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High Boost Ratio Hybrid Transformer DC-DC Converter for PV Grid Applications

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Abstract: ***Attempts were made by scientists for utilizing solar power. Solar drives, solar water heater, solar concentrators are some examples. Recently because of energy shortage green gas effect, attention was given for generating electric power from solar power. This paper proposes a non isolated, high boost ratio hybrid transformer dc-dc converter with applications for low voltage renewable energy sources. The proposed converter utilizes a hybrid transformer to transfer the inductive and capacitive energy simultaneously, achieving a high boost ratio with a smaller sized magnetic component. the turn-off loss of the switch is reduced, increasing the efficiency of the converter under all load conditions. The voltage stresses on the active switch and diodes are maintained at a low level and are independent of the changing input voltage over a wide range as a result of the resonant capacitor transferring energy to the output of the converter.***

Keywords: High boost ratio dc-dc, high efficiency, hybrid transformer, photovoltaic (PV) module.

1. Introduction

Due to the rising costs and limited amount of nonrenewable energy sources, there is an increasing demand for the utilization of renewable energy sources such as photovoltaic (PV) modules. Integrating the power from the PV module into the existing power distribution infrastructure can be achieved through power conditioning systems (PCS).

Typical PCS can be accomplished using a single-stage or a double-stage as shown in Fig. 1

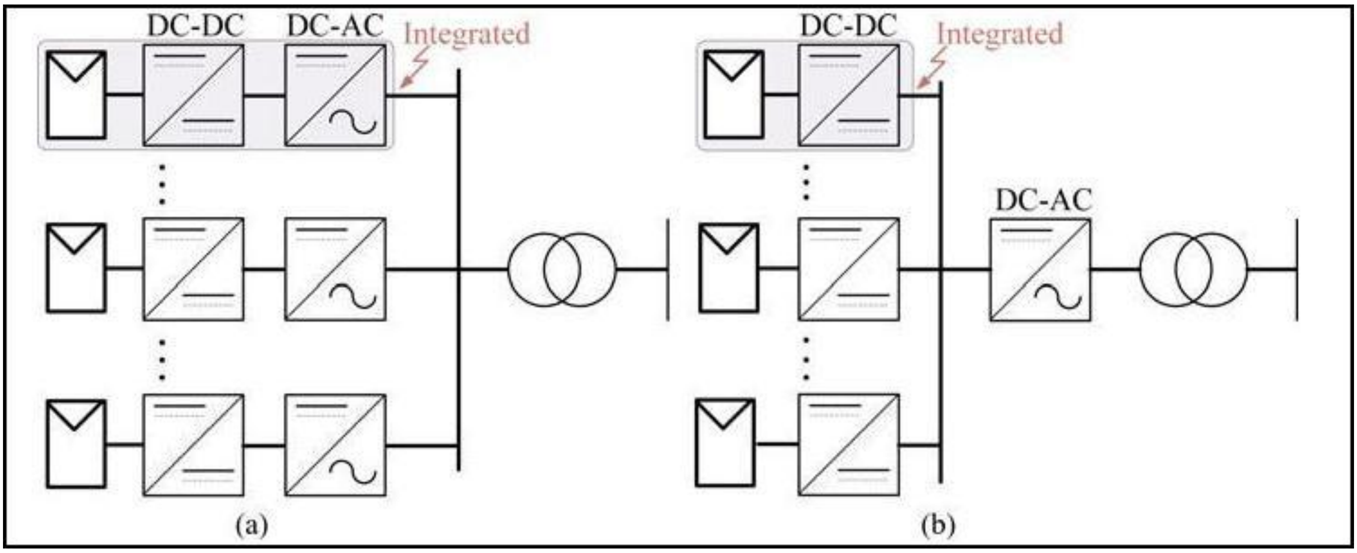

Figure 1: (a) Two-state PV module integrated microinverter. (b) Parallal PVmodule integrated microconverter with centralized inverter

The double-stage PCS consists of a dc-dc conversion stage that is connected to either a low power individual inverter or a high-power centralized inverter that multiple converters could connect to. The dc-dc conversion stage of the PCS requires a high efficiency, high boost ratio dc-dc converter to increase the low dc input voltage from the PV panel to a higher dc voltage.

