PV BASED DUAL-OUTPUT DC/DC CONVERTER WITH SIMULTANEOUS BOOST AND BUCK OUTPUTS

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Abstract—The future of electrical system is being propelled by a fundamental shift to cleaner and more efficient converter systems. This lead to the emergence of photovoltaic (PV) cell based generation of electricity for electric systems. A PV based dual output DC-DC converter with simultaneous boost and buck outputs is discussed. The topology consists of a dual output converter with simultaneous boost as well as buck outputs. The energy harvested from solar energy can be thus utilized for producing different dc outputs. The system has lesser number of components, as well as lesser coordination communication requirements compared to other integrated topologies. Compared to traditional buck converters, the proposed converter has higher reliability, due to its inherent shoot-through protection and has a wider range of step-down outputs.

Keywords— photovoltaic, direct current, dual output, harvest, inherent, shoot-through, step-down

INTRODUCTION

Due to the drastic increase of global energy demand and rapid consumption of conventional fossil fuel resource, renewable energy has become more popular. The renewable energy resources as those derived from natural processes and replenished at a faster rate than they are consumed. Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves, and geothermal heat. Among several renewable energy resources, energy harvesting from the photovoltaic (PV) effect is the most essential and sustainable way because of abundance and easy accessibility of solar radiant energy around the earth[1]. The photovoltaic technology for converting solar energy to electricity can be utilized in many areas such as dc nanogrids, multilevel inverters, plug-in hybrid electric vehicles etc for energy conversion[3]. For conditioning the dc voltage to the required levels a DC/DC converter is usually needed. Different types of DC/DC converters are nowadays widely used in industrial as well as communicational sectors for power conditioning. A PV based dual output dc/dc converter with simultaneous boost and buck outputs for power conditioning of a renewable power system is presented. A photovoltaic source is modeled as a representation of renewable source system[2]. The topology consists of a PV sourced multiple output converter with simultaneous boost as well as buck outputs. The energy harvested from solar panel can be thus utilized for producing different dc outputs of different voltage levels. The system has lesser number of components, as well as lesser coordination communication requirements compared to other integrated topologies. Compared to traditional buck converters, the proposed converter has higher reliability, due to its inherent shoot-through protection and has a wider range of step down outputs. The Conventional IBuBuBo converter [1] is also analyzed and compared with proposed PV based dual output DC/DC converter.

PHOTOVOLTAIC CELL AND MPPT

Photovoltaic Cell

The renewable energy sources like wind, solar, geothermal and biomass represent an alternative to traditional methods of producing electrical energy. Among them solar source is becoming popular due to its effectiveness nowadays. Solar energy can be converted directly into electricity using photovoltaic panels (PV) through the photovoltaic effect. The photovoltaic effect is the basic physical process through which a solar cell converts sunlight into electricity. A PV panel may consist of a number of solar or photovoltaic cells arranged in series or parallel.

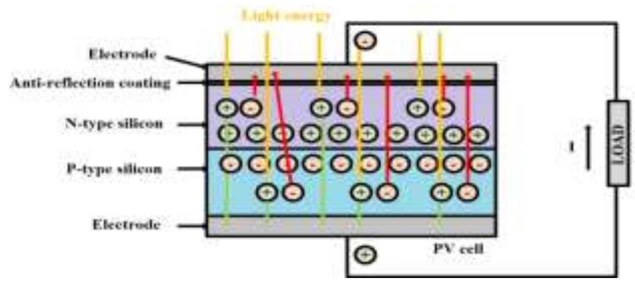

Fig 1 Representation of PV cell working

The PV cell is basically a PN junction diode so when light is incident on it, free charge carriers are created i.e. electron hole pairs are created. From light energy absorbed by them gives the charge carriers the energy to cross the potential barrier. The electrons will start moving towards N type semiconductor layer and holes will be started moving towards P type semiconductor material. Thus by connecting a metal electrode in both ends we can channelize these charges to either side of the load. The fig 1 shows the representation of a PV cell working. The PV cells can be modeled as a current source in parallel with a diode. When there is no light present to generate any current, the PV cell behaves like a diode[2]. As the intensity of incident light increases, current is generated by the PV cell. The current source I_{ph} represents the cell photocurrent. R_{sh} and R_s are the shunt and series resistances of the cell, respectively. R_s represents usually the structural resistance of the device like contact resistance, p-n bodies etc and R_{sh} exists mainly due to leakage current of p-n junction, fabrication methods of PV cell etc. Usually the value of R_{sh} is very large and that of R_s is very small, hence they may be neglected to simplify the analysis. Load is connected across it. I_{pv} represents PV current. The fig 2 shows (a) PV cell modeled as a diode circuit and (b) Simplified equivalent circuit of PV array.

