HYBRID TRANSFORMER BASED DC–DC BOOST CONVERTER FOR PHOTOVOLTAIC APPLICATIONS

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Abstract: Now-a-days due to the shortage of electric power and rising cost of non-renewable energy resources generating electric power from the renewable energy resources such as PV modules are increasing day to day. This paper presents non-isolated, high step-up dc–dc converter with hybrid transformer for low voltage renewable energy resources applications. The proposed converter utilizes hybrid transformer to transfer the inductive and capacitive energy simultaneously, achieving high step-up voltage with smaller sized magnetic component, the turn-off loss of switch is reduced, increasing the efficiency of the converter under all load conditions. By changing the input voltage the voltage stresses on the active switch and diodes are maintained at low level and are independent as a result of the resonant capacitor transferring energy to the output of the converter. Due to the high system efficiency and the ability to operate with a wide variable input voltage, the proposed converter is an attractive design for alternative low dc voltage energy sources, such as solar photovoltaic modules and fuel cells.

Keywords: Energy sources with low dc voltage, High boost ratio DC–DC, High efficiency, Hybrid transformer, Photovoltaic (PV) module.

I. 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).

![Fig.1. (a) two-state PV module integrated Microinverter. (b) Parallel PV module integrated Microconverter with centralized inverter.](image)

Typical PCS can be accomplished using a single stage or a double-stage as shown in Fig. 1. 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 non-isolated; however, transformer-isolated converters tend to be less efficient and more expensive due to the increased manufacturing costs. A non-isolated dc–dc converter with a high boost ratio would be advantageous for a two-stage PCS because it can be easily integrated with current PV systems while reducing the cost and maintaining a high system efficiency. Due to the different output voltages from the PV panel, it would be beneficial to have a system with a high efficiency over the entire PV voltage range to maximize the use of the PV during different operating conditions.

II. 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. As 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 fly back 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 in L1, and when 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.

III. PROPOSED METHOD

A. PROPOSED CONVERTER TOPOLOGY AND OPERATION ANALYSIS

Fig. 4 shows the circuit diagram of the proposed converter. \( C \) 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 turn on of \( Dr \) is determined by the state of the active switch \( S1 \). \( Do \) is the output diode similar to the traditional coupled inductor boost converter and \( Co \) is the output capacitor. \( Ro \) is the equivalent resistive load.

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

![Block diagram of the proposed converter.](image)

Fig. 5. Operation modes of the high boost ratio dc-dc converter with hybrid transformer. (a), (b), (c), (d), (e), (f), (g), (h), (i), (j), (k), (l), (m), (n), (o), (p), (q), (r), (s), (t), (u), (v), (w), (x), (y), (z). [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, \( Cc \) is
charged by $C_c$, and the secondary reflected input voltage $V_{Vin}$ of the hybrid transformer together by the resonant circuit composed of secondary side of the hybrid transformer, $C_r$, $C_c$, $L_r$, and $D_r$. The current in MOSFET S1 is the sum of the resonant current and linear magnetizing inductor current.

At time $t_1$, 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 $C_c$ is charged which causes the voltage on the MOSFET to be clamped.

At time $t_2$, [see Fig. 5(c)]: At time $t_2$, the capacitor $C_c$ is charged to the point that the output diode $D_o$ is forward biased. The energy stored in the magnetizing inductor and capacitor $C_r$ is being transferred to the load and the clamp diode D1 continues to conduct while $C_r$ remains charged.

At time $t_3$, [see Fig. 5(d)]: At time $t_3$, diode D1 is reversed biased and as a result, the energy stored in magnetizing inductor of the hybrid transformer and in capacitor $C_r$ is simultaneously transferred to the load. During the steady-state operation, the charge through capacitor $C_r$ must satisfy charge balance.

At time $t_4$, [see Fig. 5(e)]: The MOSFET S1 is turned ON at time $t_4$. Due to the leakage effect of the hybrid transformer, the output diode current $i_o$ will continue to flow for a short time and the output diode $D_o$ will be reversed biased at time $t_0$; then the next switching cycle starts.

B. ANALYSIS AND ADVANTAGES OF THE PROPOSED CONVERTER

I) Fixed Voltage Stresses of the Power Devices:

The voltage stresses for MOSFET S1 and clamping diode D1 are obtained

$$V_{S1} = V_{D1} = \frac{V_{Vin}}{1-D} = \frac{V_0}{2+n}$$

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

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

$$T_r = 2\pi \sqrt{L_r C_r}$$

$$f_r = \frac{1}{T_r}$$

II) Advantages Over Conventional Non resonant High Step-Up Converter:

In the proposed high boost ratio dc–dc converter 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. 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 coupled inductors. 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.

In order for the proposed converter to be used in higher power level conversion applications, the interleaving method applicable to the traditional high boost ratio PWM dc–dc converter can be employed. This gives the advantages of standard interleaved converter systems such as low-input current ripple, reduced output voltage ripple, and lower conduction losses. The difference between standard interleaved converters and the proposed interleaved converter is that the clamping can also be shared by the interleaved units reducing the total number of components in the system. Using the capacitor $C$. 

IV. SIMULATION RESULTS

In order to verify the effectiveness of the proposed converter, the converter was designed in MATLAB/SIMULINK environment. From the simulation analysis of the circuit, two control methods can be adopted for the proposed converter. The first method is utilizing a variable frequency control, which is accomplished by using a fixed $f_0$ control and varying the $T_{internal}$ to obtain the desired gain. Another control method is the traditional PWM converter control by adjusting the
duty cycle of the switch for a fixed frequency to obtain the desired boost gain. Although the fixed \( T \) control is optimal, however, in real control implementation, PWM control with fixed switching frequency is preferred because of its simplicity. In the

![Fig. 7. Simulation diagram of proposed high boost ratio hybrid dc-dc converter (single stage).](image)

![Fig. 8. Simulation diagram of proposed high boost ratio hybrid dc-dc converter (two stage).](image)

![Fig. 9. Output voltage at input voltage=30V (single stage).](image)

![Fig. 10. Output voltage at input voltage=30V (two stage).](image)

![Fig. 11. Simulated waveforms of high boost converter with single stage: switch voltage, output diode voltage, input current, and current of resonant capacitor of the proposed converter with 30-V input and 400-V output under different output power level a) 110W, b) 160W, c) 220W.](image)

![Fig. 12. Simulated waveforms of high boost converter with two stages: switch voltage, output diode voltage, input current, and current of resonant capacitor of the proposed converter with 30-V input and 800-V output under different output power level a) 110W, b) 160W, c) 220W.](image)
simulation model, the proposed converter was designed to convert the low dc voltage, V with the voltage varying from 20 to 45 V, to a constant high dc output, V_in=400 V. To maintain a low voltage stress on the active switch M1 and reasonable duty cycle range, the turns ratio n of hybrid transformer was chosen to be 40:9.

CONCLUSION

This paper presents a highly efficient 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.

REFERENCES