Optimized interleaved boost converter with high step up voltage gain for photovoltaic applications

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Photovoltaic system is considered as the targeted solution for recent energy crises. Since this system is recyclable and has a long lifetime, it is distributed throughout the earth and mainly they are pollution free. To transmit power from PV to load, high efficiency interface is essential. In this paper, we proposed a high step-up interleaved boost converter with two stage switched-capacitor and coupled-inductor. MPPT controller also used to increase the efficiency of photovoltaic power generation system. This method produces a high step up voltage gain with reduced duty ratio, compared to other techniques the voltage stress on the switch is greatly reduced, which also reduces the ripples and the conduction loss. Two-stage switched-capacitors not only extend the voltage gain, but also effectively use the coupled inductor. The passive clamp circuit makes main switches to turn off under zero voltage switching and the zero current switching is turned on due to inductor inherent leakage. Since the current falling rate is controlled by leakage inductance, diode reverse recovery problem is alleviated and efficiency is improved.

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1. Introduction

Nowadays, with global energy shortage, renewable energy resources have turned the attention of many researchers. Among renewable energy technologies Photo-Voltaic (PV) system is one of the most widely used technique. Generally in PV power generation system two main problems occur, that is power generation varies with weather condition and its low conversion efficiency. A DC to DC high step up converter is very essential to overcome the inherent low voltage characteristic. These converters were widely used in many applications such as automobile head lamps as a high–intensity discharge lamp, Uninterruptible Power System (UPS) and also for the communication power system. Conventional converter has been used to provide high step up gain, but it has a drawback of high voltage stress on the switches, which makes high performance low voltage devices unsuitable. If the duty ratio approaches unity, the overall efficiency gets degraded, so the conventional converters like boost and buck-boost converters can't satisfy the application needs [1-3].

To produce high step up voltage gain many topologies have been presented with a minimum duty ratio [4]. With simple structure DC-DC fly back converter generates a high voltage gain. Due to leakage inductance of transformer there is a high voltage stress on the active switches, and the voltage stress on the active switches can be clamped using few Energy-Regeneration techniques [5-6]. By increasing the turns of the transformer, the existing isolated voltage-type converter like phase-shifted full-bridge converter, able to produce high step-up gain, but more electrolytic capacitors are essential to reduce the input current ripples. Other isolated converters like active-clamp dual boost and active-clamp full bridge boost converter can achieve high efficiency and high step up conversion [7-8]. To improve conversion efficiency switched capacitor based converter was proposed to achieve a large voltage conversion ratio [9-11]. But this technique produces high transient current and large conduction loss in the switch, and also to obtain extremely high step up conversion more switched capacitor cells are needed, which makes the circuit complex [12]. Based on switched-capacitor cell concepts many topologies were presented to reduce the electromagnetic interference and switching loss by using soft-switching schemes [13]. The coupled-inductor technique is an another solution to achieve high step-up gain by adjusting the turn ratio [14]. The parasitic capacitor and the leakage inductance of the coupled-inductor will resonate together, and to absorb voltage ringing on the output diode, proper snub circuit is used. Both cost and complexity of the circuit gets increased by using two active switches with additional protection circuit.

For universal power factor correction interleaved voltage doubler circuit was proposed with automatic current sharing capability and to increase low-line efficiency lower active switch stress is used. However the diode stress remains very high and the voltage gain is not high enough. High step up ratio converter and ultra step-up converter has proposed to provide large step-up voltage ratios, but the diode voltage stress remains high [15-16]. A Low conversion efficiency and its dynamic weather condition are the major problem in the PV power generation system. To increase the efficiency of PV system, it should be operated at maximum power point at any time. To overcome this many MPPT algorithms was proposed [17-18]. In this paper, modified two-phase interleaved boost converter is cascaded together, which has an advantage of the automatic current sharing capability simultaneously. This proposed technique greatly reduces the voltage stress of switches and diodes which greatly enhance the overall efficiency.

