GRID SYNCHRONIZING THREE PORT DC TO DC CONVERTER FOR SOLAR POWER SYSTEMS

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ABSTRACT

A three-port DC to DC converter integrating photovoltaic and battery power for the renewable power system is presented in this project. The converter circuit contains five power switches, two coupled inductors, and two active clamp circuits. The coupled inductors are used to achieve high step-up voltage gain. Two sets of active clamp circuits are used to improve the system efficiency. Among the three ports, one port is connected to the PV source, second port is connected to battery, and third one to the load. The solar power is selected as the renewable energy source and battery as the storage device; the battery can either supply the load with the solar energy, and at the same time, it can store the excess power from the solar panels for backup use. Maximum power point tracking technique is employed to obtain maximum power from PV source. Therefore, the control scheme of the converter provides maximum utilization of PV power most of the time. This converter is suited for renewable power systems which are sourced by solar, wind, etc. This converter has merits of high boosting level, reduced number of devices, and simple control strategy. The overall system and control schemes are modeled in MATLAB Simulink.

Keywords: Three-port converter, Energy storage, PV cells, Coupled inductor, Bidirectional power path, High step-up voltage gain.

INTRODUCTION

Integrated multiport converters for interfacing several power sources and storage devices are widely used in recent years. Instead of using individual power electronic converters for each of the energy sources, multiport converters have the advantages including fewer components, lower cost, more compact size, and better dynamic performance. In many cases, at least one energy storage device should be incorporated. The combination strategies of the multiport converter include sharing switches, capacitors, inductors, or magnetic cores. One could select a proper topology by considering many aspects such as cost, reliability, and flexibility depending on the applications.

Therefore, the bidirectional power path must be provided for the battery port. It is studied that for the DC-DC converters connected to the solar panels, voltage gain extension cells such as coupled inductors, transformers, and switched capacitors are often employed to achieve high voltage conversion ratios. Thus, power switches with lower voltage rating and lower turn-on resistance can be chosen for the converters to reduce conduction losses. In this project, a high step-up three-port DC-DC converter for the hybrid PV/battery system is proposed with the following advantages: (1) high voltage conversion ratio is achieved using coupled inductors, (2) simple converter topology which has reduced number of the switches and associated circuits, and (3) simple control strategy which does not need to change the operation mode after a charging/discharging transition occurs unless the charging voltage is too high [5].

BLOCK DIAGRAM DESCRIPTION

The block diagram comprises three-port DC to DC converter, solar panel, battery, pulse width modulator, monitor and managing terminals, and load (Fig. 1).

Solar panel

In general, a large number of interconnected solar panels, known as solar PV array, are installed in an array field. These panels may be installed as stationary or with a sun-tracking mechanism. Solar panels get energy from the sun to create electricity. Solar panels make renewable energy. A common misconception about solar panels is that they produce energy from the sun's heat. They actually produce energy from the sun's light [2]. Unlike a generator, a solar panel is a solid state way of producing electricity, meaning that it has no moving parts. Solar panels are often mounted on rooftops. Panels are also commonly used in outer space, where they are one of the few power sources available.
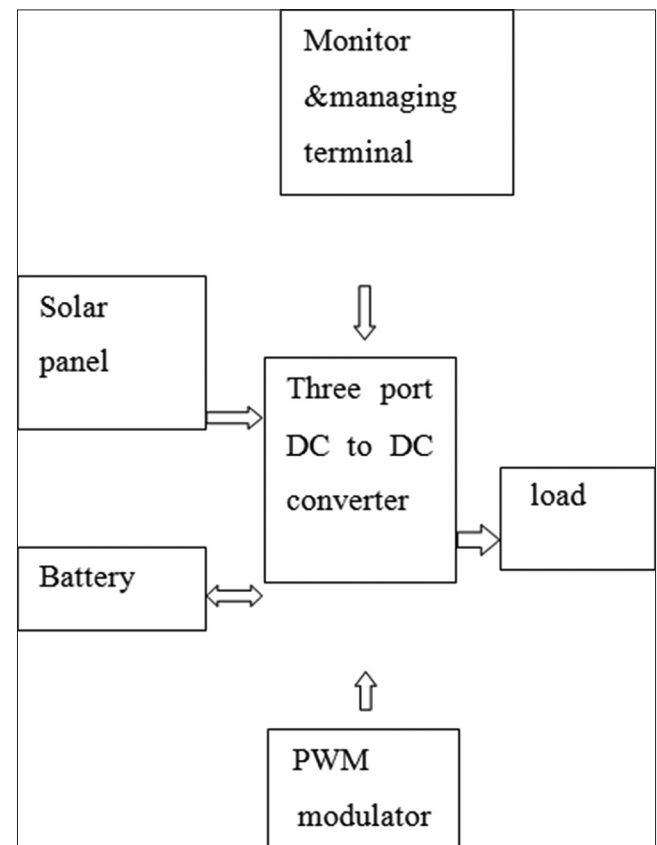

