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MODELING AND SIMULATION OF LLC RESONANT CONVERTER FOR PHOTOVOLTAIC SYSTEMS

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ABSTRACT

Photovoltaic (PV) power generation is one of the rapidly growing renewable energy source due to increasing electricity demand and depletion of fossil fuels. To be more competitive and reliable when compared to other renewable energy sources, several research works are being carried out in field of PV. It is necessary to design PV panels and the Power Conditioning Systems (PCSs) in such a way that its performance, efficiency increases and cost reduces. Photovoltaic Power Conditioning Systems require a very efficient DC-DC converter which is capable of regulating a wide range of input voltage in order to generate more power. This paper discusses about a new type of resonant converter that provides voltage regulation through Pulse width Modulation (PWM) control by adding a secondary side bi-directional ac switch to the resonant converter for wide range of input voltage which is supreme for Photovoltaic applications.

Key Words

Series resonant converter, LLC converter, Efficiency, PV systems

1. INTRODUCTION

The increased dependence on energy sources and limited availability of fossil fuels has led to the exploration of new and renewable energy resources. Among various renewable energy resources, Photovoltaic power is one of the emerging industries that is reliable and is steadily growing due to decrease in prices. Large efforts are being taken worldwide to reduce the cost of electronics devices used in PV Power generation system with increased performance and efficiency. An essential part of the PV power generation system is the Power Conditioning Systems (PCSs) whose major function is to convert one form of electric power to another as required by the utility grid and to track maximum power from the PV module [1]. The power output characteristics of PV module is not uniform because of the fluctuating nature of environmental aspects like temperature, solar radiation, dust deposition, wind speed, shading etc. To overcome this problem several research work has been carried out in this field to track the Maximum Power of PV module individually to extract maximum radiation from it. The DC-DC converter requires wide range of input voltage to extract more power from the PV module under different environmental conditions [2]. The main aim is to improve the performance of these electronic. This paper discusses about a research done to design a converter topology in which a secondary side bi- directional ac switch is added to the converter to provide high boost ratio that is supplied to the grid or stand-alone inverter.

2. OBJECTIVE OF THE RESEARCH

The proposed circuit is designed to satisfy certain requirement of the converter such as, to have simpler design with fewer parts to reduce the system cost, to accommodate different types of PV panels (generic) working under different operating conditions, to improve the performance by providing high boost ratio for the converter.

3. PROPOSED TOPOLOGY

The literature exploration gives background information about several research works that was carried out to develop a DC-DC converter to give high efficiency and broad range of control of input voltage. Tsun Hsiao Hsia et al. [3] proposed a DC- DC converter: primary side consisting of a constant frequency converter while the secondary side consists of a series resonant tank. This configuration has importance when efficiency and size are the main concern. Bo Yang et al. [4] proposed a LLC (Inductor Inductor Capacitor) converter in distributed

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power systems. This topology has advantages such as reduced switching losses, conduction losses which resulted in increase in efficiency by 2-3%. Similar research works were carried out on LLC converter by Reza Beiranvand et al. [5] [6], Yue chen et al. [7], Fariborz Musavi et al. [8] to improve the performance while reducing the cost of electronics.

Taking the literature as guidance, a new topology as shown in Figure1 is developed to design a high efficiency LLC resonant converter and inverter for Photovoltaic systems. The proposed LLC converter is based on the principle of series resonant converter. The series resonant converter is efficient because it allows direct power transfer to the load and the primary side MOSFET attains Zero Voltage Switching (ZVS) while secondary side Diode attains Zero Current Switching (ZCS). But the drawback in Series resonant converter is insufficient input voltage regulation needed for PV systems. The proposed topology is a hybrid series resonant with PWM boost converter which makes use of high frequency bi directional AC MOSFET and achieves wide range of input with fixed frequency control.