2. MPPT

Maximum power point tracking is a technique used to achieve maximum power from photovoltaic devices. MPPT works under various algorithms. The ability of this algorithm is to detect the output which is the most important factor to be considered in choosing MPPT technique [19]. At different points irradiance levels on the solar panel surface varies. Due to this variation in one system, there may be multiple local maximum power points. There are several publications that deals with MPPT, but each technique has its own drawbacks.

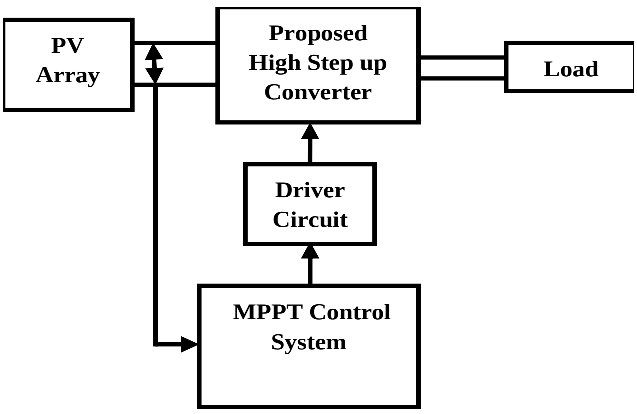


Fig. 1. MPPT Control system.

In this paper fuzzy logic control is used for maximum power point tracking. Neither integral nor proportional control loop exists in this system and the control signal is generated by fuzzy logic controller. By comparing other artificial intelligence control methods like neural network and genetic algorithm, this method proven to be fast and robust. Without steady state oscillation this system accurately tracks the maximum power point even under rapidly changing atmospheric condition [20-21]. While using neural network it has to be trained periodically to guarantee accurate MPPs, because the PV array characteristics changes with time, to overcome these drawbacks incremental conductance is a right solution. Independent of PV characteristic tracks the true MPPs. This MPPT method along with our proposed converter can yield efficiency more than 95%. The MPPT controller together with our proposed converter is connected between the load and the PV panel as shown in Fig. 1. In this method voltage or current controls the proposed converter at the MPP, which makes PV to deliver the maximum power to the load.

3. Proposed High step up converter

The converter proposed in this paper can also be called as an optimized two phase interleaved boost converter. This proposed converter is integrated with MPPT controller for high step-up conversion as shown in Fig. 2.

The interleaved boost converter is added with two capacitors and two diodes. During the period of energy transfer the stored energy in partial inductor is stored in one of the capacitors together with the stored energy of other capacitor is moved to the output to gain higher voltage. When compared with interleaved two phase boost converter, the proposed converter will achieve twice the voltage gain, and both active switches and diodes produce only less voltage stress. Since this proposed converter is integrated with MPPT controller, it automatically tracks for the maximum MPP and produce higher conversion ratios. Our main objective of this converter is to achieve high voltage gain and steady state analysis is made for duty cycle more than 0.5 and when it operates in continuous conduction mode. In discontinuous conduction mode and when the duty ratio less than 0.5, there is no sufficient energy transfer between the inductor, blocking capacitor, capacitor at the output side and load side , hence in this mode achieving high voltage gain is not possible. In addition, automatic current sharing characteristic is featured when there is a duty ratio greater than 0.5 and due to the blocking capacitor charge balance. The automatic current sharing capability is not possible under the condition when the duty ratio is less than 0.5.