Fig. 1: Block diagram of three port converter

Battery

Battery acts as an energy storage device. The battery can either supply the load with the solar energy at the same time or store the excess power from solar panels for backup use. Therefore, the bidirectional power path must be provided for the battery port [1]. A storage battery receives electrical energy as direct current and stores it in the form of electrical energy by a reversible electrochemical reaction. On connecting to an electrical load, it supplies electrical energy by converting the stored chemical energy back into electrical energy as direct current.

PWM modulator

The most popular method of controlling the output voltage is to incorporate pulse width modulation control. The controlled DC output voltage is obtained by adjusting the on and off periods of the power semiconductor switches. PWM is the process of modifying the width of the pulses in a pulse train in direct proportion to a small control signal; the greater the control voltage, the wider the resulting pulses become.

Load

Loads are classified into two types. They are linear loads and nonlinear loads. Electrical loads consuming alternating current power consume both real power, which does useful work, and reactive power which dissipates no energy in the load and which returns to the source on each alternating current cycle [7]. Nonlinear loads create harmonic currents in addition to the original AC current. Addition of linear components such as capacitors and inductors cannot cancel these harmonic currents, so other methods such as filters or active power factor correction are required to smooth out their current demand over each cycle of alternating current and so reduce the generated harmonic currents.

CIRCUIT DIAGRAM

The circuit diagram of three-port DC to DC converters includes five power switches, two coupled inductors, and two active clamp circuits. The power switches used in the three-port converter circuit is metal oxide semiconductor field effect transistor (MOSFET) (Fig. 2) [9].

MOSFET

Discrete power MOSFETs employ semiconductor processing techniques that are similar to those of today's VLSI circuits although the device geometry, voltage, and current levels are significantly different from the design used in VLSI devices. The MOSFET is based on the original field-effect transistor introduced in the 70 seconds [3]. Fig. 3 shows the device symbol for a MOSFET.

Active clamp circuit

Two sets of active clamp circuits formed by S_2, L_{K1}, Cc_1 and S_5, L_{K2}, Cc_2 are used to recycle the leakage energy. L_{K1} and L_{K2} both are composed of a small leakage inductor from the coupled inductor and an external leakage inductor. Two independent control variables, duty cycles d_1 and
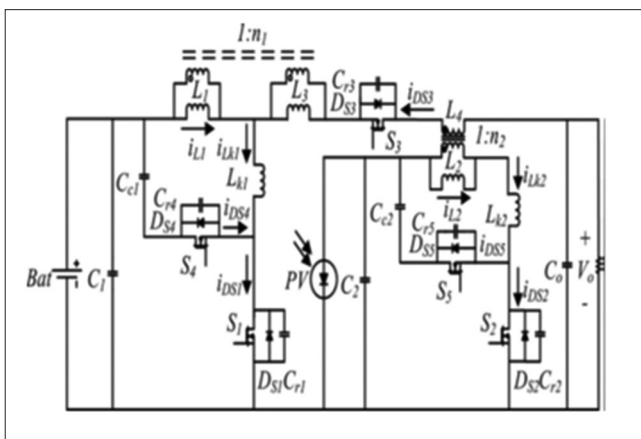
d_2, allow the control over two ports of the converter, whereas the third port is for the power balance [5]. The fixed-frequency driving signals of the auxiliary switches S_3 and S_4 are complementary to primary switch S_1. Again, S_3 provides a bidirectional path for the battery port. Active clamp circuits are also used to improve the system efficiency.