The operating principle of the LLC converter is similar to the resonant converter along with a clip circuit to double the voltage. The primary side of isolation transformer is a full bridge switching network consisting of switches S_1 to S_4 to lower the switch count and also the network operates at series resonant frequency, f_r (expressed in equation 1). The secondary side of isolation transformer consists of a bidirectional switch (MOSFET), S_5. To determine resonant frequency f_r, the secondary side resonant inductor L_r and resonant capacitor C_{r1}, C_{r2}. Certain assumptions are made for simplification of the proposed converter topology. They are:

i. C_o is greater than V_O, C_{r1}, and C_{r2}.
ii. C_{r1}, C_{r2} are equal.
iii. L_m is greater than L_r.

$$f_r = \frac{1}{2\pi\sqrt{L_r(C_{r1}+C_{r2})}} \quad \text{…. (1)}$$

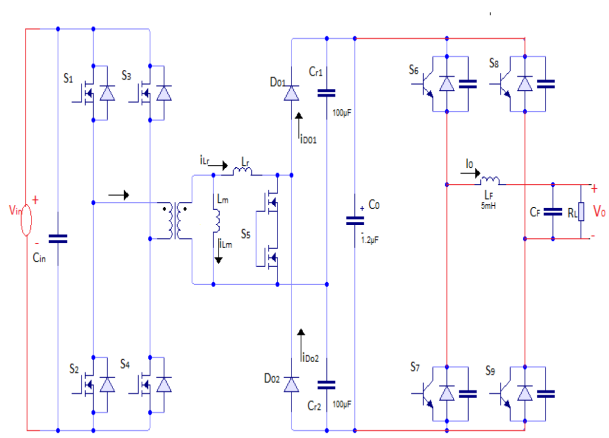

Figure1: Proposed LLC resonant converter

The bidirectional ac switch is devised as a two drain connected MOSFET. When S_5 is turned on, fr is doubled, secondary transformer is shorted and Lr steps in as boost inductor. When S_5 is turned off, Lr oscillates C_{r1}, C_{r2}. Once this process is completed the inverter operation is triggered.

3.1 Modes Of Operation

To completely understand the proposed topology, the circuit can be explained in three modes: PWM boost mode, series resonant mode and idle mode.

MODE 1-[$t_0 < t < t_1$] PWM boost mode: In this mode, S_1 and S_4 conduct to produce a positive voltage in the primary side of the transformer. The secondary winding of the transformer gets shorted when switch S_5 conducts due to which current in the leakage inductance is nearly zero and the voltage across C_{r1} is lower. The average voltage of the resonant capacitance, V_{cr1} is half of the output voltage V_o. The voltage ripple of the resonant capacitance is given by, Δv_{cr} (expressed in equation 2). The voltage across the resonant capacitor during all the operating mode is given by, $v_{cr2} = V_0 - v_{cr1}$.

$$\Delta v_{cr} = \frac{P_o T_s}{2 V_o C_r} \text{……………….. (2)}$$

$$i_{Lr}(t) = \frac{nV_{in}}{L_r}(t - t_o) \text{……………… (3)}$$

In this mode, when S_5 is turned on leakage inductor steps in as boost inductor and the current in it increases linearly (expressed in equation 3). Similarly when switch S_2 and S_3 conduct in the second cycle, a negative voltage is

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produced on the primary side of the transformer and the converter steps in the second PWM mode.

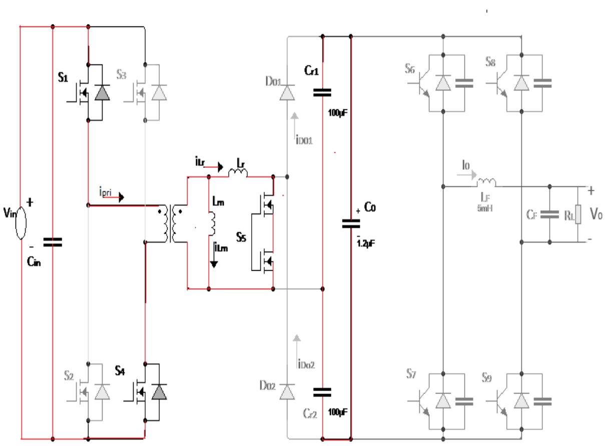

Figure2: PWM boost mode operation

MODE 2-[$t_1 < t < t_2$] series resonant mode: In this mode switch S_5 turns off and the converter operates as a series resonant converter. The resonant inductor L_r that was charged in mode 1 (expressed in equation 4), discharges in mode 2 through the parallel combination of C_{r1} and C_{r2}. The operating voltage required by the inverter is obtained in this mode and it is triggered. Similarly after S_2 and S_3 turns on in second part, the ac switch S_5 turns off again to step into series resonant mode again and the process repeats.

