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A Novel Two-Stage Cascaded Interleaved Boost Converter with High Voltage Gain for Solar PV System with MPPT Technique

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Abstract: This paper presents a design and simulation of a two-stage cascaded Interleaved Boost Converter (CIBC) for solar applications controlled by using maximum power point tracking method. The proposed two-stage CIBCs consist of two Interleaved Boost Converters IBC connected in series is to extract the maximum power from PV system and to provide a high voltage output with less ripple voltage. The modeling of PV and power converters are studied by simulation in MATLAB/SIMULINK. Results show that the proposed system design has high energy conversion efficiency.

I.INTRODUCTION

Photovoltaic (PV) system is one of the main contributions to the future of electricity supply and becoming more popular because of the zero emission and running costs but the voltage levels obtained is low and unregulated, thus make boost converter is required to increase and regulate the output voltage level [1]. Conventional boost converter has a disadvantage of the voltage stress across the switches is equal to output voltage which cause switching loss and decrease the efficiency [2]. The CIBC is a solution of this problem that provides a high voltage gain with low losses and less stress of switches [3]. IBC has more advantages over conventional boost converter, such as remarkable reduction in output voltage ripple and input current ripple, higher power density, higher current density, improved efficiency, reduced EMI and faster response [1]. A maximum

power point tracking (MPPT) extracts maximum power from the solar panel at the

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weather conditions changes such as irradiation and temperature. [5] It provides the switches with designated pulses to operate at the required duty cycle. This paper proposes the design of a high efficiency twostages CIBCs for maximum power extraction from a PV system. Fig. 1 shows the block diagram of the proposed system. The output voltage from the PV panel is (52 V) and the output load voltage is (520 V). The switches of both converters are controlled by MPPT control to assure maximum power is extracted from the solar system into the load.

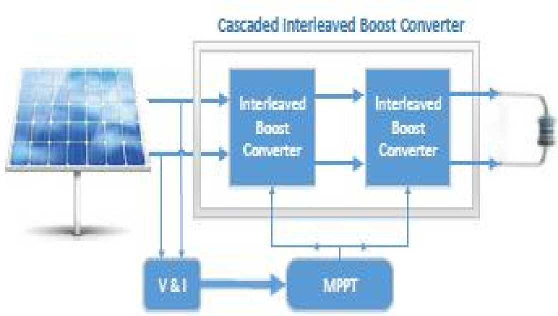

Fig. 1. The block diagram of proposed system.

II. SYSTEM MODELING

A. Interleaved Boost Converter IBC, as displayed in Fig. 2, is a boost converter with two switches (MOSFETs) and two inductors connected in parallel to divide the input current among the inductors which improves the reliability and efficiency with smaller size of filter component and less ripple voltage and current over conventional boost converter [4]. IBC components are considered as below [5].

$$V_o = \frac{V_s}{1-D} \quad (1)$$

$$I_s = \frac{P_s}{V_s} \quad (2)$$

$$\Delta I_L = \frac{V_s D}{f_s L} \quad (3)$$

$$L = \frac{V_s D}{f_s \Delta I_L} \quad (4)$$

$$C = \frac{V_o D}{\Delta V_o R f_s} \quad (5)$$

Here, Vs and Vo are the input and output voltages, Is and Ps are input current and input power, D is the duty ratio, _IL is the inductor current ripple, _Vo is the output voltage ripple, fs is switching frequency, L is the inductance, C is the capacitance, and R is the resistance. The gate pulses is (360_=2 = 180_).

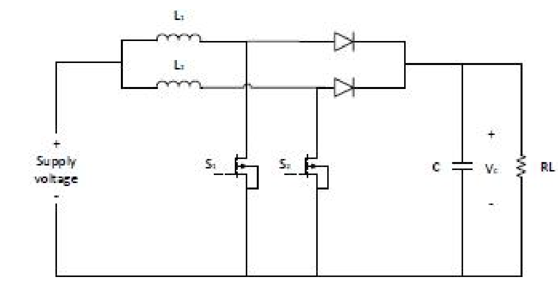

Fig. 2. Interleaved boost converter.

