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Application of Bi-Directional Converter to a Battery-Backed up PV System

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SUMMARY

Concerns about the environmental impact of using fossil fuels for meeting the expected increase in global demand for electricity is increasing worldwide. Using environmentally safe energy sources (such as solar and wind) and energy storage are increasingly being considered as potential solution to this issue by the industry. Energy storage systems like battery, pumped hydro, and/or compressed air are most suitable for the renewable energy sources like solar and wind.

The system studied in this paper consists of a solar cell, battery and a bidirectional converter (BDC). A BDC is a converter that can transfer energy between its input and output ports in either direction. In other words, it can be used to charge and discharge battery. Based on environmental condition and PV output, the BDC is controlled by changing duty cycle of switches in BDC to operate the BDC in either charging or discharging mode.

In the system under study, load receives energy directly from solar cell while the PV system generates sufficient energy. Excess energy charges the battery bank using BDC. The battery supplies power to the load when there is no energy available or not enough energy available from the Sun (cloud cover or nighttime).

The battery will be charged when PV is available and will be discharged every time PV is not supplying energy. The Maximum Power Point Tracking (MPPT) controller utilized is Perturb & Observe (P&O), which extracts maximum power from solar cell under changing irradiance and temperature. This system itself is discussed in detail in this paper. Its performance and simulations results also will be discussed. Simulation and analysis of model output was carried out via PSim.

KEYWORDS

Step-Up; Step-Down; Bi-Directional Converter; Maximum Power Point Tracking (MPPT); PV System.

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1. Introduction

There is no doubt that electricity has transformed living standards of human race. Access to electrical energy is a major determining factor in how well off a nation is or is not [1]. Currently fossil fuels are providing most of electricity consumed around the world [2]. This plus the ever-increasing demand for electricity is raising alarm worldwide. This is mainly due to the adverse effects on environment, observed around the world, which are contributed to use of fossil fuels [3].

In addition, to their negative impact on the environment, we need to consider the fact that fossil fuel resources are of finite nature and will need to be supplemented and/or replaced in distant future to be able to meet the increasing demand. Due to negative impact of burning fossil fuels on the environment, people have become more aware of emission of greenhouse gases such as CO2. Hence, an urgent need has developed for finding a sustainable clean energy source to either replace or supplement fossil fuels [4].

Renewable resources on the other hand are abundant by nature and have less negative impact on environment [5]. Therefore, due to the negative impact of fossil fuels as well as the fact that they are depleting fast, generating energy by renewable energy resources are taking center stage. There is greater emphasis on development of renewable energy system like wind system, PV system, Hydrogen fuel cell, etc. [2]. These facts account for the rising popularity of the distributed generation systems around the world [6].

Clean energy generated from renewable resources such as solar (PV, or thermal collectors) and wind (turbines) have replaced/supplemented fossil fuels generated electricity. Many domestic, industrial, or commercial applications use alternate sources of energy such as wind and solar [7]. Use of the Eco-friendly (noiseless and pollution free) electricity generated using PV has grown significantly [4]. However, we cannot ignore the major drawback of solar PV system; it has very low conversion efficiency. Hence, to extract the maximum power possible from the PV panels we need to use more sophisticated control algorithm such as MPPT controller [3].

Installed PV base is increasing exponentially. This is due to the positive impact of the PV systems on the environment as well as realization that fossil fuel resources are dwindling fast. This in turn has increased the need for a reliable and efficient invertor that allows for interfacing PV system generating DC electricity with the grid that operates on AC electricity.

Energy generated by solar cells is highly variable. This is due to highly variable nature of solar radiation. It has annual, seasonal, monthly, weekly as well as daily variations. The PV system itself also has non-linear characteristics and is not only affected by availability of solar radiation, but also by changes in temperature. To obtain maximum power from PV cells we need to use MPPT [8], [12]. In addition, we need to add a means through which excess energy generated can be stored [9].

Due to the need for energy storage, PV systems are usually augmented with battery (or another energy storage system) to assure power can be provided to the load when needed. For proper operation, we need a system to charge as well as discharge the battery system. To accomplish this we need a BDC [10].

BDC is a class of DC-DC converters that can transfer power in either direction between its input and output ports. The charging and discharging mode of the BDC is determined based on the PV generated energy supplied to the load and the need to either store it’s excess in the battery or supplement it from battery across the DC link [12].