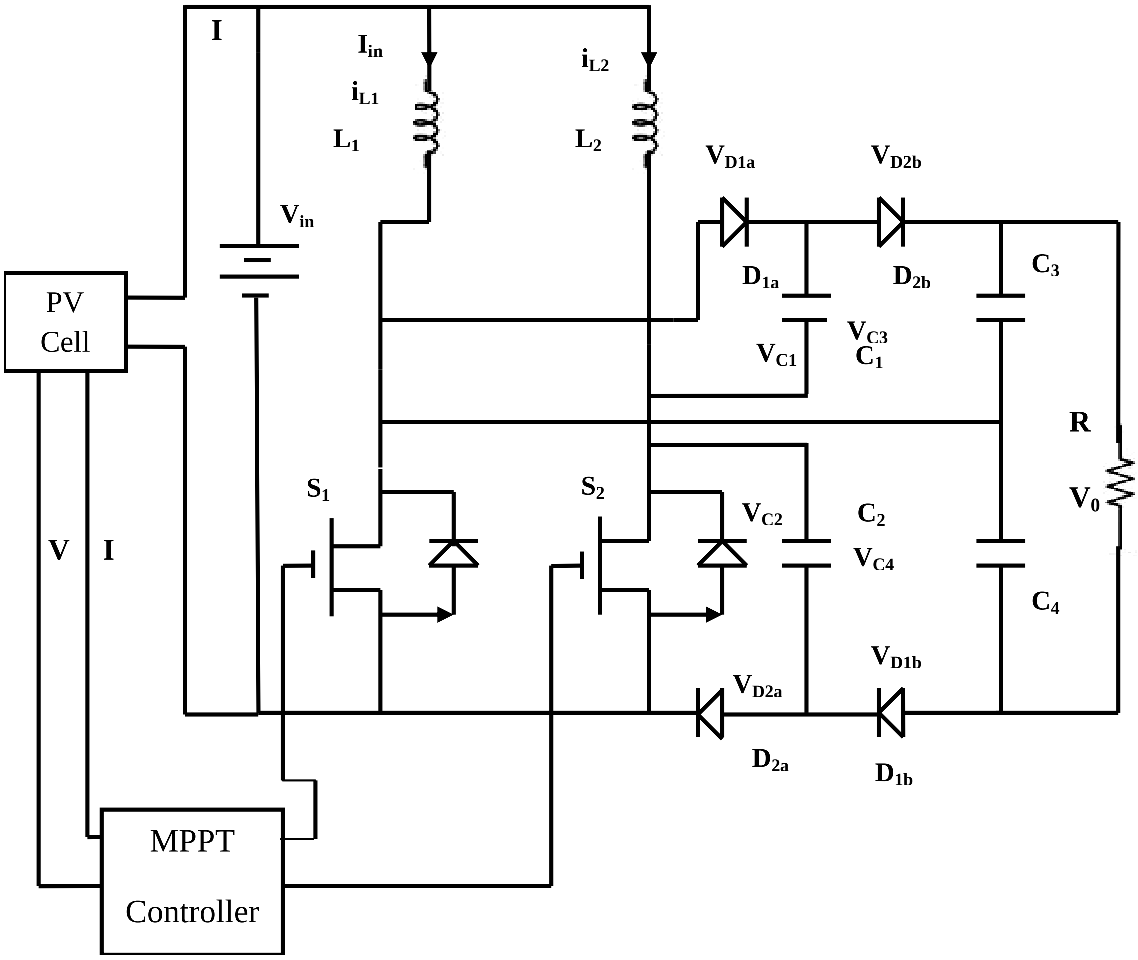


Fig. 2. Proposed Converter Integrated with MPPT controller.

4. Modes of operations

4.1 Mode 1

In this mode when $t_0 \leq t < t_1$, S1 and S2 switches are turned ON, where D_{1a},D_{1b},D_{2a},D_{2b} are turned OFF. To store energy in L_1 and L_2, both i_{L1} and i_{L2} gets increased. Diodes D_{1a} and D_{2a} voltages are clamped to V_{C1} and V_{C2} of capacitor voltage respectively, and diodes D_{1b} and D_{2b} voltages are clamped to (V_{C4} –V_{C2}) and (V_{C3}-V_{C1}). From capacitors C_3 and C_4 load power is supplied and its corresponding equation is shown below.