B. Two-stage Cascaded Interleaved Boost Converter

CIBCs are two IBCs connected in series as shown in Fig. 3. The first-stage IBC steps-up the PV output voltage which becomes the input voltage of the second-stage IBC that boosts this voltage into the high voltage gain.

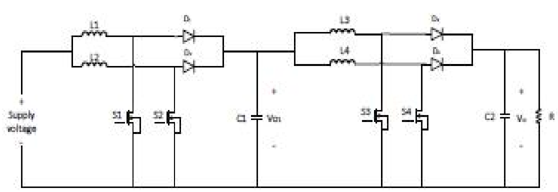

Fig. 3. Two-stage cascaded interleaved boost converter.

C. CIBC Modeling

The proposed circuit is identified in two cases for the operation of each stage of CIBC [6]. Mode 1: S1; S3 are ON, S2; S4 are OFF, D1;D3 are OFF, D2;D4 are ON (Fig. 4). Inductor currents and capacitor

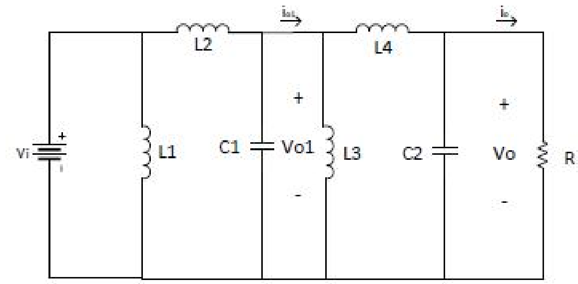

Fig. 4. Equivalent circuit for mode 1.

voltages can be written as [7] [8]:

$$\frac{di_{L_1}}{dt} = \frac{1}{L_1}V_i \tag{6}$$

$$\frac{di_{L_2}}{dt} = \frac{1}{L_2}(V_i - V_{o_1}) \tag{7}$$

$$\frac{di_{L_3}}{dt} = \frac{1}{L_3}V_{o_1} \tag{8}$$

$$\frac{di_{L_4}}{dt} = \frac{1}{L_4}(V_i - V_o) \tag{9}$$

$$\frac{dv_{o1}}{dt} = \frac{1}{C_1}(i_{L_2} - i_{o1}) \tag{10}$$

$$\frac{dv_o}{dt} = \frac{1}{C_2}(i_{L_4} - i_o) \tag{11}$$

Mode 2: S1; S3 are OFF, S2; S4 are ON, D1;D3 are ON, D2;D4 are OFF (Fig. 5). Inductor currents and capacitor

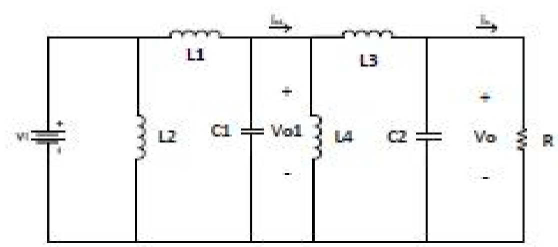

Fig. 5. Equivalent circuit for mode 2.

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$$\frac{di_{L_1}}{dt} = \frac{1}{L_1}(V_i - V_{o_1}) \quad (12)$$
$$\frac{di_{L_2}}{dt} = \frac{1}{L_2}V_i \quad (13)$$
$$\frac{di_{L_3}}{dt} = \frac{1}{L_3}(V_i - V_o) \quad (14)$$
$$\frac{di_{L_4}}{dt} = \frac{1}{L_4}V_{o_1} \quad (15)$$
$$\frac{dv_{o_1}}{dt} = \frac{1}{C_1}(i_{L_1} - i_{o_1}) \quad (16)$$
$$\frac{dv_o}{dt} = \frac{1}{C_2}(i_{L_3} - i_o) \quad (17)$$