BDC design/control plays a significant role in how the entire system functions. As stated before, the array output voltage/energy changes with changing temperature and radiation. To accommodate the changes the BDC must be able to provide wide output gain range. Technologies such as battery chargers; uninterrupted power supplies (UPS) and solar systems utilize these high gain converters. These converters are able to convert high output voltage to low output DC voltage (or vice versa), especially in solar applications [8].

In this paper, we will describe a system consisting of a load, PV, battery bank, and a BDC capable of not only transferring energy in both direction, but also increasing or decreasing voltage in either direction. System design will be explained. The results of simulations performed (using PSIMs software) will be presented and discussed.

2. System Description

Since PV characteristic is nonlinear, it is important to determine the best operating point using Maximum Power Point Tracking (MPPT). In this paper, we used Perturb & Observe (P&O) technique to extract maximum power from solar cell. P&O is easy to implement and uses small number of parameters. In this technique, terminal voltage and current are measured to calculate power then the system is perturbed. If the new output power is greater than the previous one, the perturbation of duty cycle is carried out in the intended direction otherwise; it is moved in the opposite orientation [5]. Figure 1 shows the flowchart for the P&O method used [7].

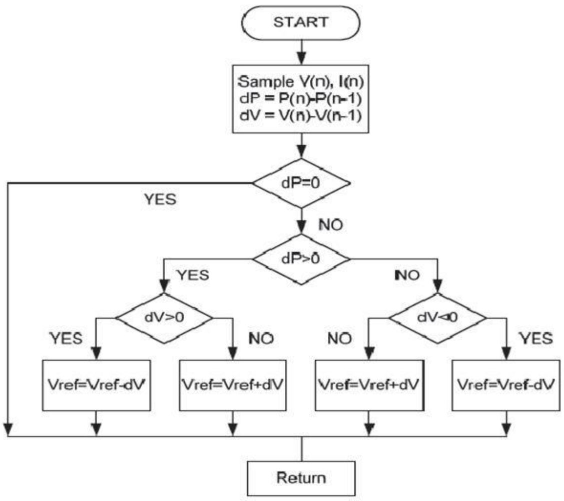

Fig. 1. P&O Algorithm

We are using a bi-directional converter introduced by Ms. Patel [11]. Fig 2 shows the circuit of the bi-directional converter to charge energy storage system. Because solar modules have varying output depending on environmental condition, battery or PV system can be used to supply the load.

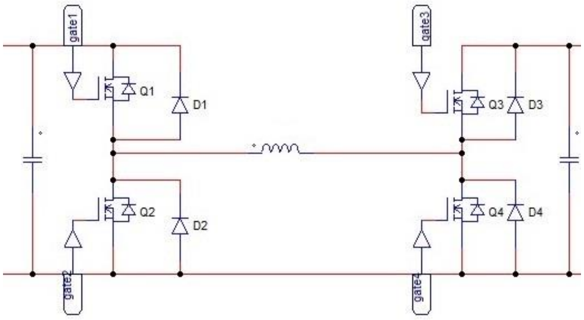

Fig. 2. Bi-directional Converter

Bidirectional converter (BDC) can transfer power in both forward and reverse direction. When the PV system is operating under normal weather condition, it supplies the load with the required voltage, while under changing weather conditions i.e. clouding; it uses the energy storage unit to deliver power to the load at rated voltage. The charging of battery takes place through forwarding mode of BDC.

BDC works in two modes: Step-Up (Boost) and Step-Down (Buck). MOSFET switches Q1 and Q4 are working in transferring energy from the input port to the output port. MOSFTE switches Q2 and Q3 are responsible for reverse power flow. Table 1 shows the sequence of MOSFETs switching.

Table I – Switching Sequence of the Switches

Direction	Mode	Q1	Q2	Q3	Q4
forward	Buck	switching	off	off	off
forward	Boost	on	off	off	switching
reverse	Buck	off	off	switching	off
reverse	Boost	off	switching	on	off

3. Simulation:

As mentioned before, the system works in two direction as follows:

A. Forward Mode:

Whenever the irradiance occurs, the PV panel generates the supply voltage. Depending on PV module output, BDC controller decides whether BDC need to work on forward Step-Down or forward Step-Up mode. Battery charging happens in this mode using the derived power from PV module.

B. Reverse Mode:

During complete shading or no irradiance, there is no PV power in system so the charged battery will supply load. Depends on PV module output controller decides whether BDC need to work on reverse Step-Down or reverse Step-Up mode.

Fig 3 shows full system schematic including all switches and controllers needed for switches.