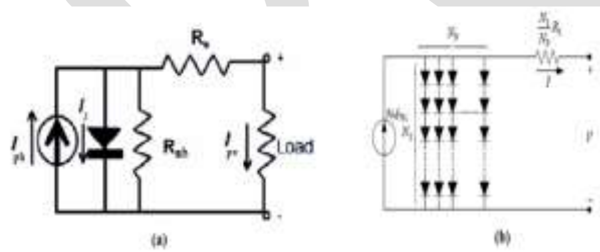

Fig 2 (a) PV cell modeled as a diode circuit (b) Simplified equivalent circuit of PV array

Maxing Power Point Tracking

The power characteristic of the PV is nonlinear and has a particular point for which the power generated by the PV is maximal. This is usually noted MPP (Maximum Power Point). In order to get maximum power of the PV panel several Maximum Power Point Tracking (MPPT) algorithms are used. There are several MPPT algorithms, among them “Perturb and Observe” (P&O) is widely used. The fig 3 shows the flowchart representation of P&O algorithm.

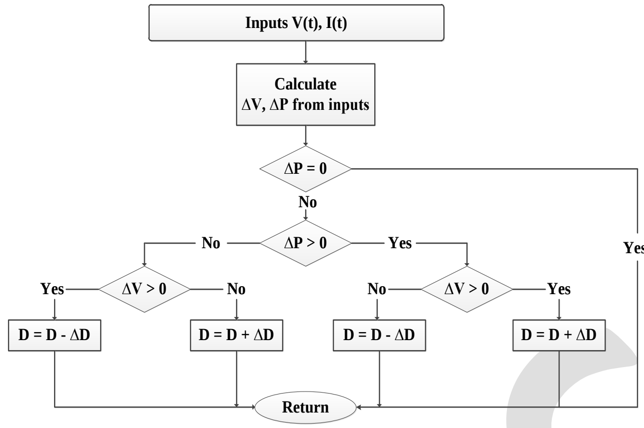

Fig 3 P & O algorithm

The principle of P&O is to send perturbations in the operating voltage of the PV array which makes the output power is approaching to maximum. To be specific, the array terminal voltage is perturbed periodically. The perturbation is incrementing or decrementing. Then the P&O algorithms operate by comparing the PV output power with that of the previous perturbation cycle. If the PV array operating voltage changes and power increases, the MPPT controller moves the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way.

CONVENTIONAL IBUBUBO CONVERTER

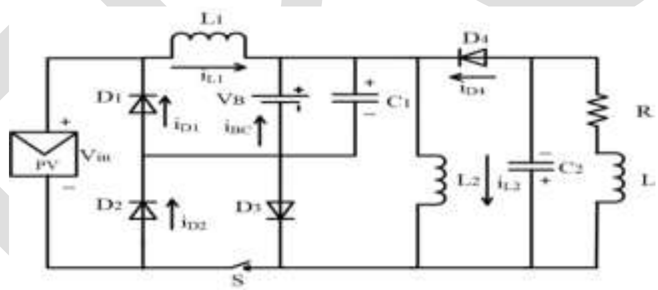

Fig 4 Conventional IBuBuBo Converter

The Conventional IBuBuBo converter is a single stage converter. It is an integrated buck buck boost (IBuBuBo) converter. The converter allows a portion of the input power to be processed once only, resulting in enhanced conversion efficiency. Additionally, due to the absence of a transformer, the size and manufacturing cost of the converter can be reduced. It is derived through the integration of a buck converter into a buck-boost converter. The conventional IBuBuBo converter [1] is shown in fig 4. It consists of an input inductor L_1, a rechargeable battery V_B, a capacitor C_1 to absorb the ac current ripple of the battery, an output inductor L_2 to supply the load, a power switch S, four diodes (D_1 to D_4), and an output capacitor C_2. The battery current, i_{BC} denotes the total current flowing out of the battery and capacitor C_1. Diodes D_1 and D_3 provide the current paths of negative i_{BC} during different operation periods while diode D_2 serves as a path for positive i_{BC}. Diode D_4 links the energy to the load from inductor L_2.