Coupled inductor

The coupled inductors are used to achieve high step-up voltage gain and to reduce the voltage stress of input side switches. Two coupled inductors with winding ratios n_1 and n_2 are used as voltage gain extension cells. Coupled inductors are connected across the active clamp circuit. By increasing the winding ratios of the coupled inductors, the output voltage can be increased [8].

WORKING OF THREE-PORT CONVERTER

There are four operation periods based on the available solar power. First, the sun is in the eclipse stage and the solar irradiation is either unavailable or very low. This operation period is defined as period 1, and the battery will serve as the main power source [1]. As the sun starts to shine and the initial solar irradiation is enough for supplying part of the load demand, the operation period is changed to period 2. The load is supplied by both solar and battery power in this period. For period 3, the increasing isolation makes the solar power larger than the load demand. During period 4, the charging voltage of the battery reaches the preset level [9].

According to the solar irradiation and the load demand, the three-port converter can be operated under two modes. In the battery balance mode (mode 1), maximum power point tracking is always operated for the PV port to draw maximum power from the solar panels. The power sharing of the inputs can be represented as;

$$P \text{ load} = P_{PV} \text{ SVC} + B_b \text{at SVC} \qquad (1)$$

Where,
P_{load} is the load demand power,
P_{PV} SVC is the PV power under,
Solar voltage control (SVC) and,
P_{bat} SVC is the battery power under SVC.

In mode 1, maximum power is drawn from the PV source [5]. The battery may provide or absorb power depending on the load demand. When the battery charging voltage is higher than the maximum setting, the converter will be switched into battery management mode (mode 2). In mode 2, MPPT will be disabled; therefore, only part of the solar power is drawn. The power sharing of the inputs can be represented as;

$$P_{load} = P_{PV} \text{ BVC} + P_{bat} \text{ BVC} \qquad (2)$$

BVC is the PV power under battery.

Voltage control (BVC) and P_{bat} BVC are the battery charging power under SVC [8]. If the load gets increased and the battery voltage is reduced, the converter will be switched to mode 1.
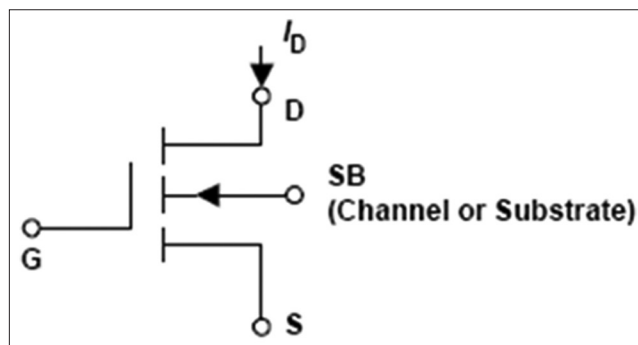

Fig. 2: Circuit diagram of three-port DC to DC converter

Fig. 3: Symbol of MOSFET

CONTROL STRATEGY

The operation modes of the converter are determined by the conditions of available solar power and battery charging states. Controlling the converter in each mode requires different state variables to regulate voltages of the input and output ports [2]. There are three control loops for the proposed converter: Output voltage control OVC, SVC, and BVC.