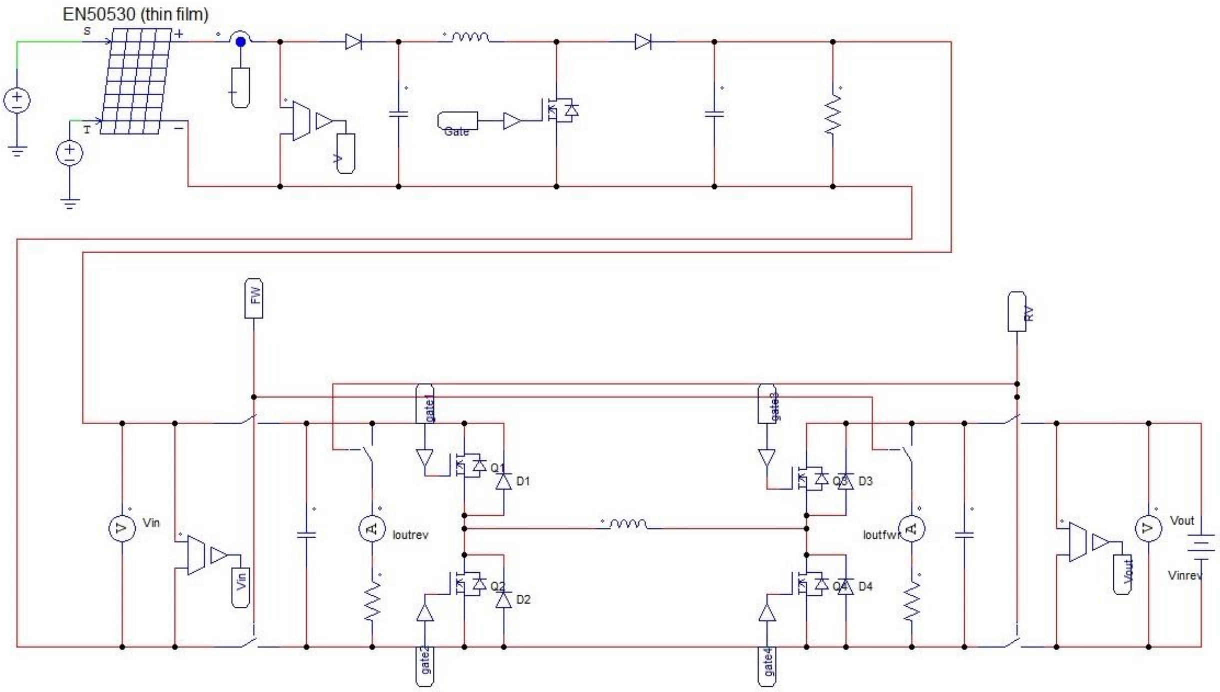

Fig. 3. System Schematic

In Forward Mode, all ‘FW’ switches are operating and PV panel is charging the battery. In addition, in Reverse Mode, all ‘RV’ switches are operating and battery is charging the load.