Modes of operation

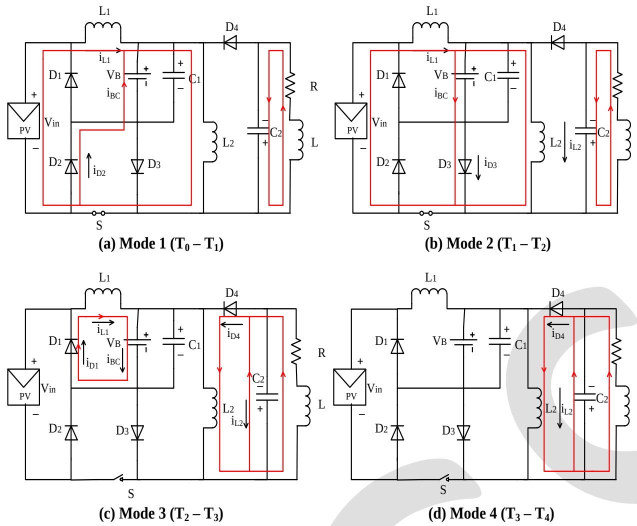

Fig 5 Modes of operation

To explain the working principle of the converter, the circuit operation modes is shown on fig 5 and the key theoretical waveforms up to two switching cycles are given in fig. 6.

The different modes of operation of converter are explained as follows.

- **Mode 1** (T_0 −T_1): In Fig 3.2(a) shows operation in this mode. During this stage, switch S is ON, diodes D_1, D_3, and D_4 are reverse biased, and diode D_2 is forward biased. The PV source charges the inductor L_1. The battery current i_{BC} is positive and flow through inductor L_2, S, and D_2.
- **Mode 2** (T_1 −T_2): This mode happens when the PV source is enough to charge inductor L_2 as shown in Fig 3.2(b). The extra energy from PV source charges the battery and the capacitor C_1, and hence, i_{BC} is reversed. Diode D_3 provides the path for the negative i_{BC} while diode D_2 is reverse biased. Currents of the two inductors reach their peaks at time T_2 when the switch is just turned OFF. During the first two modes of operation, the load is sustained by the output capacitor C_2.
- **Mode 3** (T_2 −T_3): Mode 3 starts when switch S is turned OFF. The operation stage is shown in Fig 3.2(c). Diodes D_2 and D_3 are reverse biased, and inductor L_1 discharges its stored energy to the battery and capacitor C1 through diode D_1. Inductor L_2 begins to release its stored energy in previous stages to the output capacitor C_2 and the load through diode D_4.
- **Mode 4** (T_3 −T_4): During this stage, switch S is OFF, and the input inductor L_1 is completely discharged. The operation stage is shown in Fig 3.2 (d). Inductor L_2 continues to discharge its stored energy to the output capacitor C_2 and the load through diode D_4 until the next switching period.

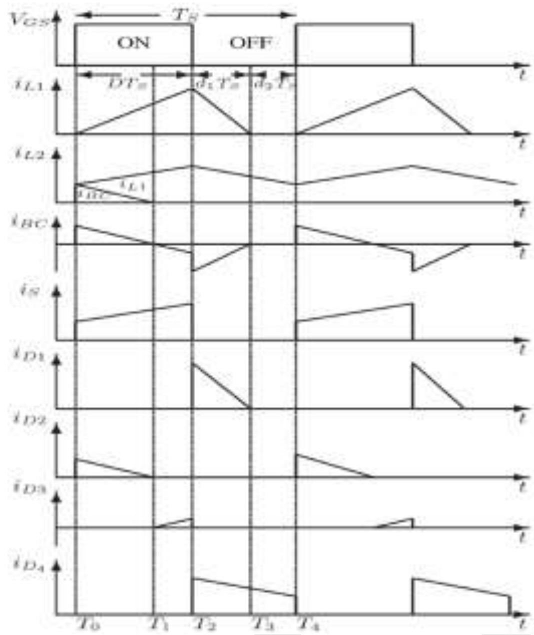

Fig 6 Waveforms of Conventional IBuBuBo Converter

The control logic of Conventional IBuBuBo converter is shown in fig 7, the MPPT output is compared with a repeating sequence to produce gate pulses.