The high boost ratio dc-dc converter for such systems can be isolated or nonisolated [1]; however, transformer-isolated converters tend to be less efficient and more expensive due to the increased manufacturing costs. For low-input voltage energy sources, it is possible to float the source such that the converter circuit does not require isolation between the input and output. The transformer-isolated circuits tend to be less efficient and more expensive. Another important function of the dcdc converter for PV applications is being able to implement maximum power point tracking (MPPT).

The ability to implement MPPT for an individual PV panel would ensure that a large cluster of PVcould maintain maximum power output from each panel without interfering with the other panels in the system. The major consideration for the main power stage of the converter in being able to implement an accurate MPPT is that the input current ripple of the converter has to be low.

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2. High Boost DC-DC Converter

Of the many high boost ratio dc dc converter topologies, a combination of flyback and boost converters was proposed to increase the boost ratio without significant cost and efficiency penalties [9], [10]. As shown in Figure 2, the output voltage is the sum of a flyback converter, which consists of L1=L2, D1, and C1, and a boost converter, which consists of L1, M1, D2, and C2. Since the flyback output is nD=(1- D) and boost output is 1=(1-D), the total output voltage is (1 + nD)/(1- D). Here, n is the turns ratio between the secondary and primary, and D is the switch duty cycle. When the switch M1 is turned on, the energy is stored inL1, andwhen M1 is turned off, the energy is released to charge both C1 and C2 through diodes D1 and D2. The problem is when M1 turns on these diodes need to be turned off, and a parasitic capacitance across D1 and the leakage inductance can cause severe ringing and additional voltage stress on D1.

In [11] and [12], a circuit is proposed to add a capacitor between two windings, or x and y, and a diode is added between boost output and secondary of the flyback winding to circulate the energy, as shown in Figure 3. The added capacitor, C1, stores the energy when the switch M1 is turned on and maintains a constant voltage related to the turns ratio n, duty cycle D, and input voltage Vin. During switchoff state during which D1 and D3 conduct, C1 energy is

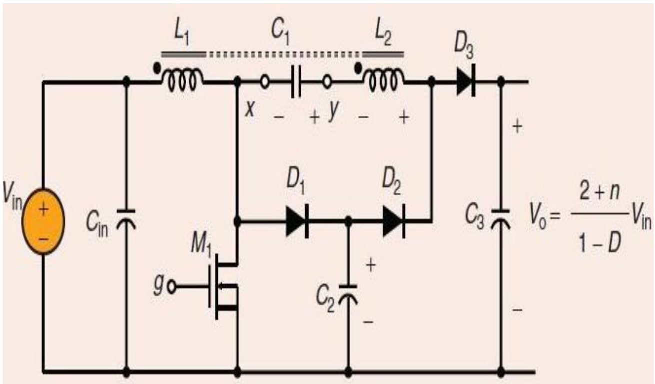

Figure 2: A high boost ratio dcdc converter circuit derived from cascading a flyback converter and a boost converter

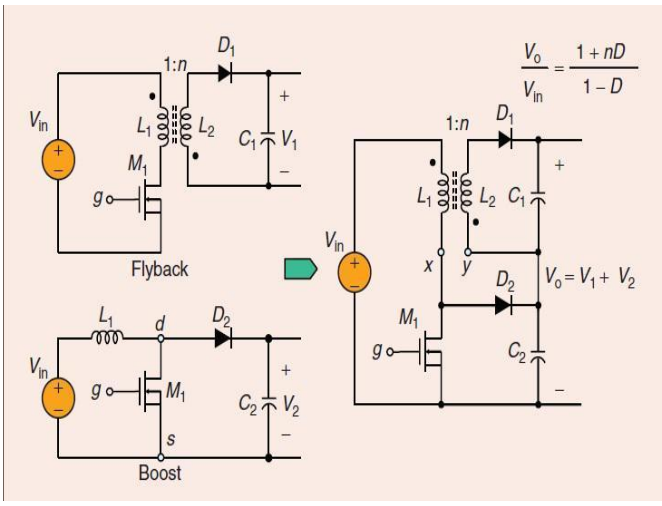

Figure 3: A high boost ratio dc-dc converter using capacitor coupling

released to output, and the output voltage equals the sum of the two capacitor voltage and the secondary winding voltage. If the leakage inductance is negligible, then the output voltage equals (2+ n)Vin/(1- D). Compared with the version with combination of flyback and boost converters, this circuit allows a higher-voltage boost ratio, and thus the turns ratio or duty cycle can be reduced for the same output voltage. However, the magnetic core was not fully utilized because it functioned more as an inductor than as a transformer. Light load efficiency of the converter is also reduced because switching losses were more dominant under light load conditions.