The OVC is a simple voltage regulation loop. SVC is used to regulate the voltage of the PV port and implement the MPPT algorithm. BVC is the battery voltage regulation loop to prevent overcharging. It is noted that the PV port is operated under SVC most of the time [3]. The control scheme is shown in Fig. 4.

RESULTS

The below-mentioned Fig. 5 shows the Simulink model of an overall system taken under observation. It consists of three subsystems. They are listed below:
- PV panel subsystem,
- SVC subsystem, and
- Battery voltage control subsystem.

The SVC loop mentioned comprises MOSFET switches. The gating signals for the MOSFET switches are provided from the PWM generator which varies the pulse signals according to the power consumed by the load (Fig. 8).

The power generated from the PV port is now larger than the load demand, so the battery port should be charged to store additional power (Figs. 9 and 10).
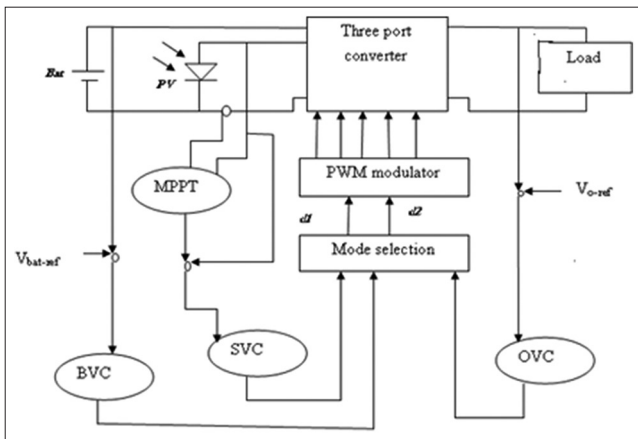

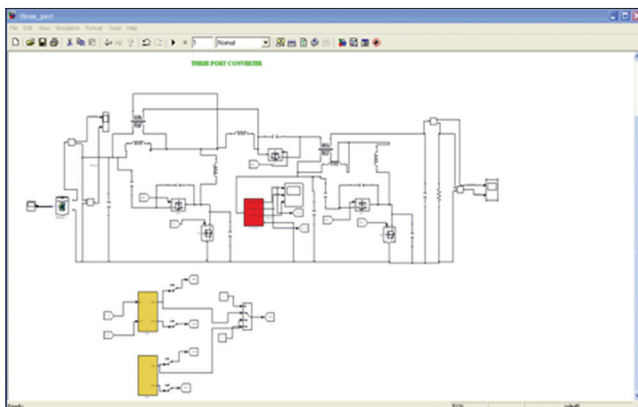**Fig. 4: Control scheme of the three-port converter**

Fig. 5: Simulink model of three-port converter

The input voltage from PV panel is 57.5 volt DC, and the input voltage from battery is 30 volt DC. The output voltage obtained whereas both solar and battery power are available is 120 volt DC (Fig. 11).

Here, the battery will serve as the main power source. At this stage, the output DC voltage produced will be 58 volt (Fig. 12).

In this mode, battery power will not make the solar power larger and the output voltage produced will be 60 volt DC (Fig. 13).

In this mode, maximum solar power will be obtained using maximum power point tracking. The output voltage produced during this mode is 99 volt DC.