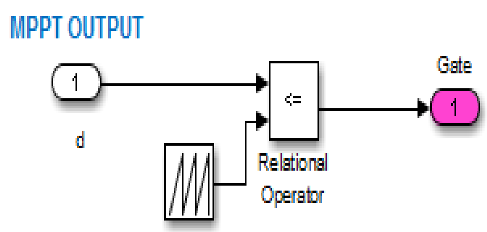

Fig 7 PWM generation of Conventional IBuBuBo converter

The Conventional IBuBuBo converter can only operate in buck mode. Therefore only buck output can be obtained. As the component count is more the loss of the converter will be high. The conventional IBuBuBo converter is simulated for sufficient PV input condition and verified the result. For an input of 12 V, the converter output is 5.7-4.8 V. The output is varying within a range. The large number of component count increases the losses of the converter. The Conventional IBuBuBo converter is limited to step down applications.

PV BASED DUAL OUTPUT DC/DC CONVERTER WITH SIMULTANEOUS BOOST AND BUCK OUTPUTS

Most of the consumer products require voltages at different levels with respect to loads. Therefore the need of power conditioning circuits to create these different levels is important. A PV based dual output DC/DC converter topology which can produce simultaneous boost and buck outputs is proposed. The PV Based Dual output DC-DC converter is synthesized by replacing the control switch of a boost converter topology with series connected switches and using the additional switch nodes to generate step-down dc outputs. The converter consists of a single input and multiple outputs. Simultaneous buck as well as boost output can be produced. The fig 8 shows circuit diagram of PV based dual output DC/DC converter.

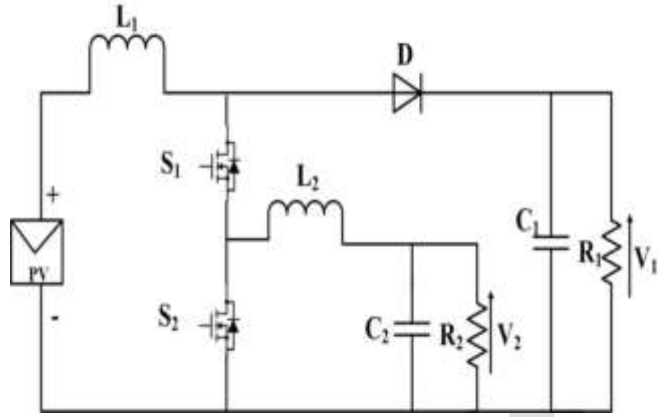

Fig 8 PV based dual output DC/DC converter with simultaneous boost and buck outputs

The fig 8 shows PV based dual output DC/DC converter, it consist of two switches, S_1 and S_2, two inductors L_1 and L_2, two capacitors C_1 and C_2, one diode D, and two load resistors R_1 and R_2.

Modes of operation

The topology consists of three modes of operation depending on the status of two bidirectional switches, S_1 and S_2. The modes of operation are shown in fig 9 and the key waveforms of converter are shown in fig 10.

- **Mode 1** (Both S_1 and S_2 are ON): This mode of operation is similar to the controllable switch S of conventional boost converter being turned ON. The equivalent circuit of mode 1 is shown in fig 9 (a). The diode D is reverse biased during this interval, while the buck inductor current i_{L2} freewheels through the switch S_2. As this mode has two switches in ON state, the converter has inherited shoot-through protection.
- **Mode 2** (S_1 ON and S_2 OFF): In this mode of operation the switch S_1 is ON and the switch S_2 is OFF. The equivalent circuit of mode 1 is shown in fig 9 (b). The diode D is forward biased. The inductor current i_{L1} will be divided into two, one part flows through D to capacitor C_1 and load and the other part flows through inductor L_2 to linearly charge it. In this mode, the step-down converter draws energy from the source.
- **Mode 3** (S_1 OFF and S_2 ON or Both S_1 and S_2 OFF): In this interval, the inductor current i_{L2} freewheels through the switch S_2 or through its anti-parallel diode (if S_2 is not being gated). This interval is thus analogous to freewheel period associated with conventional buck converters, either the lower switch conducts in synchronous switching scheme or the diode conducts. The diode D conducts the inductor current, i_{L1}. Hence, both the inductors give out their energy to their respective outputs. The operation stage is shown in Fig 9(c).