$$L_1 \frac{di_{L_1}}{dt} = V_{in} \quad (1)$$

$$L_2 \frac{di_{L_2}}{dt} = V_{in} \quad (2)$$

$$C_1 \frac{dv_{C_1}}{dt} = 0 \quad (3)$$

$$C_2 \frac{dv_{C_2}}{dt} = 0 \quad (4)$$

$$C_3 \frac{dv_{C_3}}{dt} = -\frac{(v_{C_3}+v_{C_4})}{R} \quad (5)$$

$$C_4 \frac{dv_{C_4}}{dt} = -\frac{(v_{C_3}+v_{C_4})}{R} \quad (6)$$

4.2 Mode 2

In this mode when $t_1 \leq t < t_2$, switch S_2 is turned OFF, while switch S_1, diodes D_{2a} and D_{2b} remains conducting. And the C_1 stored energy and inductor L_2 stored energy is released to load and to the C_3 of the output capacitor, while the part of inductor L_2 stored energy is stored in C_2. The Capacitor voltage of this mode V_{C3}=V_{C2}+V_{C1}, this makes i_{L2} to decrease linearly and i_{L1} to increase continuously. The equation corresponding to this is shown below.

$$L_1 \frac{di_{L_1}}{dt} = V_{in} \quad (7)$$

$$L_2 \frac{di_{L_2}}{dt} = V_{in} + v_{C_1} - v_{C_3} = V_{in} - v_{C_2} \quad (8)$$

$$C_1 \frac{dv_{C_1}}{dt} = i_{C_2} - i_{L_2} \quad (9)$$

$$C_2 \frac{dv_{C_2}}{dt} = i_{C_1} + i_{L_2} \quad (10)$$

$$C_3 \frac{dv_{C_3}}{dt} = -i_{C_1} - \frac{(v_{C_3}+v_{C_4})}{R} \quad (11)$$

$$C_4 \frac{dv_{C_4}}{dt} = -\frac{(v_{C_3}+v_{C_4})}{R} \quad (12)$$

4.3 Mode 3

In this mode when $t_2 \leq t < t_3$, both S_1 and S_2 are turned ON, other operations are same as that of mode 2.

4.4 Mode 4

When $t_3 \leq t < t_4$, Switch S_2 remains conducting in this mode of operation and switch S_1 is turned OFF.

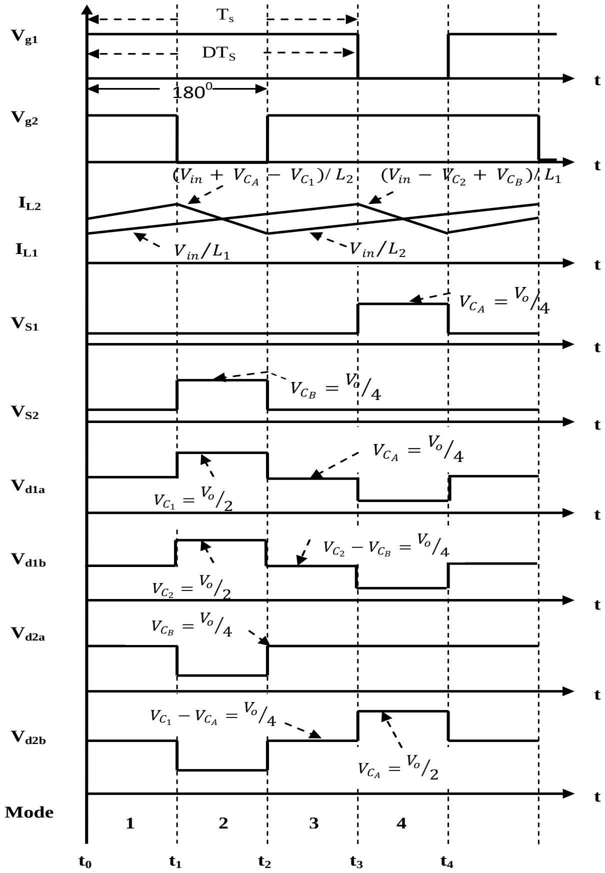


Fig. 3. Proposed converter operating at CCM.

