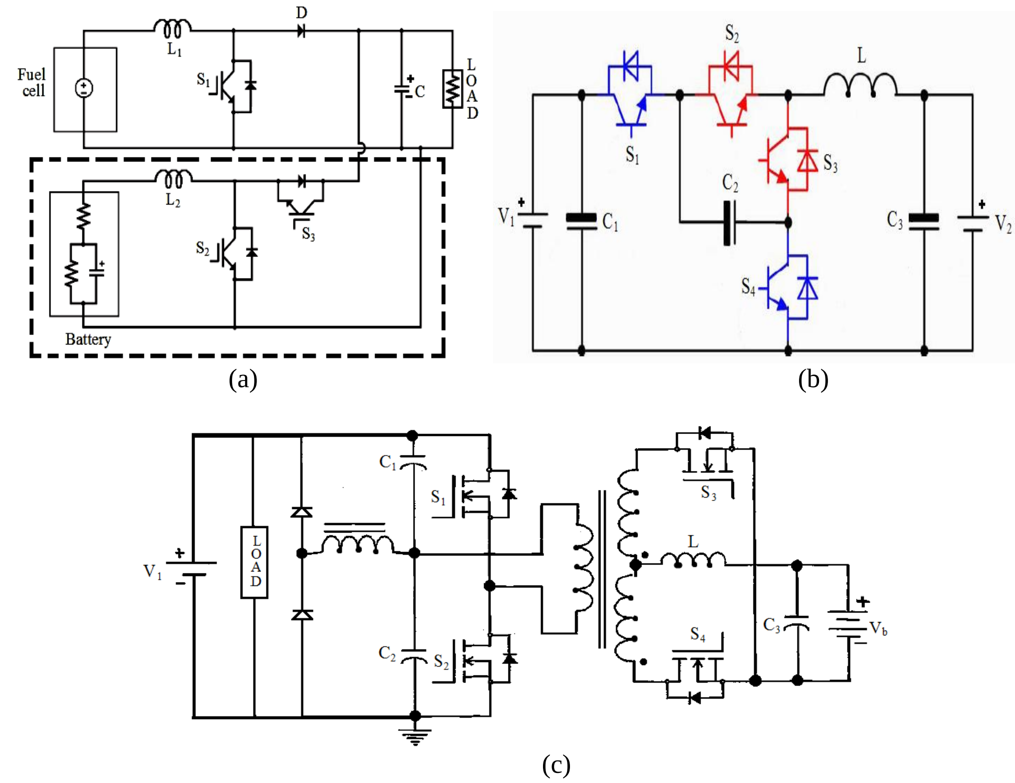

Fig.1. Different bi-directional dc-dc converter topologies for PV systems

The Fig. 2 represents the BDC which is having the flexibility of using it for MPPT implementation as well as for battery charge control in a simple manner. There exist '2' switches in BDC. The switch S_1 operates in buck mode where as switch S_2 operates in boost mode. The tuning of inductor and capacitor filters is required in order to reduce the ripples in the output voltage across the resistive load. The diode shown in Fig. 2 allows current to flow in one direction only from PV source to load. The BDC is simple to design and has better efficiency as described by authors in [6]. Since it consists of only '2' switches, the cost of implementation also decreases considerably.

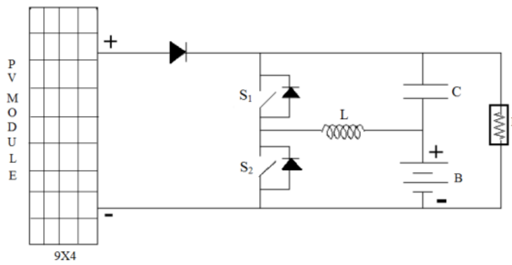

Fig.2. BDC better suited for battery charging /discharging process

III. Block Diagram Of Standalone PV System

The block diagram of standalone PV system along with the BDC is shown in Fig. 3. The BDC inherently consists of battery (refer Fig. 2) which operates according to load requirement. If PV power generated is more, then excess power will be transferred to battery so that charging process takes place. If PV power generated is less, then battery will supply additional load power by discharging process. The converter generates duty ratio (d) such that, the load voltage and output power can be controlled.

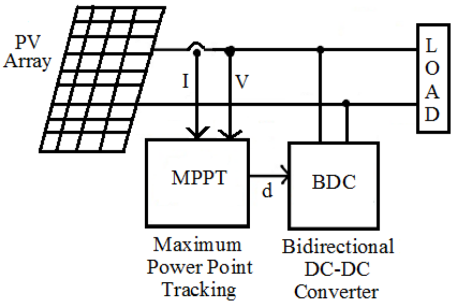

Fig.3. Block diagram of PV array with Bidirectional dc-dc converter

IV. Single Diode Model Of PV Array

The equivalent circuit of a single diode model of PV array is considered from [13], since it is simple circuit and easy to analyze.