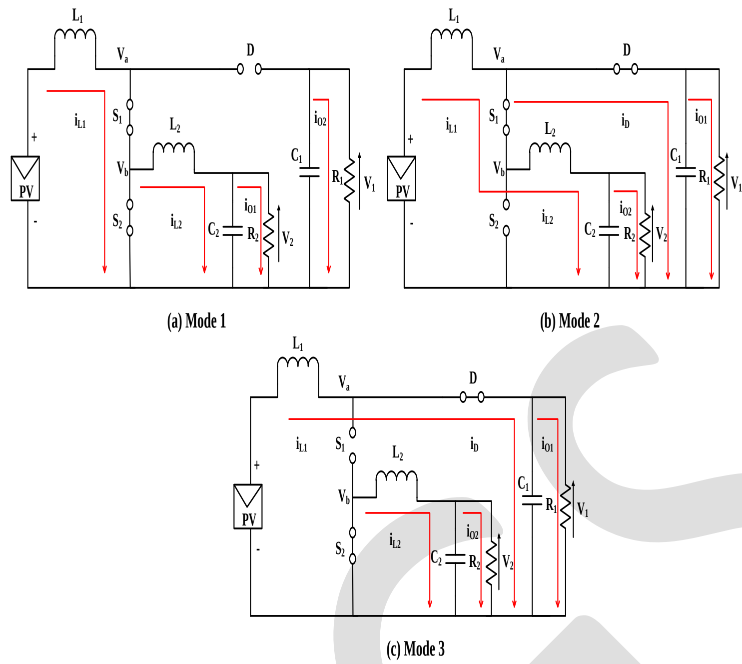

Fig 9 Operational stages of PV based dual output DC/DC converter

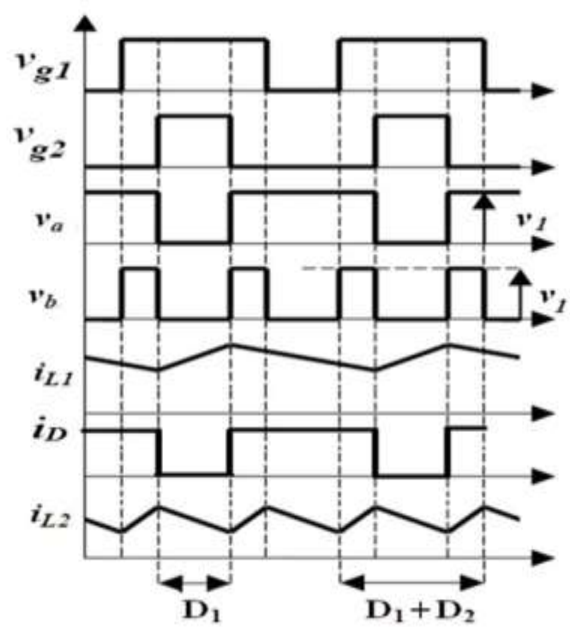

Fig 10 Key waveforms of PV based dual output DC/DC converter

Steady state analysis

For steady state analysis, the duty cycles are defined as the time duration of modes 1 and 3. The equations can be written as below:

For inductor L_1,

$$V_{in} * D_1 + (V_{in} - V_1)(1 - D_1) = 0 \qquad \text{........ (1)}$$

$$\frac{V_1}{V_{in}} = \frac{1}{1-D_1} \quad \text{…….. (2)}$$

For inductor L_2,

$$(V_1 - V_2)D_2 + (-V_2)(1 - D_2) = 0 \quad \text{…….. (3)}$$

$$\frac{V_2}{V_1} = D_2 \quad \text{……. (4)}$$

Control stratergy

The PV based dual output converter uses P & O (Perturb and Observe) MPPT (Maximum Power Point Tracking) method. The control logic of PV based dual output converter DC/DC converter is shown in fig 11, the MPPT output is compared with a repeating sequence to produce gate pulses.

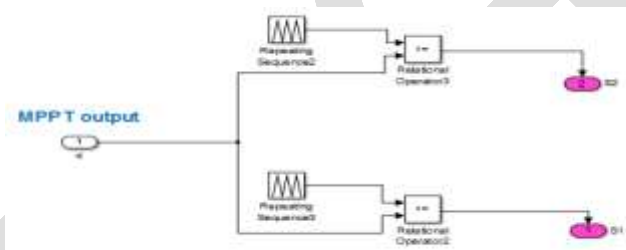

Fig 11 Control logic of PV based dual output converter DC/DC converter

The PV based dual output converter DC/DC converter is able to produce simultaneous buck as well as boost output can be obtained. Compared to Conventional IBuBuBo converter, PV based dual output converter has better performance as it is capable of producing buck as well as boost outputs. For a 12V input voltage from PV panel, 6V and 18V buck and boost outputs are produced. The component count is also less. Therefore the loss of the system is low.