CONCLUSION

A three-port DC-DC converter for renewable power system is presented. This converter uses five power switches, two coupled inductors, and two active clamp circuits. Two coupled inductors are employed as voltage gain extension cells for high voltage output applications. Two
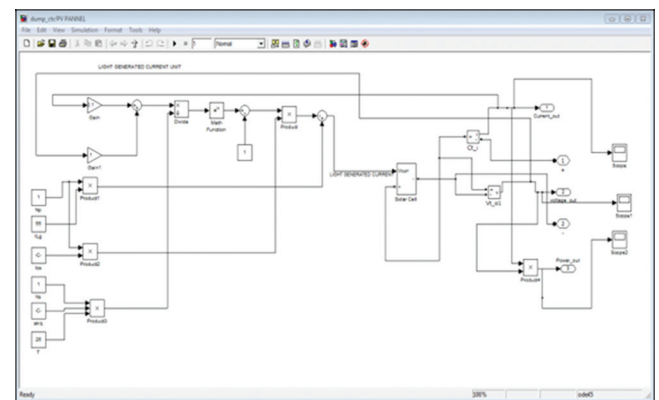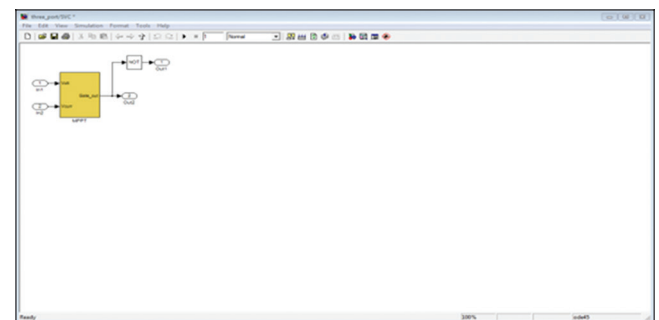

Fig. 6: Simulink model of a PV panel
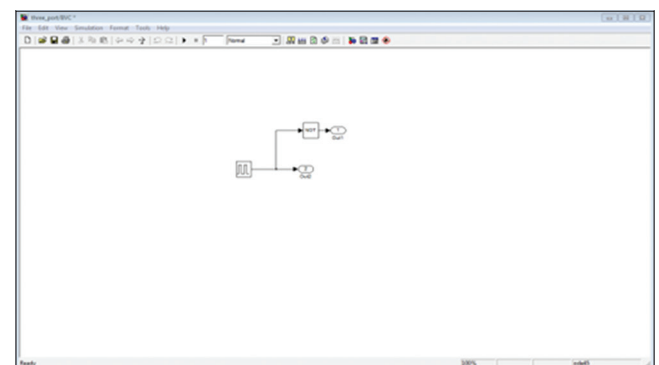

Fig. 7: Simulink model of a SVC loop

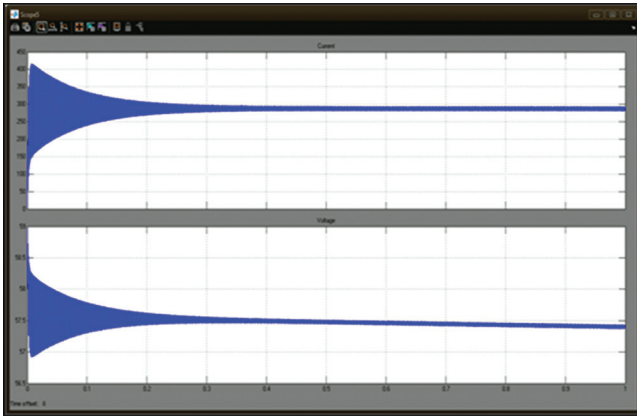**Fig. 8: Simulink model of battery voltage control**

Fig. 9: Input from PV panel. The input voltage from PV panel is 57.5 volt, DC
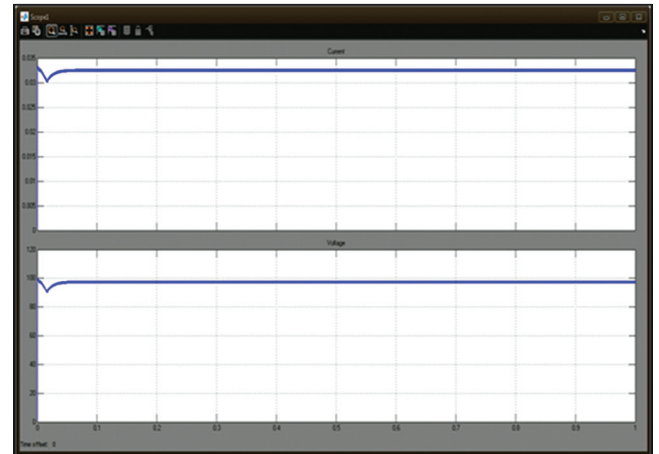