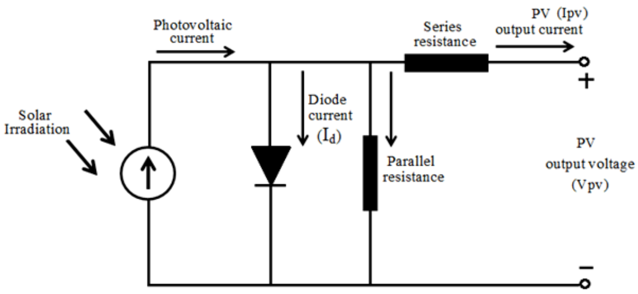

Fig .4 Equivalent circuit of PV module.

V. Battery Model

The battery model is considered is as shown below in Fig. 5. It consists of a voltage controlled voltage source in series with an internal battery resistance. This battery model is clearly explained by authors in [14,15,16].

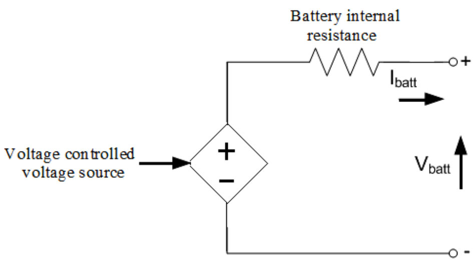

Fig. 5 Battery equivalent model

The battery is connected to the BDC and its state of charge (soc), voltage and current waveforms are examined. The simulation results are shown in section VI.

VI. Simulation Results

The simulation of BDC along with battery model has been modeled in MATLAB/SIMULINK environment. The simulation results show the battery performance characteristics like battery soc, battery output current and output voltage.

The simulation results are shown below:

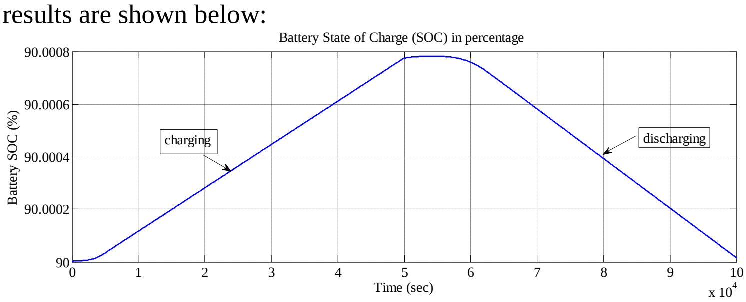

Fig. 6 Battery state of charge (in %)

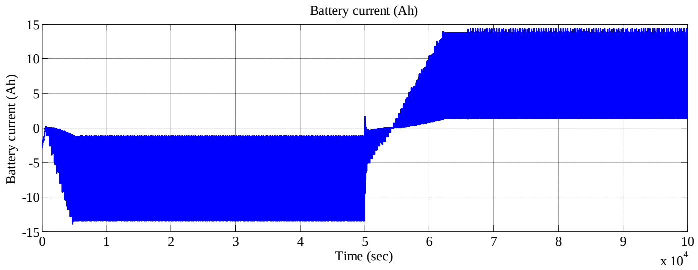

Fig. 7 Battery current (in Ah)

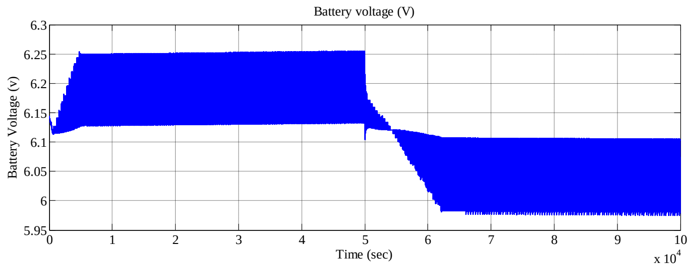

Fig. 8 Battery voltage (in V)

Inferences from output

From simulation results, it can be easily inferred that, when battery current is decreased (negative value), then the battery output voltage value is increased (positive value) as shown in Fig 7 and Fig. 8. When the battery voltage is around 6.15V before 5 seconds, then current is around '-1.5Ah' as shown in Fig. 7 and Fig.8. When battery voltage is around 6.1V after 6 seconds, then current is obtained as '1.5Ah'. The state of charge is also clearly observed from Fig 6.

Until 5 seconds, the BDC working as buck converter, so the slope of the graph is positive indicating that charging process is taking place, whereas at 5 to 6 seconds, the BDC is removed from circuit because the PV array is operated at Maximum power point (MPP). The battery will be in floating stage i.e., it will neither charge nor discharge. After 6 seconds, the BDC will be working as boost converter. So, slope of curve is negative indicating about discharging process as shown in Fig. 6.

VII. Conclusion

In this paper, the main focus is given on examining the battery operating characteristics in a standalone Photovoltaic system. The bidirectional dc-dc converter plays a crucial role in controlling battery characteristics like soc, voltage and current and also harvesting maximum power from PV module or array. The scope of this paper is to study only about the battery output characteristics. Hence, battery related simulation results only shown in section VI.

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