MATLAB SIMULINK MODEL AND RESULTS

Conventional IBuBuBo Converter

The Simulink model of conventional IBuBuBo Converter is shown in fig 12.The simulation of conventional IBuBuBo Converter is done using MATLAB Simulink software. The ripple component of the output is high. The switching frequency is chosen to be 10 KHz. The inductor1 current of the converter is discontinuous where as inductor2 current of the converter is continuous. The battery voltage, current and state of charge (SOC) is also shown. The battery current is reversed and SOC remains the same. For an input of 12 V, the converter output is 5.7-4.8 V.

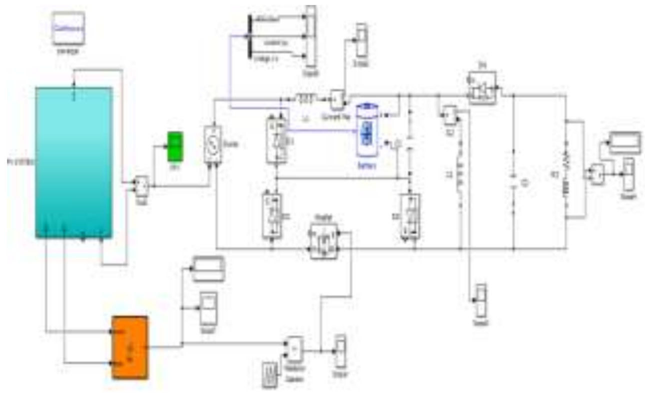

Fig 12 Simulink model of conventional IBuBuBo Converter

Table 1 Parameters of IBuBuBo Converter

Components	Specifications
Inductor L_1	15 µH
Inductor L_2	100 µH
Capacitor C_1	100 µF
Capacitor C_1	100 µF
R L load	30 Ω, 20mH

The large component count increases loses of the converter. The ripple content in the output voltage is high. The output is varying within a range. The output waveforms are shown in fig 13.