$$i_{Lr}(t_1) = \frac{nV_{in}d_{ac}T_s}{L_r} \ldots\ldots\ldots\ldots (4)$$

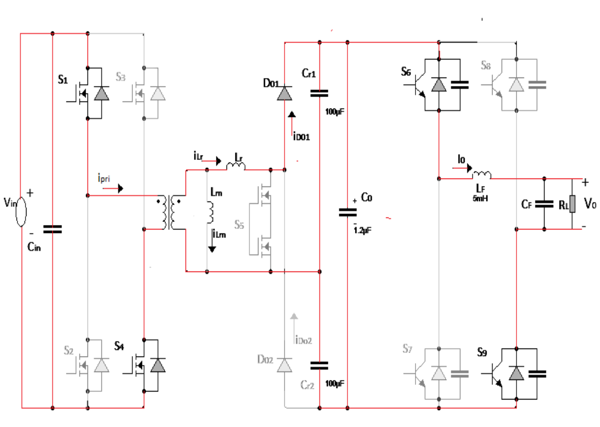

Figure3: Series resonant mode operation

MODE 3-[$t_2 < t < t_3$] idle mode: In this mode, the current in L_r decreases to zero (expressed in equation 5) and the converter operates in idle mode. During this mode there is no power transfer from source to load. At this condition, the circuit operates at a constant frequency. ZCS is achieved on the secondary side of the output diode, ZVS is achieved on the primary side of the MOSFET and the switches S_1 and S_4 turn off. During this period the voltage across C_{r1} is higher (expressed in equation 6).

$$i_{Lr}(t_2) = i_{Lr}(t_3) = 0 \ldots\ldots\ldots (5)$$

$$v_{cr1} = \frac{V_o}{2} + \Delta v_{cr} \ldots\ldots\ldots\ldots\ldots (6)$$

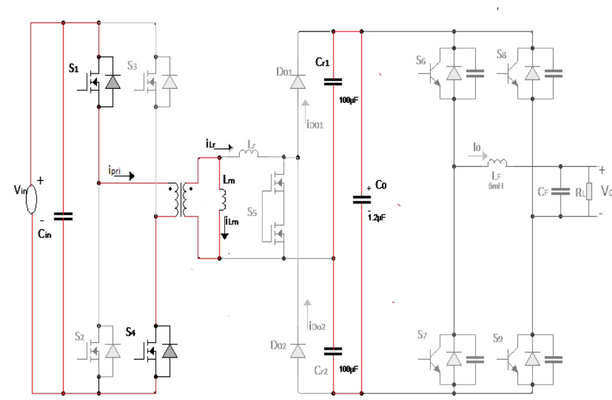

Figure4: Idle mode operation

3.2 Design Procedure Of Converter

The transformer turns ratio 'n' (expressed in equation 7) should be selected in such a way that the nominal input voltage should produce appropriate output voltage.

$$n = \frac{V_o}{2V_{in-nom}} \ldots\ldots\ldots\ldots\ldots (7)$$

Cr (expressed in equation 8) is selected depending on the required resonant frequency. It should be larger than Lr as it affects the voltage rating of switch S_5 to reduce the voltage across S_5 and C_r. The value of L_r (expressed in equation 9) is chosen in such that the ratio between leakage inductance and magnetizing inductance will produce appropriate conversion ratio within the range of required frequency. The design procedure of this topology has higher L_m/ L_r ratio.

$$C_r > \frac{P_o T_s}{V_o^2} \ldots\ldots\ldots\ldots\ldots (8)$$

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$$L_r < \frac{V_o^2}{2\omega_r^2 P_o T_s} \text{...........} \quad (9)$$

4. SIMULATION AND RESULTS

A LLC converter consisting of DC input source, full bridge inverter, full bridge LLC resonant converter, high frequency transformer, half bridge rectifier, filter circuit and resistive load is shown in the figure 5. The DC input voltage is inverted to AC by the full bridge MOSFET which in turn is connected to primary side of the transformer. The secondary side of the transformer is connected to the LLC resonant tank circuit. The output voltage of the resonant tank circuit is converted to DC by the half bridge rectifier, which is then doubled by the clip circuit and fed to the inverter. The full bridge inverter converts the DC voltage to AC and synchronizes the switching frequency and output frequency, which is then, supplied to the AC grid or standalone systems.

