ANALYSIS AND DESIGN OF HIGH BOOST RATIO CONVERTER FOR EFFICIENT ENERGY TRANSFER FROM PV MODULE

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ABSTRACT

Attempts were made by scientists for utilizing solar power in different ways. Solar drives, solar water heater, solar concentrators are some examples. Recently because of energy shortage attention was given for generating electric power from solar power. This proposed project presents a non-isolated, high boost ratio hybrid transformer dc-dc converter that has the applications in low voltage renewable energy sources. The proposed converter makes use of a hybrid transformer to transfer the inductive and capacitive energy simultaneously. This helps to achieve a high boost ratio .The proposed system combines pulse width modulation along with resonant mode operation. This helps to minimize the turn off losses of the switch and thereby improving the efficiency of the converter. Since the input to the converter is hybrid linear sinusoidal current waveform, the input current ripple and conduction losses are low. 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*: *Energy Sources with Low Dc Voltage, High Boost Ratio Dc–Dc, High Efficiency, Hybrid Transformer, Photovoltaic (Pv) Module.

I. INTRODUCTION

As the non-renewable energy is getting exhausted and its cost being high , the demand for renewable energy is increasing and non-renewable energy sources like PV modules have been widely used . Power conditioning systems (PCS) is used for integrating the power from the PV module into the existing power distribution system. PCS can be single-stage or a double-stage [1]–[7], [15], [16]. In double-stage PCS dc–dc conversion stage 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 are of two types : isolated or non-isolated [1]. Isolated converters are less efficient and more expensive due to the increased manufacturing costs. For a two stage PCS , a non-isolated dc–dc converter with high boost ratio is more suitable because it can be easily integrated with current PV systems and the cost can also be reduced and provides higher efficiency [1]. The output voltage range from a PV panel varies and so it would be better to use a system with the high efficiency so that maximum output can be obtained during different operating conditions. Dc–dc converter in PV applications is also used to implement maximum power point tracking (MPPT). A large cluster of PV could maintain maximum power output from each panel without interfering with the other panels in the system if it is possible to implement MPPT for each individual PV panel. The major consideration to implement an accurate MPPT is that the input current ripple of the converter has to be low.

For PV module converter applications, the high efficiency over a wide load range and input voltage range is extremely important because the performance is weighted differently for specific load levels and input voltages. In this paper, a high boost ratio dc–dc converter with hybrid transformer is presented in order to achieve high efficiencyover wide input voltage and output power ranges. A small resonant inductor is added and the capacitance of the switched-capacitor in the energy transfer path is reduced and this modification helps to achieve a hybrid operation mode [17], [18], which combines pulse width modulation (PWM) and resonant power conversions. This method is introduced in the proposed high boost ratio dc–dc converter.

The total power delivered is increased by transferring the inductive and capacitive energy simultaneously and thereby the losses in the circuit are also decreased. The two transformer modes, where the transformer operates under normal conditions and where it operates as a coupled-inductor, are combined together and therefore the magnetic core can be used more effectively and smaller magnetics can be used. Smaller current ripple than the previous high boost ratio converter topologies is achieved by the continuous input current of the converter. Since the current ripple is low, 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 independent of the input voltages. The turn-off current of the active switch is reduced due to the introduction of the resonant portion of the current. The decreased RMS current value and smaller turn-off current of the active switch helps to enhance high efficiency at light output power level and low-input voltage operation. The voltage stresses of the diodes are kept under the output dc bus voltage.

II. PROPOSED CONVERTER TOPOLOGY ANDOPERATION ANALYSIS

Fig. 1 shows the circuit diagram of the proposed high boost ratio hybrid dc-dc converter with various components. C_{in} is the input capacitor; HT is the hybrid transformer having the turns ratio 1:n; S_1 is the active MOSFET switch; D_1 is the clamping diode, that provides a current path for the leakage inductance of the hybrid transformer when S_1 is OFF, C_c captures the leakage energy from the hybrid transformer and transfers it to the resonant capacitor C_r by means of a resonant circuit composed of C_c , C_r , L_r , and D_r ; L_r is a resonant inductor, which operates in the resonant mode; and D_r is a diode used to provide an unidirectional current flow path for the operation of the resonant portion of the circuit. C_r is a resonant capacitor, which operates in the hybrid mode. The turn-on of D_r is determined by the state of the active switch S_1. D_0 is the output diode and C_o is the output capacitor. R_o is the equivalent resistive load at the output side.