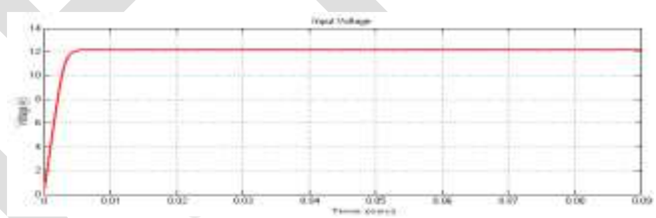

Fig 13 (a) Input Voltage

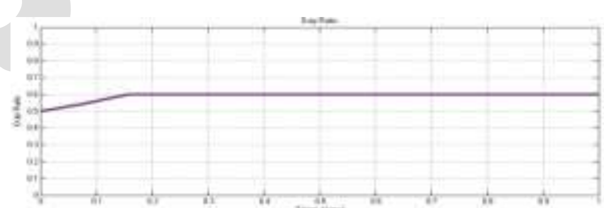

Fig 13 (b) MPPT Output

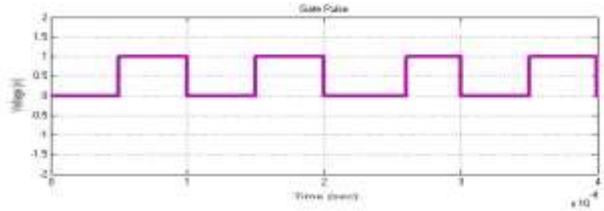

Fig 13 (c) Gate Pulses

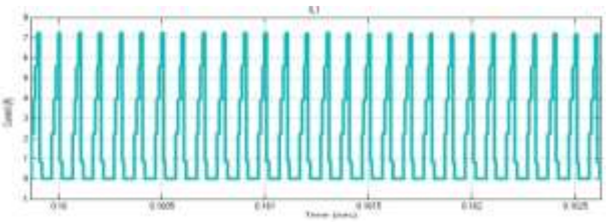

Fig 13 (d) Inductor 1 Current, i_{L1}

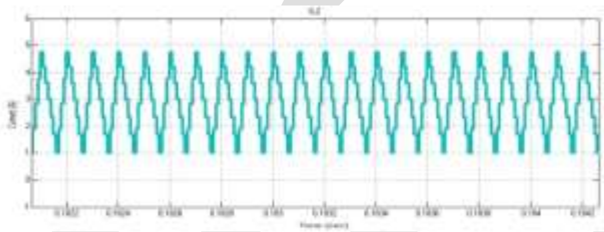

Fig 13 (e) Inductor 2 Current, i_{L2}

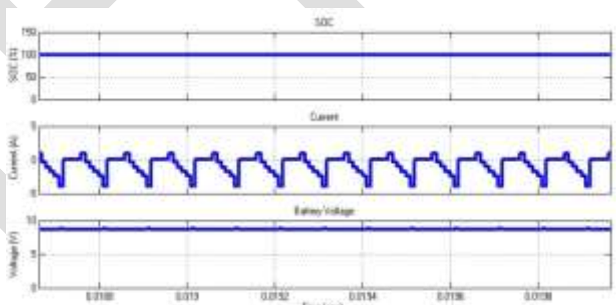

Fig 13 (f) Battery SOC, Current, Voltage

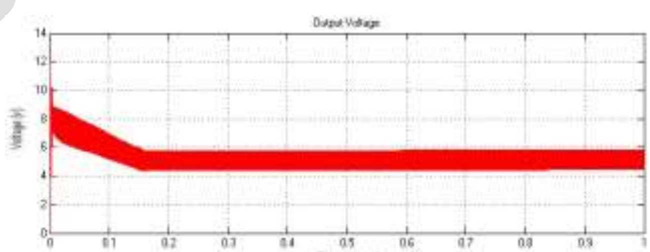

Fig 13 (g) Output Voltage

PV Based dual output DC/DC converter with simultaneous boost and buck outputs

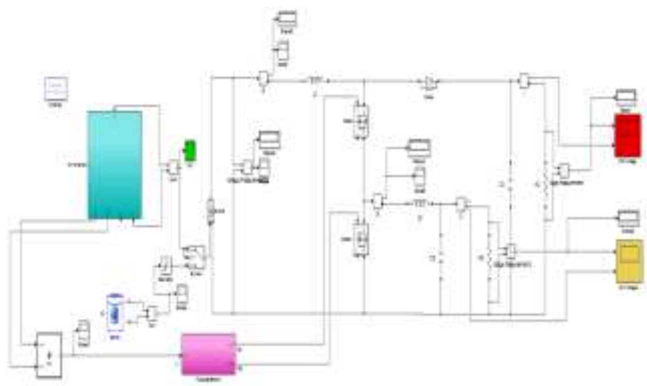

Fig 14 Simulink model of PV based dual output DC/DC converter

The simulink model of the PV based dual output converter is shown in fig 14. The converter is able to produce buck and boost outputs simultaneously. The switching frequency is chosen to be 10 KHz. The inductor currents are continuous

Table 2 Parameters of PV based dual output DC/DC converter

Components	**Specifications**
Inductor L_1	3 mH
Inductor L_2	2.2 mH
Capacitor C_1	421 µF
Capacitor C_1	250 µF
Load R_1	27.27 Ω
Load R_2	9.09 Ω