D. PV Panel

The simplified circuit of solar PV cell is shown in Fig. 6. The solar cell output current is defined by: [9] [10]

$$I = I_{ph} - I_D - I_{sh} \quad (18)$$
$$I = I_{ph} - I_o[exp(q(V + I_{rs})/K_T) - 1] - (\frac{V + I_{rs}}{R_{sh}}) \quad (19)$$

Where, Iph is photo current, ID is diode current, Io is diode saturation current, q is electron charge (1:6 _ 10 19);K is Boltzmann constant (1:38 _ 10 23); Irs is reverse saturation

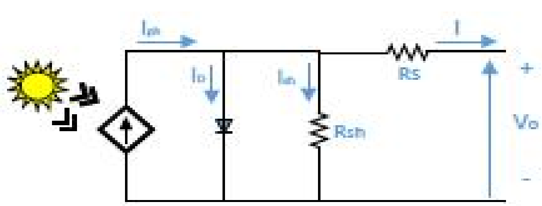

Fig. 6. Equivalent circuit of solar PV cell.

current, V is solar cell voltage, Isc is cell current, Rs and Rsh are series and shunt resistances, and T is temperature. The specification of solar panel is listed in Table I.

TABLE I
PARAMETERS VALUES OF SOLAR PANEL

Parameters	Values
Maximum Power, P_m	350.226 W
Open circuit voltage, V_oc	64.2 V
Voltage at P_m, V_mp	54.7 V
Short circuit current, I_sc	5.96 A
Current at P_m, I_mp	5.58 A

A control technique is required to harvest the peak power from the solar panels.

E. Maximum Power Point Tracking

MPPT is a control technique to adjust the terminal voltage of PV panel to harvest the highest available power and to maintain operation at this point by using MPPT algorithm. Perturband- Observe (P& O) method is used for MPPT because of its simplicity [11]. It depends on the calculation of PV power and voltage by observing the PV voltage and current. The pulses generated by MPPT control provided into the switches is shown in Fig. 7.

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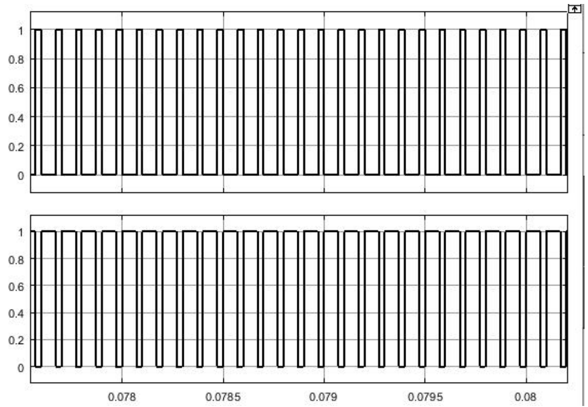

Fig. 7. Waveform of PWM generated by MPPT control.

III. SIMULATION RESULTS

The proposed design is developed by using MATLAB/ SIMULINK as shown in Fig. 8. The parameters used for the simulation are shown in Table II. In this model, the output voltage of the PV system is (52 V), which is the input voltage of the first-stage IBC that boosts it into (160 V) to the second-stage IBC to gain the output voltage (520 V). A MPPT controller is designed to generate control signal for switches in the first-stage IBC to ensure maximum power is delivered into the load. The output voltages of first stage and second-stage is shown in Fig. 9. Fig.10. shows the system output voltage and current of the first-stage IBC. Fig. 11. is the inductor current of firststage IBC, and the second-stage IBC. Fig. 12. displays the PV source voltage, first-stage IBC output voltage, and system output voltage. Fig. 13. compares input current with first-stage IBC output current and load current.

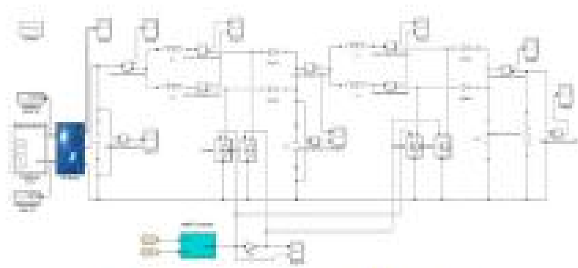

Fig. 8. The simulation model of CIBC fed by PV system.