Diode D_{1a} and D_{1b} also conducting. Then the energy stored in inductor L_1 and the energy stored in C_2 is released to load and to the C_4 of the output capacitor, while the output capacitor $V_{C4}=V_{C2}+V_{C1}$. This makes i_{L1} to decrease linearly and i_{L2} remains increasing continuously.

$$L_1 \frac{di_{L_1}}{dt} = V_{in} - v_{C_4} + v_{C_2} = V_{in} - v_{C_1} \tag{13}$$

$$L_2 \frac{di_{L_2}}{dt} = V_{in} \tag{14}$$

$$C_1 \frac{dv_{C_1}}{dt} = i_{C_2} + i_{L_1} \tag{15}$$

$$C_2 \frac{dv_{C_2}}{dt} = i_{C_1} - i_{L_1} \tag{16}$$

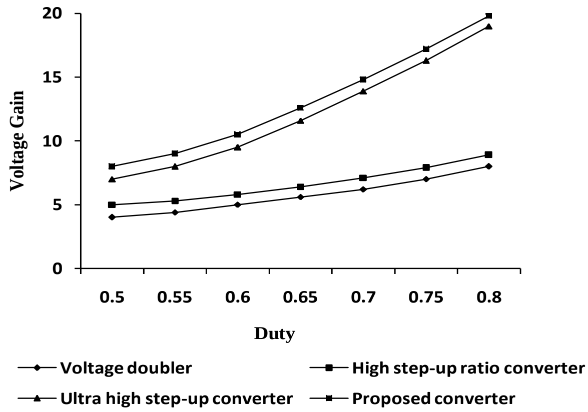
$$C_3 \frac{dv_{C_3}}{dt} = -\frac{(v_{C_3}+v_{C_4})}{R} \tag{17}$$

$$C_4 \frac{dv_{C_4}}{dt} = -i_{C_2} - \frac{(v_{C_3}+v_{C_4})}{R} \tag{18}$$

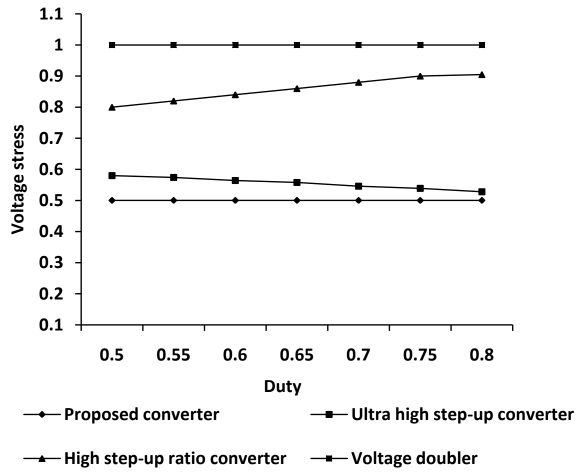
The operations of the proposed converter are symmetric and easy to implement. From the key operating waveforms as shown in Fig. 4, it is clear that four diodes and two active switches attain low voltage stress with uniform current sharing.

5. Performance evaluation

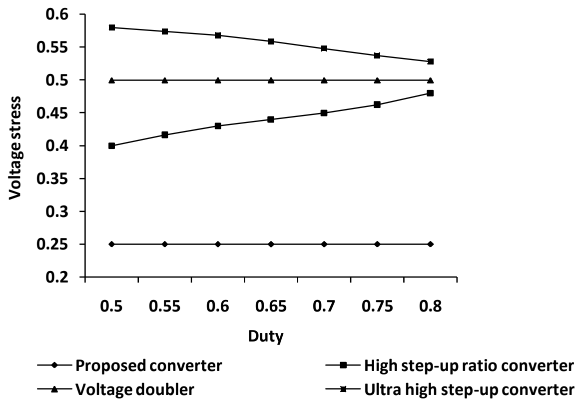
For evaluating the proposed converter performance, it is compared with the other existing high step up converters. The proposed converter characteristic curve and the comparison of the voltage gains normalized voltage stress, normalized switch and normalized diode stress of the conventional existing converters also shown in Fig. 4.



(a) Voltage gain.



(b) Diodes normalized voltage stress.



(c) Active Switches Normalized Voltage Stress

Fig. 4. Steady state characteristics comparison.