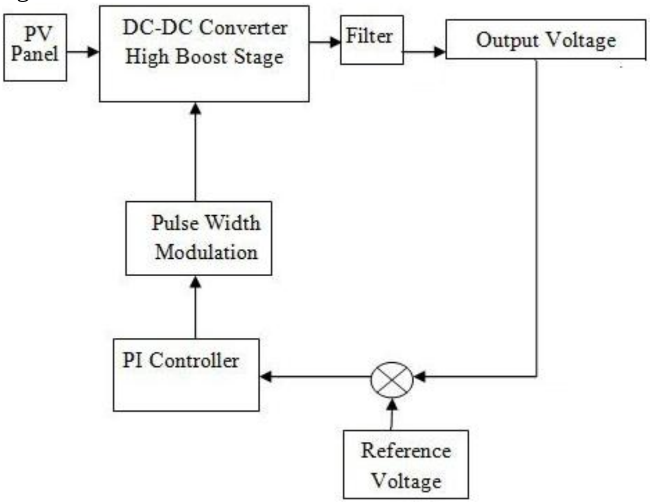

Figure 4: Block diagram of proposed converter

For PV module converter, the high efficiency over a wide load range and input voltage range is extremely important. In this paper, a high boost ratio dcdc converter with hybrid transformer is presented to achieve high system level efficiency over wide input voltage and output power ranges. By adding a small resonant inductor and reducing the capacitance of the switched-capacitor in the energy transfer path, a hybrid operation mode can be achieved. The inductive and capacitive energy can be transferred simultaneously to the high voltage dc bus increasing the total power delivered decreasing the losses in the circuit. Block diagram of the proposed converter is shown in figure 4. Output voltage is compared with a reference voltage to turn on the switch so as to keep the output voltage constant.

A. Proposed Converter Topology and Operation Analysis

Fig. 4 shows the circuit diagram of the proposed converter. C_{in} is the input capacitor; HT is the hybrid transformer with the turns ratio 1:n; S1 is the active MOSFET switch; D1 is the clamping diode, which provides a current path for the leakage inductance of the hybrid transformer when S1 is OFF, Cc captures the leakage energy from the hybrid transformer and transfers it to the resonant capacitor Cr by means of a resonant circuit composed of Cc , Cr , Lr , and Dr ; Lr is a resonant inductor, which operates in the resonant mode; and Dr is a diode used to provide an unidirectional current flow path for the operation of the resonant portion of the circuit. Cr is a resonant capacitor, which operates in the hybrid mode by having a resonant charge and linear discharge. The turnon of Dr is determined by the state of the active switch S1. Do is the output diode similar to the

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traditional coupledinductor boost converter and Co is the output capacitor. Ro is the equivalent resistive load.

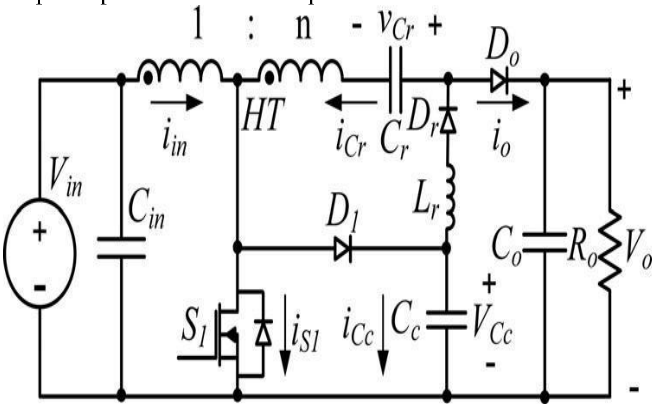

Figure 5: Proposed high step-up dcdc converter with hybrid transformer

Fig. 4 illustrates the five steady-state topology stages of the proposed dcdc converter for one switching cycle. The five operation modes are briefly described as follows:

[t0 ,t1], [see Fig. 5(a)]: In this period, MOSFET S1 is ON, the magnetizing inductor of the hybrid transformer is charged by input voltage, Cr is charged by Cc , and the secondary reflected input voltage nVin of the hybrid transformer together by the resonant circuit composed of secondary side of the hybrid transformer, Cr , Cc , Lr , and Dr . The current in MOSFET S1 is the sum of the resonant current and linear magnetizing inductor current. [t1 ,t2], [see Fig. 5(b)]: At time t1 , MOSFET S1 is turned OFF, the clamping diode D1 is turned ON by the leakage energy stored in the hybrid transformer during the time period that the MOSFET is ON and the capacitor Cc is charged which causes the voltage on the MOSFET to be clamped.