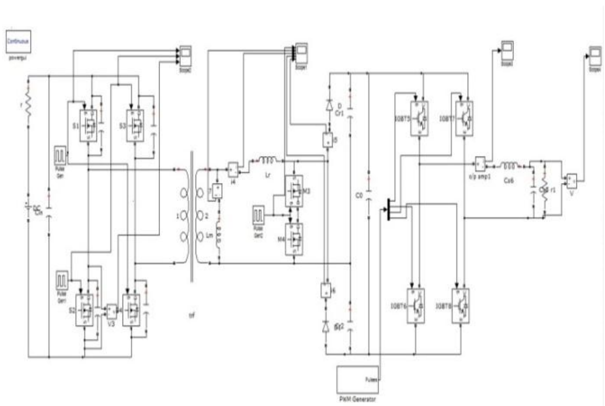

Figure5. LLC converter with inverter

The simulation of LLC converter is done using MATLAB and the results obtained are shown below. The waveforms of DC input voltage, MOSFET output voltage of S_1, S_2 and S_4 are shown in Figure6. The simulated output (voltage and current) of the proposed converter is shown in Figure8. The steady state output voltage and current of inverter is shown in Figure7 and 9 respectively. The specification parameters of elements used in the simulation circuit is shown in the Table 1.

Table 1: Parameters used in the simulation

Elements	Values/Specification
f_s	130kHz
S_1-S_4	IRFZ48
S_5	IRF640
D_{o1},D_{o2}	IN4007
n	5
L_m	713.3µH
L_r	33.5µH
C_{r1},C_{r2}	100nF
C_0	1.2µF
C_{in}	88µF

Figure6. Output voltage of S_1, S_2, S_3, S_4 and S_5.

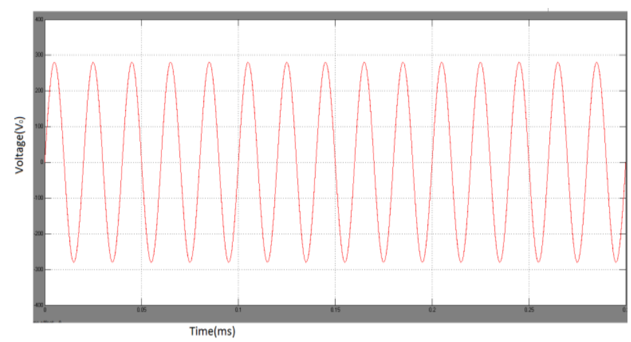

Figure7. Steady state output current of inverter.

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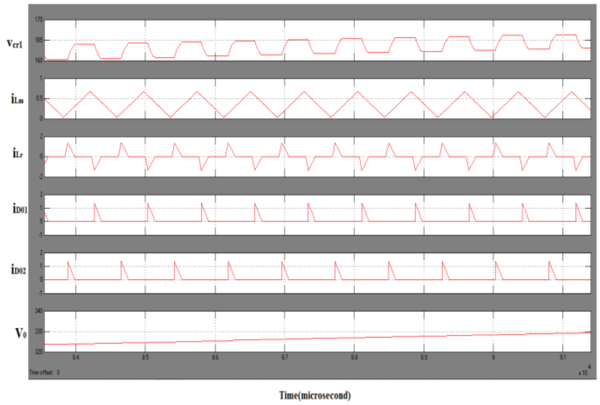

Figure8. Simulation output of proposed converter.

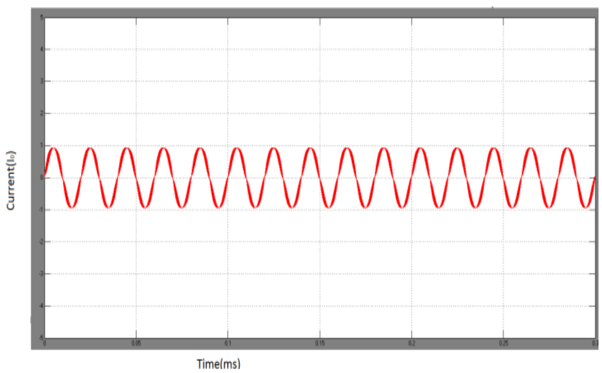

Figure9. Steady state output voltage of inverter.

5. CONCLUSION

The increase in energy demand and growth in PV has made it is necessary to improve the performance and reduce the cost of electronic devices used in Power Conditioning systems. Generally, the converter in PCS has certain design requirements like wide range of input voltage, high efficiency, high boost ratio, high output power etc. that is difficult to obtain. So taking this as a main concern, the proposed LLC converter along with the inverter achieved these requirements by ZCS of output diodes, ZVS of switches of primary side, direct power transfer to the load and low circulating current. The simulation of the proposed converter with inverter topology resulted with an output voltage nearer 320V which is ideal for PV systems.

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