When compared with the other existing boost converters, the Converter proposed can attain higher voltage gain as shown in Fig. 4(a), lower voltage stress for diodes as shown in Fig. 4(b) and lower voltage stress on switches as shown in Fig. 4(c). For the application required more voltage gain, this proposed converter is more suitable and can attain higher efficiency by adopting lower voltage rating on the switching components.

6. Result

The performances of the proposed converter with MPPT controller for PV system are discussed in this section.

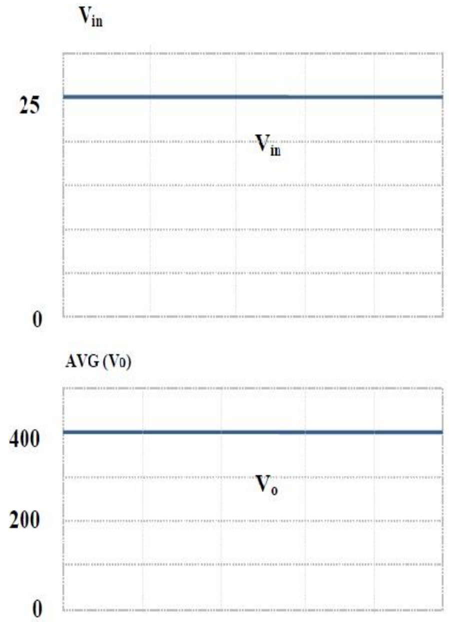


Fig. 5. Input and output Voltage.

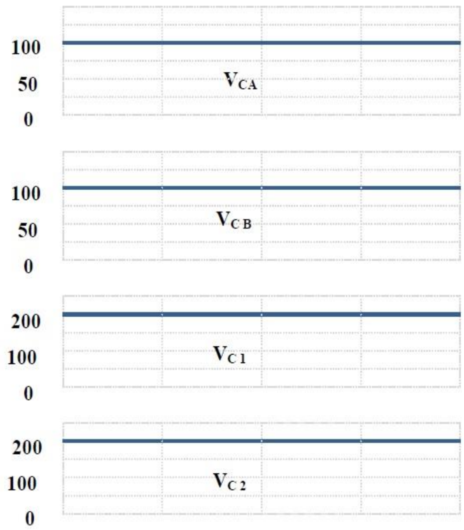


Fig. 6. Results obtained for blocking capacitor & Output capacitor.

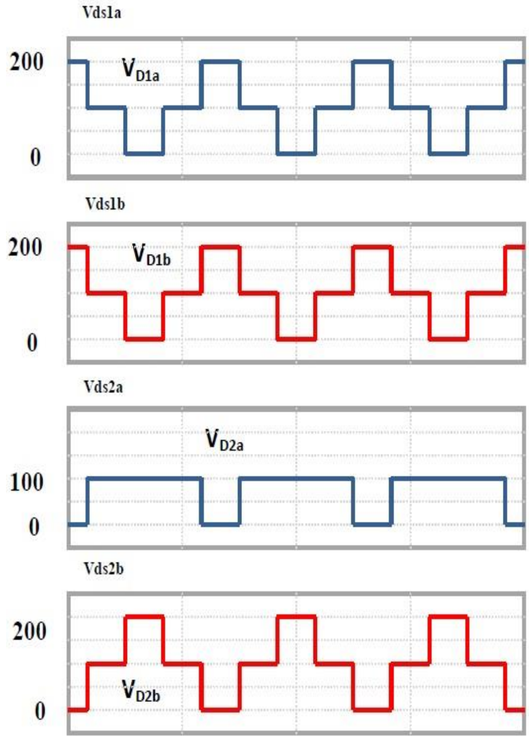


Fig. 7. Voltage stress on VDS1, VDS2, VC1& VC2 capacitor.