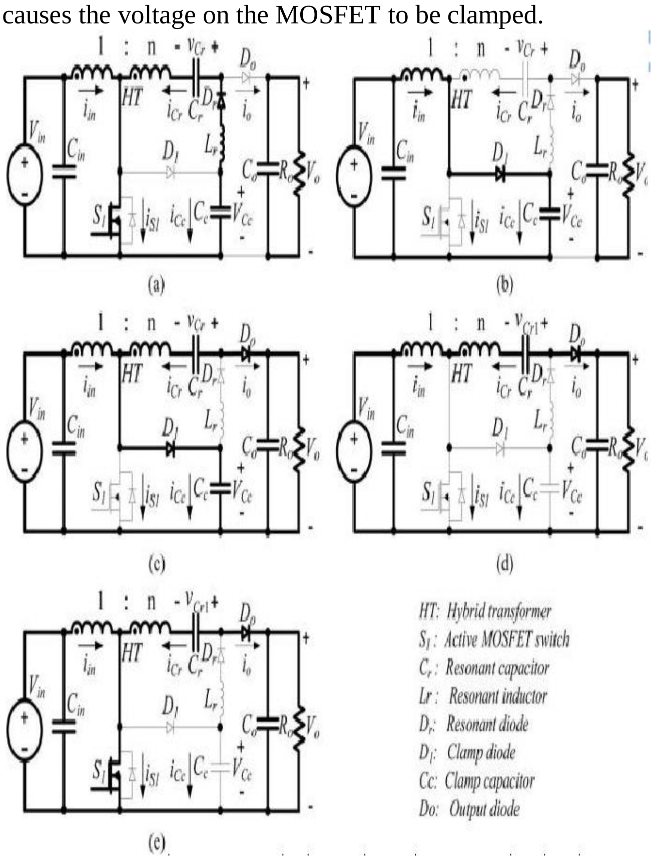

Figure 6: Operation modes of the high boost ratio dcdc converter with hybrid transformer

[t2 ,t3], [see Fig. 5(c)]: At time t2 , the capacitor Cc is charged to the point that the output diode Do is forwarded biased. The energy stored in the magnetizing inductor and capacitor Cr is being transferred to the load and the clamp diode D1 continues to conduct while Cc remains charged.

[t3 ,t4], [see Fig. 5(d)]: At time t3 , diode D1 is reversed biased and as a result, the energy stored in magnetizing inductor of the hybrid transformer and in capacitor Cr is simultaneously transferred to the load. During the steady-state operation, the charge through capacitor Cr must satisfy charge balance. The key waveform of the capacitor Cr current shows that the capacitor operates at a hybrid-switching mode, i.e., charged in resonant style and discharged in linear style.

[t4 ,t0], [see Fig. 5(e)]: The MOSFET S1 is turned ON at time t4 . Due to the leakage effect of the hybrid transformer, the output diode current io will continue to flow for a short time and the output diode Do will be reversed biased at time t0 ; then the next switching cycle starts.

B. Analysis and Advantages of the Proposed Converter

1) Fixed Voltage Stresses of the Power Devices:

From the circuit diagram of t0 to t1 and t1 to t2 in Fig. 4, respectively, the voltage stresses for MOSFET S1 and clamping diode D1 are obtained

$$V_{S1} = V_{D1} = \frac{V_in}{1-D} = \frac{V_0}{2+n} \qquad (1)$$

From the circuit diagram of t0 to t1 and t2 to t3 in Fig. 4, one obtains the voltage stress of diode resonant diode Dr and output diode Do

$$V_{Dr} = V_{D0} = V_0 - V_{Cc} = V0 - \frac{V_in}{1-D} = \frac{(1+n)V_0}{2+n} \qquad (2)$$

C. Simulation Results

The MATLAB simulation results verify the successful operation of high boost ratio hybrid transformer. Figure 7 shows the simulation diagram and Figure 8 shows the output voltage across the load.