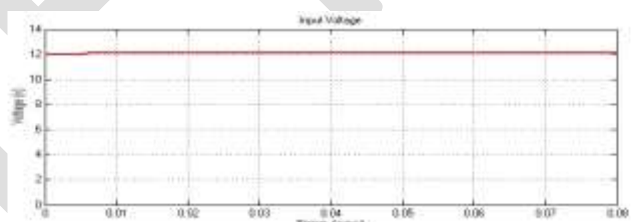

Fig 15 (a) Input Voltage

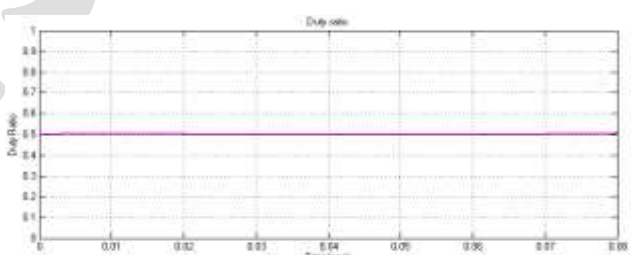

Fig 15 (b) MPPT output

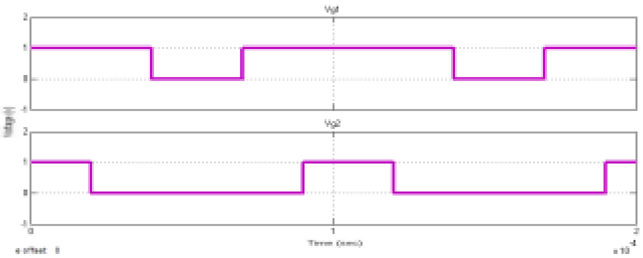

Fig 15 (c) Gate Pulses

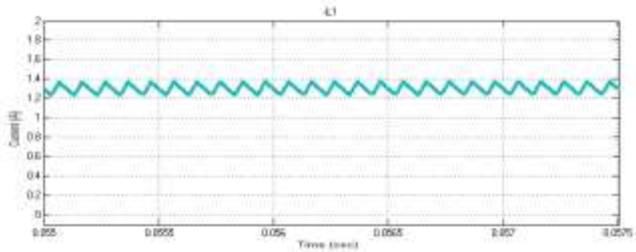

Fig 15 (d) Inductor 1 Current, i_{L1}

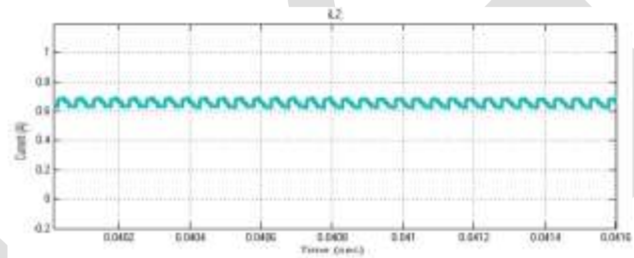

Fig 15 (e) Inductor 2 Current, i_{L2}

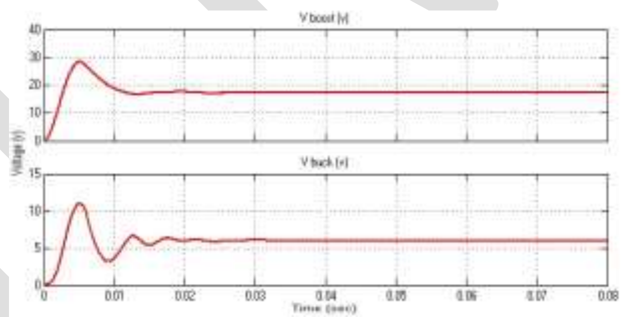

Fig 15 (f) Output Voltages

The output waveforms are shown in fig 15. Compared to Conventional IBuBuBo converter, PV based dual output converter has better performance as it is capable of producing buck as well as boost outputs. For a 12V input voltage from PV panel, 5.9V and 17.3V buck and boost outputs are produced. The component count is also less. Therefore the loss of the system is low.

Converter comparision

Comparing the Conventional IBuBuBo converter, the PV based dual output DC/DC Converter has better performance. It is capable of producing buck as well as boost outputs simultaneously. The Table 3 shows the comparison between two converters. For an input of 12V, the Conventional IBuBuBo converter has buck output varying within a range. The component count of the converter is also high compared to the PV based dual output DC/DC Converter. This increases the losses of the converter.

Table 3 Comparison of Converter performances

DC/DC Converter	**Conventional IBuBuBo Converter**	**PV based Dual output converter**
Converter Type	Single Output	Multiple Output
Vin (V)	12	12
Vout (V)	5.7-4.8	V_{buck} = 5.9 V_{boost} = 17.3
Component Count	More	Less
Losses	More	Less
Applications	Limited to buck applications	Buck and boost applications

The Conventional IBuBuBo converter is limited to buck applications but PV based dual output DC/DC Converter can be used to systems that needs both buck and boost voltages simultaneously. It can be used in several applications like multilevel inverters, computer mother boards, dc nano grids etc.

CONCLUSION

A PV based dual output DC-DC converter with simultaneous boost and buck outputs is discussed. The use of renewable energy as source reduces the emission of green house gases and it is absolutely noise free. The topology consists of a multiple output converter with simultaneous boost as well as buck outputs. The energy harvested from solar energy can be thus utilized for producing different dc outputs. The system has lesser number of components, as well as lesser coordination communication requirements compared to other integrated topologies. Compared to traditional buck converters, the proposed converter has higher reliability, due to its inherent shoot-through protection and has a wider range of step-down outputs. The PV based dual output DC-DC converter be used in several applications like multilevel inverters, computer mother boards, dc nano grids etc.

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