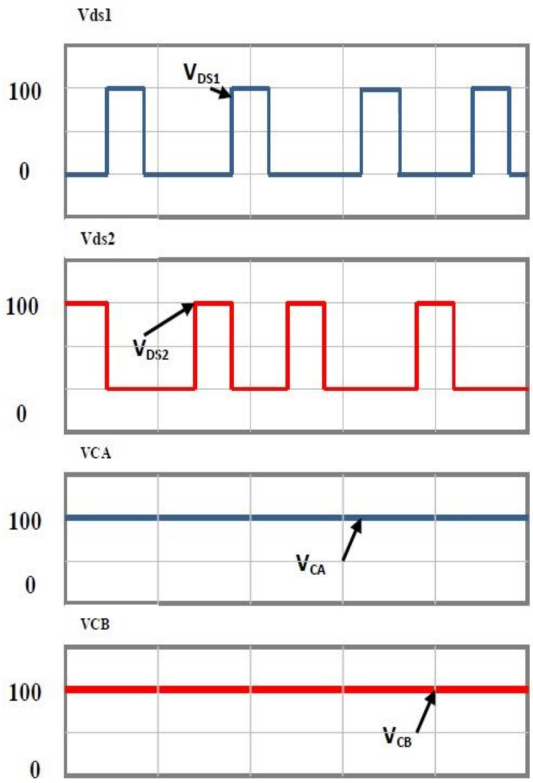


Fig. 8. Voltage stress on VD1a, VD1b, VD2a & VD2b capacitor.

The input 25V and output 400V with 400W rating is constructed using the proposed converter. Both switch S1 and S2 has the equal duty ratio of 0.75 with switching frequency 40HZ. The interleaved construction can reduce the input ripples, output ripples and the size of inductors by increasing the switching frequency. Fig. 5 shows the input voltage and the corresponding output voltage of our proposed method. And in Fig. 6. The blocking capacitor waveform and output capacitor waveform are shown. The active switch voltage stress is $1/4^{th}$ of the voltage output as shown in Fig. 7. The voltage crosses diodes V_{D1a}, V_{D1b} and V_{D2b} equals $1/2^{th}$ of voltage output as shown in Fig. 8. Power loss distribution is analyzed and came to the conclusion that from the switches, diodes and from the inductors major losses are occurring. In this paper, we proposed a converter to reduce the voltage stress on switches and diodes, which effectively reduces the major losses. This proposed converter along with the MPPT controller can achieve maximum efficiency of more than 96% as shown in Fig. 9. From the PV array we can obtain maximum power using MPPT controller. This MPPT controller can effectively track the maximum power point from the PV array. Our proposed converter with an MPPT controller can generate 2.4 times of more PV power when compared with the converter without using MPPT algorithm. The result shows that our proposed converter with MPPT controller is proven to be effective and can generate maximum power from the PV system.

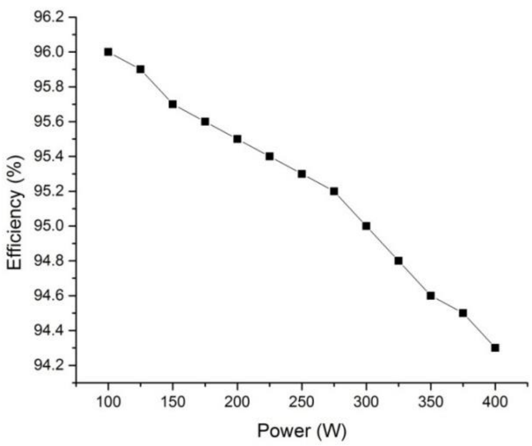


Fig. 9. Proposed Converter Efficiency.

7. Conclusion

In this paper, we analyzed a converter with MPPT controller for PV systems. The MPPT algorithm is developed for extracting maximum power from the PV array. Our proposed converter is designed from the existing two phase interleaved boost converter. It not only achieves high voltage gain, it achieves it with the reduced duty cycle. This leads the way to reduce both conduction and switching loss by choosing MOSFETs and diodes of lower voltage rating. The converter also features the uniform automatic current sharing capabilities without adding any additional circuit. While comparing with other conventional converter, our proposed converter along with MPPT controller provides better conversion efficiency. The proposed converter is validated by using the rating of 400W, 25V input and 400V output. The result shows that for high step up voltage gain applications, this method proven to be very effective.

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