3. Conclusion

From the above equations it is obvious that all the voltage stresses of the switches are independent of input voltage and load conditions. In otherwords, all the voltage stresses of the switches are optimized based on the output voltage and the turns ratio of the transformer. The resonant period Tr and the resonant frequency are given by

$$T_r = 2\pi\sqrt{L_r C_r} \qquad (3)$$

$$f_r = \frac{1}{T_r} \qquad (4)$$

Advantages Over Conventional Nonresonant High Step-Up Converter:

In the proposed high boost ratio dcdc converter. The inductive and capacitive energy can be transferred simultaneously to the highvoltage dc bus increasing the total

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power delivered decreasing the losses in the circuit. As a result of the energy transferred through the hybrid transformer that combines the modes where the transformer operates under normal conditions and where it operates as a coupled-inductor, the magnetic core can be used more effectively and smaller magnetics can be used. The continuous input current of the converter causes a smaller current ripple than that of previous high boost ratio converter topologies that used coupledinductors. The lower input current ripple is useful in that the input capacitance can be reduced and it is easier to implement a more accurate MPPT for PV modules. The conduction losses in the transformer are greatly reduced because of the reduced input current RMS value through the primary side. The voltage stress of the active switch is always at a low voltage level and independent of the input voltages. Due to the introduction of the resonant portion of the current, the turn-off current of the active switch is reduced. As a result of the decreased RMS current value and smaller turn-off current of the activeswitch, high efficiency can be maintained at light output power level and low-input voltage operation. Because of the resonant capacitor transferring energy to the output of the converter, all the voltage stresses of the diodes are kept under the output dc bus voltage and independent of the input voltage.

This paper presents a highly efficient novel high boost ratio hybrid transformer DC-DC converter for photovoltaic module applications with following features and benefits:

- This converter transfers the capacitive and inductive energy simultaneously to increase the total power delivery reducing losses in the system.
- The conduction loss in the transformer and MOSFET is reduced as a result of the low-input RMS current and switching loss is reduced with a lower turn-off current. With these improved performances, the converter can maintain high efficiency under low output power and low-input voltage conditions.
- With low-input ripple current feature, the converter is suitable for PV module and fuel cell PCS, where, accurate MPPT is performed by the dc dc converter.

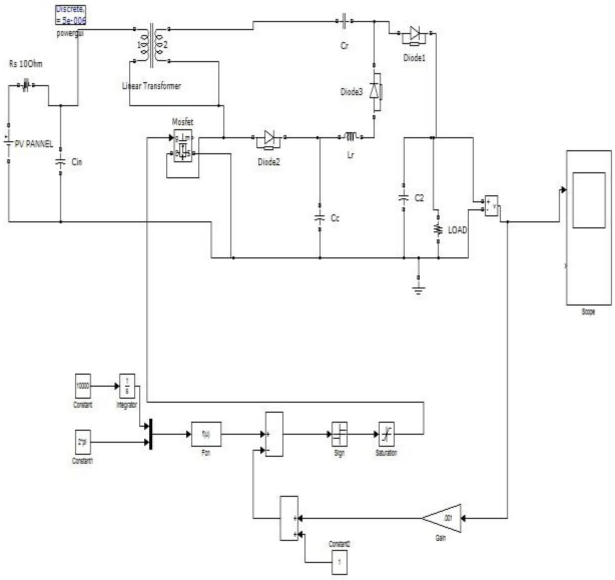

Figure 7: Simulation diagram of proposed high boost ratio hybrid dc-dc converter

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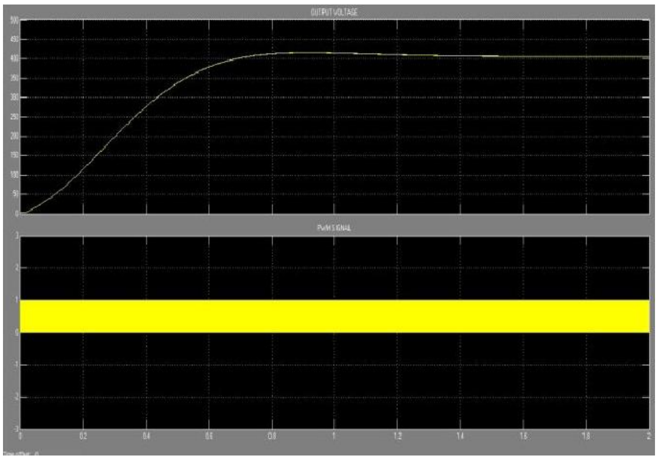

Figure 8: Output voltage of high boost ratio hybrid transformer

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