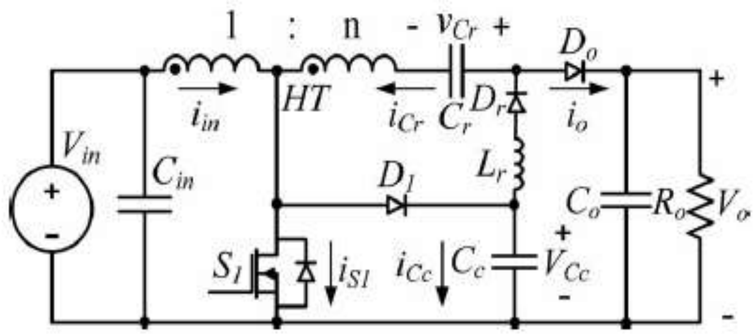


Fig. 1.Proposed High Boost Ratio Dc–Dc Converter With Hybrid Transformer

Fig. 2 illustrates the five steady-state topology stages of the proposed dc–dc converter for one switching cycle. Fig. 3 shows the key voltage and current waveforms for specific components of the converter over the switching cycle. In Fig. 3, g_1 represents the driver signal for the active MOSFET switch S_1 ; i_{s1} is the current of the MOSFET S_1 ; i_{Cr} is the current of the resonant capacitor C_t ; i_{Cc} is the current of clamping capacitor C_c ; i_{in} is the primary side current of hybrid transformer; i_o is the current through the output diode; v_{s1} and v_{Do} are the voltage waveforms of the active switch MOSFET S_1 and the output diode D_0 , respectively.

The five operation modes are briefly described as follows.

[t_0 ,t_1], [Fig. 2(a)]: In this period, MOSFET S_1 is ON, the magnetizing inductor of the hybrid transformer is charged by input voltage, C_r is charged by C_c , and the secondary-reflected input voltage nV_{in} of the hybrid transformer together by the resonant circuit composed of secondary side of the hybrid trans-former, C_r , C_c , L_r , and D_r . The energy captured by C_c is transferred to C_r , which in turn is transferred to the load during the off-time of the MOSFET. The current in MOSFET S_1 is the sum of the resonant current and linear magnetizing inductor current. The main advantage of linear and resonant hybrid mode operation is that the energy is delivered from source during the capacitive mode and inductive mode simultaneously. The turn-off current is also decreased, which causes a reduction in the turn-off switching losses.

[t_1 ,t_2], [see Fig. 2(b)]: At time t1 , MOSFET S_1 is turned OFF, the clamping diode D_1 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.

[t2 ,t3], [see Fig. 2(c)]: At time t2 , 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 D_1 continues to conduct while C_c remains charged.

[t_3 ,t_4], [see Fig. 2(d)]: At time t3 , diode D_1 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. The key waveform of the capacitor C_r current shows that the capacitor operates at a hybrid-switching mode, i.e., charged in resonant style and discharged in linear style.

[t_4 ,t_0], [see Fig. 2(e)]: The MOSFET S_1 is turned ON at time t_4 . 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 D_o will be reversed biased at time t_0 ; then the next switching cycle starts.