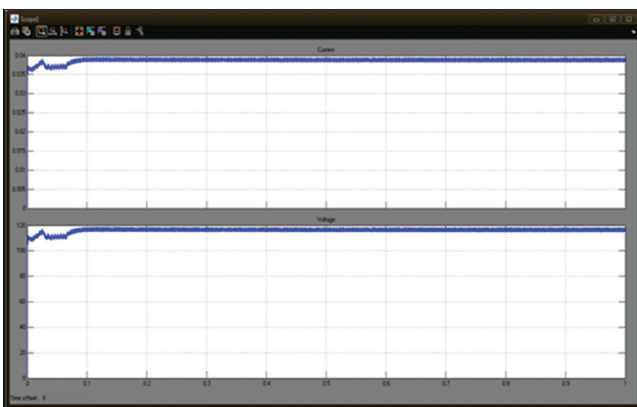**Fig. 12: Simulation output without battery power**

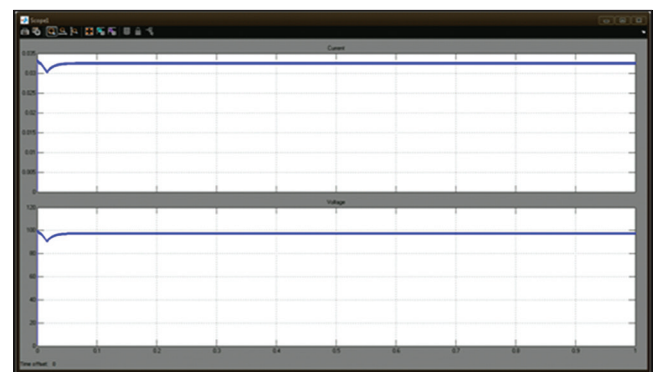**Fig. 10: Simulation output with both solar and battery power**
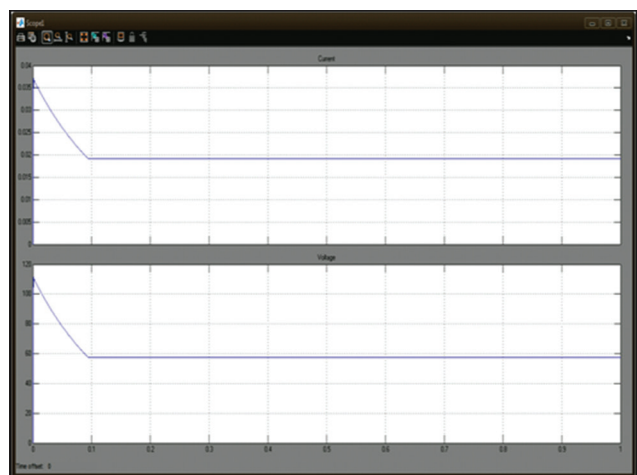

Fig. 13: Simulation result with increase in solar power

Fig. 11: Simulation output without solar power

converter at three different intervals. The three different intervals are (i) availability of both solar and battery power, (ii) availability of solar power only, and (iii) availability of battery power only. Voltage of 58 volt DC is given as input, and due to the usage of step-up converter, 120 volt DC output will be obtained. As a result, the three-port converter has merits of high boosting level, reduced number of devices, and simple control strategy.

sets of active clamp circuits are used to improve the system efficiency. The charging/discharging transitions of the battery could be achieved without changing the operation mode; therefore, the MPPT operation will not be interrupted. In light-load condition, once the charging voltage is higher than the preset level, the operation mode will be changed rapidly to protect the battery from overcharging. The highest converter efficiency is measured as 90.1%. The more relevant waveforms are presented along with theoretical analysis. The results obtained from numerical simulation and experimentation confirms the theoretical analysis performed. It is possible to verify the output power of the

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