4. Simulation and Discussion

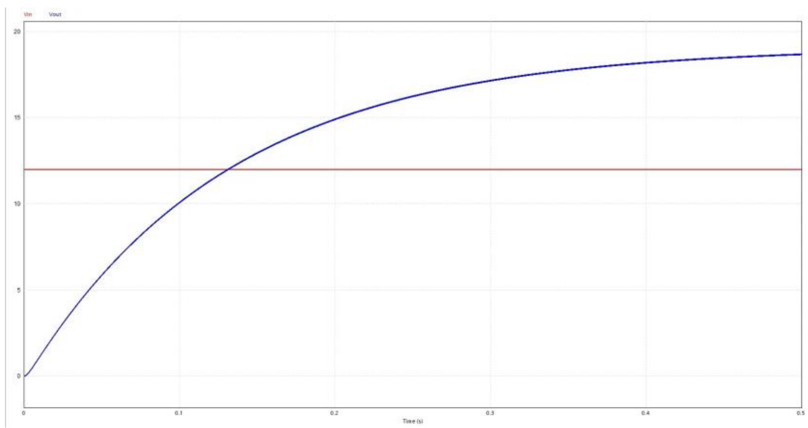

Fig. 4. Forward Boost Mode

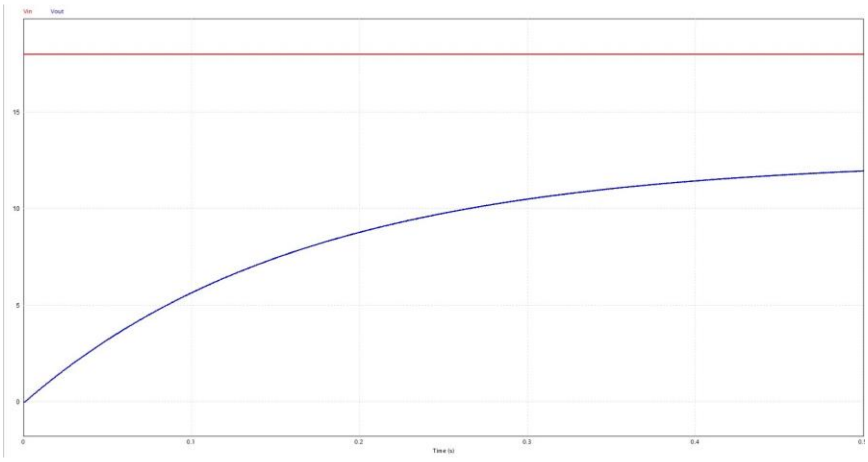

Fig. 5. Forward Buck Mode

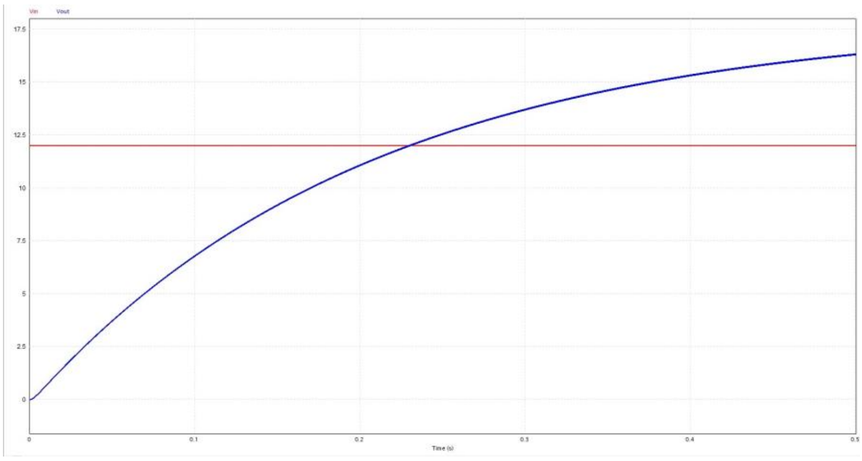

Fig. 6. Reverse Boost Mode

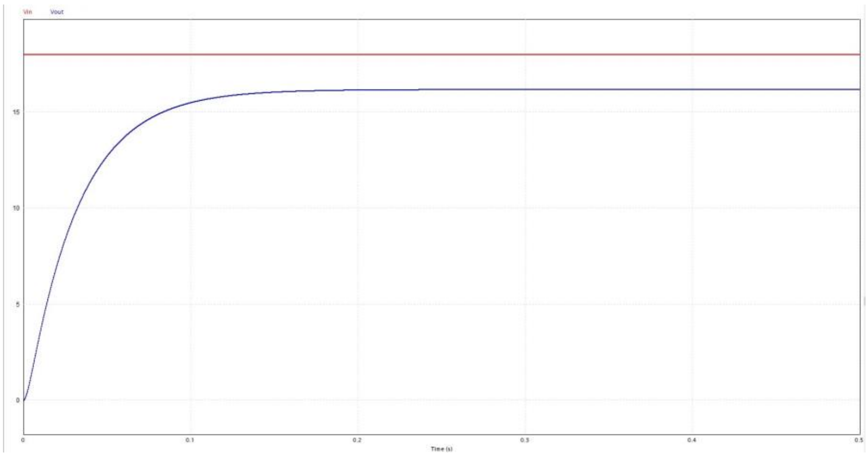

Fig. 7. Reverse Buck Mode

Figures 4-7 show the exact operation of a bidirectional converter in charging and discharging modes. The BDC controller compares output of PV system with rated voltage of the battery to decide if to store energy in battery or not. Assuming battery is to be charged then if voltage is greater than the battery voltage system will use buck mode otherwise, controller will use boost mode to reach certain voltage. As stated before, during no sunlight, controller is on reverse mode while in irradiance condition, forward mode is used.

Same basic control scheme is used to decide if we use boost or buck mode for supplying the load.

5. Conclusion

The DC load using PV panel and Battery is implemented in PSim and its effectiveness is tested under different conditions. It is found that by changing the duty cycle of BDC controller the output voltage of system will change. Therefore, to have more voltage in each mode we should have a balance between duty cycles of each direction of controller.

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