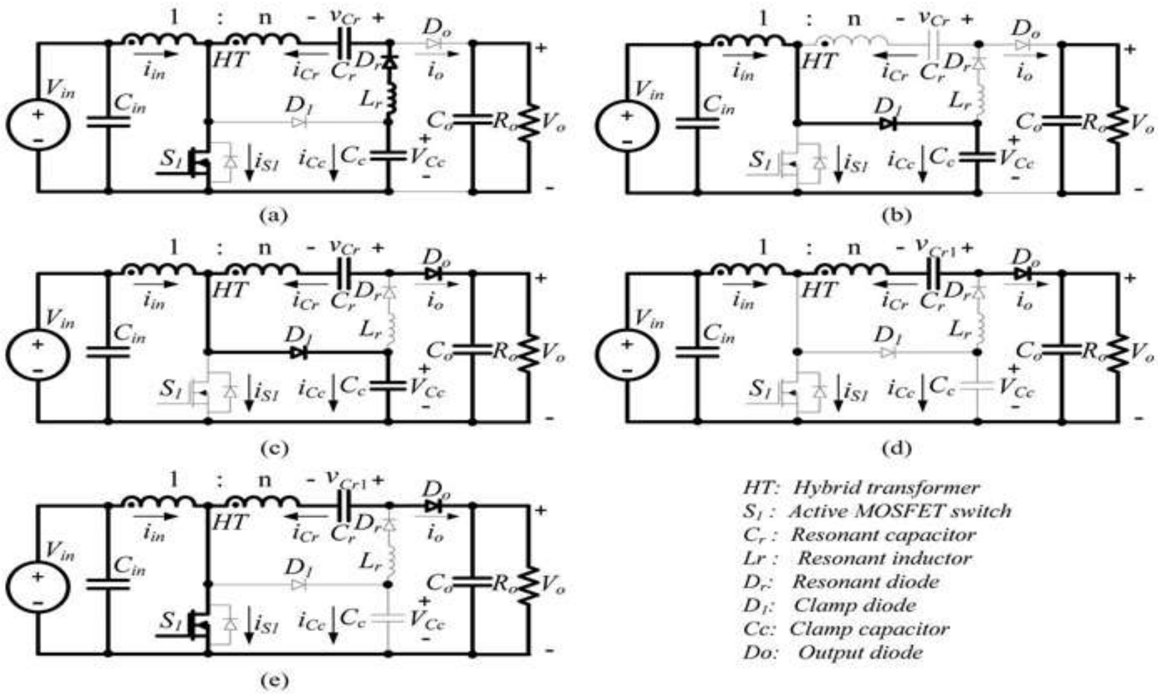


Fig.2.Operation modes of the high boost ratio converter with hybrid transformer. (a) t_0 -t_1.(b) t_1 -t_2.(c) t_2 -t_3. (d) t_3 -t_4.(e) t_4 -t_5

The boost ratio M_b is obtained by three flux balance criteria for the steady state. The first flux balance on the magnetizing inductor of hybrid transformer indicates that in steady state :

$$V_{Cc} = \frac{V_{in}}{1-D} \qquad (1)$$

Second, according to flux balance on the resonant inductor during on time

$$.V_{Cr} = nV_{in} + V_{Cc} = \left(n + \frac{1}{1-D}\right) V_{in} \qquad (2)$$

The last flux balance that governs the circuit is voltage-second balance of the magnetizing inductor in the hybrid transformer for the whole switching period