TABLE II
PARAMETERS VALUES OF COMPONENTS

Parameters	Values
Input Voltage, V_i	52 V
Input Capacitance, C_i	150 μ F
First-stage inductors, L_1, L_2	560 μ H
First-stage capacitor, C_1	100 μ F
Second-stage inductors, L_3, L_4	860 μ H
Second-stage capacitor, C_2	100 μ F
Resistance load, R	100 Ω
Output Voltage, V_o	520 V

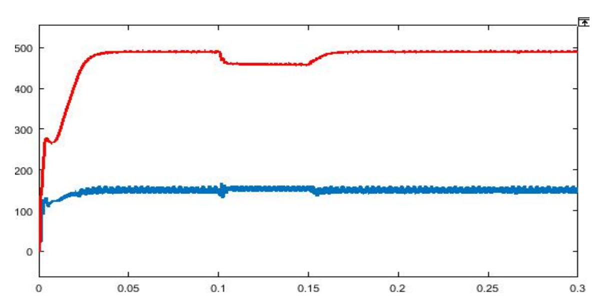

Fig. 9. Output voltages.

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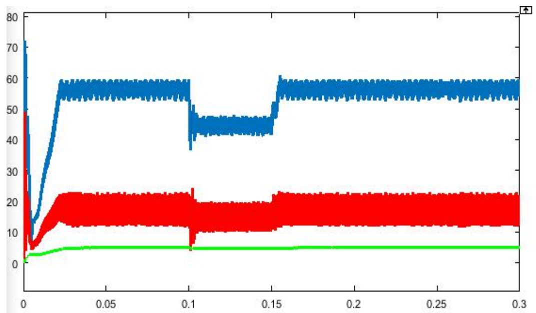

Fig. 13. System input current, first-stage output current, and load current.

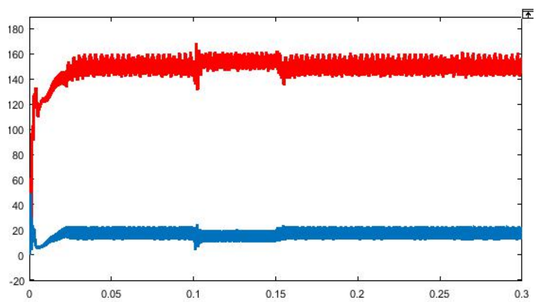

Fig. 10. First-stage IBC output current and voltage.

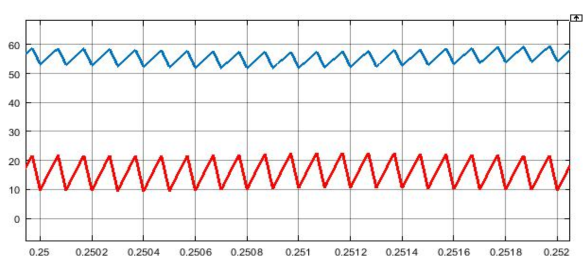

Fig. 11. Inductors current.

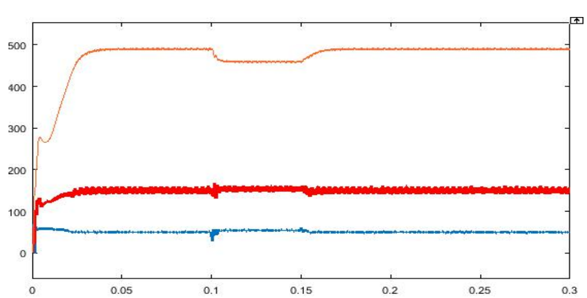

Fig. 12. First-stage input voltage, second-stage input voltage, and load voltage.

IV. CONCLUSION

In this paper, a topology of two-stage cascaded interleaved boost converters with high voltage gain is presented. The proposed system along with required power electronics and MPPT control were designed, and simulated. Two-stage cascaded interleaved boost converters can be used to extract the maximum power from PV for high voltage applications with small current ripple and improved efficiency.

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