$$V_{in}D = \frac{V_o - V_{Cr} - V_{in}}{1+n}(1-D) \qquad (3)$$

By substituting (2) into (3), the boost conversion ratio can be obtained

$$M_b = \frac{V_o}{V_{in}} = \frac{n+2}{1-D} \qquad (4)$$

III SIMULATION DIAGRAM AND RESULTS

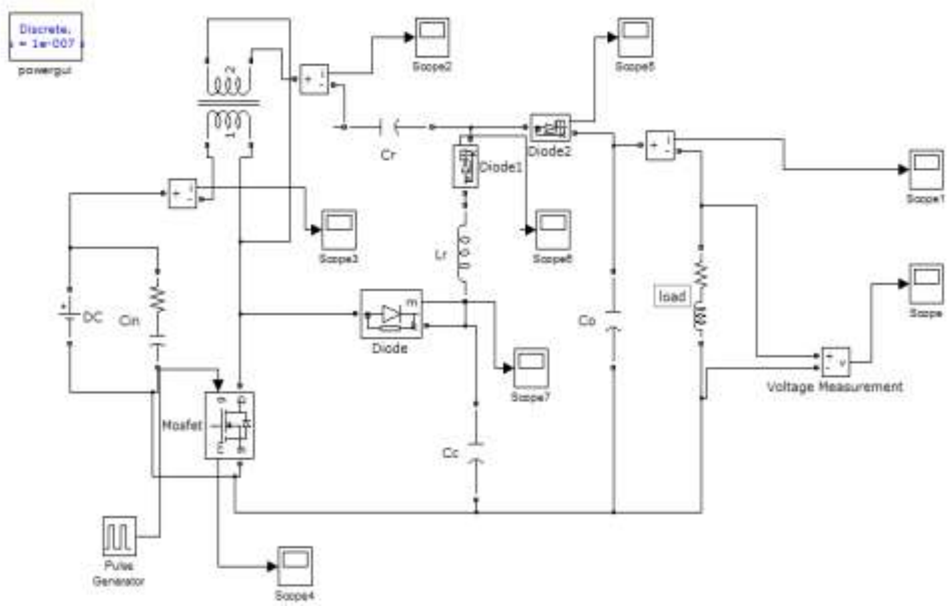
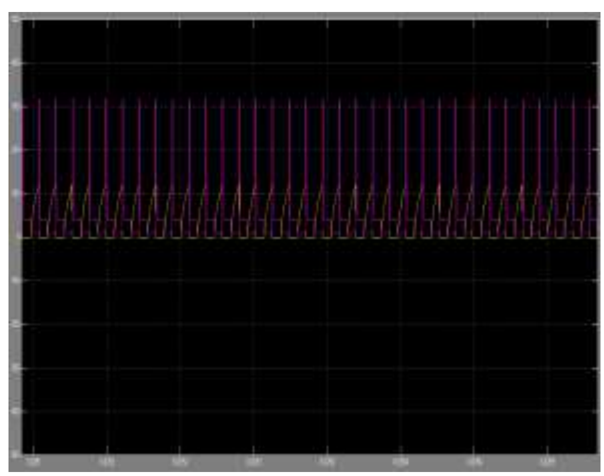
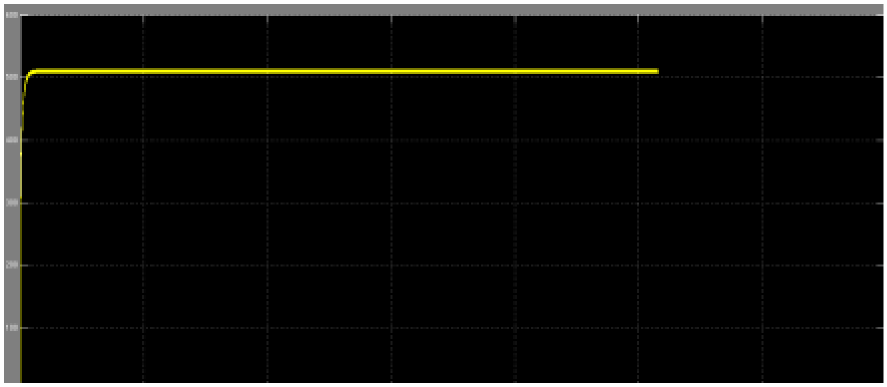


Fig 4: Simulation Model of Open Loop Circuit of High Boost Ratio Dc-Dc Converter

Input DC Voltage



Output Of The Switch(Mosfet



output voltage

Output Current

Fig 4: Simulation Results

IV. EXPERIMENTAL VERIFICATIONS

A prototype circuit that can be used for PV module power optimizer applications was built and tested to verify the effectiveness of the proposed converter. Tables given below list the design parameters and components selection for the converter. Two control methods can be adopted for the proposed converter. The first method is the variable frequency control, which is done by using a fixed T_{on} and varying the T_{off} to obtain the desired gain. Another control method is the PWM converter control by adjusting the duty cycle of the switch. In real control implementation, PWM control with fixed switching frequency is preferred because of its simplicity.

Table I
Design Parameters

Rated Power	220 W
DC Bus Voltage	500 V_{dc}
Input Voltage Range	20V-45V
Output Power Range	30W-220W
Switching Frequency	74.5 kHz
Turns Ratio n of Hybrid Transformer	40:9

Table II
Components Selection

C_{in}	5*10μF/100V ceramic caps
Hybrid Transformer	ETD 34 with L_m = 18μH
S_1	BSC077N12NS3
C_r	1μF/600V Film Cap
D_1	V12P12-M3
L_r	2.2μH
C_c	2*10μF/100V ceramic caps
D_r, D_o	HFA15TB60S
C_0	2μF/600V Film Cap

The prototype of the proposed converter was designed to convert the low dc voltage, V_{in} with the voltage ranging from 20 to 45 V, to a constant high dc output, V_o = 500 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. The resonant contribution index k_r = 0.35 was when D = 0.5. The duty ratio range for an input PV module voltage range of 20–45 V is 0.28–0.68, which is kept within a reasonable range.

V. ADVANTAGES OVER CONVENTIONAL NON-RESONANT HIGH STEP-UP CONVERTER

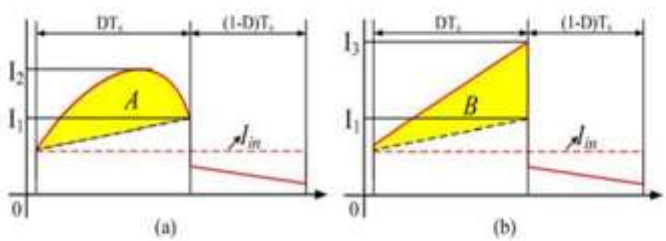


Fig. 5. Input Current Comparison Between Resonant Mode And Linear Mode: (A) Resonant Mode. (B) Linear Mode.

The methods in existence that are used to achieve high boost ratio for non-isolated dc–dc converters involves the usage of coupled-inductor and switched-capacitor techniques [8]–[14]. The converter presented in this paper makes use of hybrid-switching technique [17], [18] that combines PWM and resonant power conversion method to achieve a high boost ratio while maintaining a high efficiency. There are many advantages gained by the usage of the hybrid-switching operation.

The input currents for the resonant sinusoidal charge mode and the PWM linear charge mode are shown in Fig. 5. The converter that is proposed in this paper works on the basis of resonant sinusoidal charge mode, while a conventional non-resonant con-verter [11] works using the linear charge mode. If the output power is fixed and given input voltage, the average input currents $I_{in}$for both type of converters are equal as shown in Fig. 5. Areas *A* and *B* (see Fig 5) show the capacitive energy transferred bythe hybrid transformer of the proposed converter with resonant mode and linear energy transferred by the coupled-inductor of conventional non-resonant converter. The switching losses for a dc–dc converter are directly proportional to the switching current given by the fixed conversion voltages. As mentioned above in circuit operation, the MOSFET is turned ON at time $t = t_4$, the fast rate of change of the primary current is limited by the leakage inductor of the hybrid transformer thus reducing the turn-on losses. Now the main switching loss is the turn-off switching losses.

The turn-off switching current I_1 , as shown in 5(a)consists of only the magnetizing current because of the resonant operation. For the conventional non-resonant converter [11], the turn-off switching current I_3 , as shown in Fig. 5(b), is the sum of the magnetizing current and the switched-capacitor charge current, which is dependent on the leakage inductance of the coupled-inductor. For a given capacitor value of the, An increase in the leakage inductance can reduce the raising rate of the primary side current in order to reduce the turn-off current, for a fixed switched-capacitor value. However, the conversion ratio will decrease because of the reduced coupling factor *k* of the coupled-inductor [11]. Because of this, the leakage inductance design of the coupled-inductor has a tradeoff between the conversion ratio and a higher turn-off switching current.

The primary peak current I_2 , as shown in Fig. 5(b), is smaller than the peak current $I_3$of its switched-capacitor because of the introduction of a resonant operation mode into the PWM converter for the proposed converter. The capacitance of the charge capacitor C_r can be greatly reduced since the resonant modeis employed as opposed to the switched-capacitor mode. The advantage of using the resonant mode is that it allows the use of smaller sized magnetic components and lower profile charge capacitors for C_r. This can be used in application where a low profile PV-module-integrated dc– dc converter is needed. The leakage inductance of the hybrid transformer can also be effectively utilized as part of the resonant minor loop.

VI. CONCLUSION

In this paper a high boost ratio dc–dc converter with hybrid transformer that is suitable for renewable energy sources with low dc voltage input is proposed. In this, we are implementing resonant conversion mode along with pulse width modulation technique with coupled-inductor and switched-capacitor and we obtain the following features and benefits:

1)The converter has an advantage that it transfers the capacitive and inductive energy simultaneously and this enables to achieve higher efficiency by increasing the total power delivery by reducing losses in the system.

2)The conduction loss in the transformer and MOSFET is reduced because of the low-input RMS current and the switching loss is also reduced because of the lower turn-off current. The converter can maintain high efficiency under low-input voltage conditions because of these modifications.

3)The converter is suitable for PV module and fuel cell PCS because of the low-input ripple current feature and it helps to enhance accurate MPPT by the dc–dc converter.

A prototype-circuit that can be used for PV module applications was made and tested with 20–45 V input voltage range and 400-V dc output. Experimental results show that the MOSFET voltage was clamped at 60 V and the output diode voltage was under 350 V. These results were independent of the input voltage level.

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