PV fed LLC-LC Multi-resonant Converter based LED Driver

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***Abstract*—In this paper an efficient PV fed LLC-LC Multi-resonant Converter based LED Driver for street lighting applications is implemented . This converter integrates push-pull configuration with LLC resonant converter and LC notch filter. The behaviour of the circuit during overload conditions is explained. The Equivalent circuit and Characteristics of Proposed LLC-LC Multi-resonant Converter are discussed.**

***Index Terms*—Multi-resonant converter, push-pull configuration, Notch-filter, Zero-Voltage-Switching(ZVS)**

I. Introduction

In today's world, the generation of electricity is not only an important aspect but the saving of electricity is also an important criterion due to the depletion of fossil fuels. Therefore generation of electricity through renewable sources is gaining more importance . Photovoltaic power generation is gaining more importance due to the decrease in the cost of solar panels and they can be connected to both grid and standalone systems [1]. The LED lighting is very popular due to higher efficiency, low maintenance, minuscule size, more lifespan when compared to incandescent lamps. Due to various advantages, combination of LEDs and PV systems is becoming more popular [2]. The lifespan of the LEDs can be increased by the proper design of the driver. The important aspects that should consider while designing the LED driver are higher efficacy, longer life span and eco-friendly. In commercial and industrial applications size of the driver and energy management is very crucial [3].LED driver size can be minimized by operating the converter at the higher switching frequency. so that the size of the capacitor and inductor will be decreased as they occupy most of the space in the converter. Hard PWM switching for higher switching frequency increases the switching losses which reduces the efficiency and in addition to that there will be a temperature increase of MOSFETs and may cause damage which decrease the life span of the converter [4]. In order to make switching losses zero soft switching method is employed by using a resonant converter which achieves zero voltage switching, hence the switching losses can be minimised which improves the efficiency[5]. Generally, resonant converters of series, parallel and series-parallel nature are not preferable for front end DC-DC converters due to heavy circulating energy and heavy turnoff currents [6][7]. Multi-resonant LLC converters have ZVS, ZCS at higher gains but they have excessively stress on internal components during starting conditions, overload and short-circuit currents [9][10].

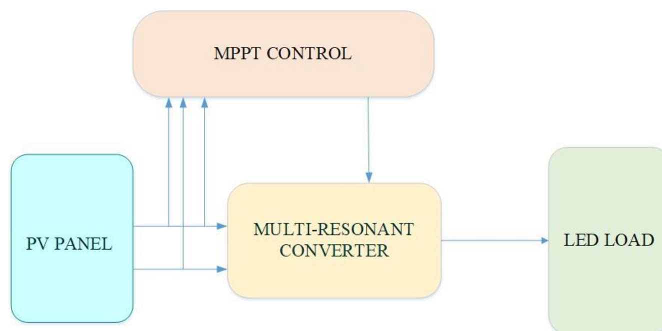

Fig. 1. Block Diagram of proposed topology with MPPT control

In order to provide overload protection and to achieve LLC Multi resonant converter for improved performance an additional tank circuit is used in this paper. The idea of this work is to implement an efficient Multi-resonant DC-DC converter with less switching losses which are fed through a PV panel for an LED load.

II. PV fed LLC-LC Multi-resonant Converter

A. Proposed topology of Multi Resonant converter

PV source is connected to the push-pull inverter where the input voltage and current to the push-pull inverter are sensed and are given as inputs to the MPPT control. Here MPPT is done using incremental conductance method; depending on

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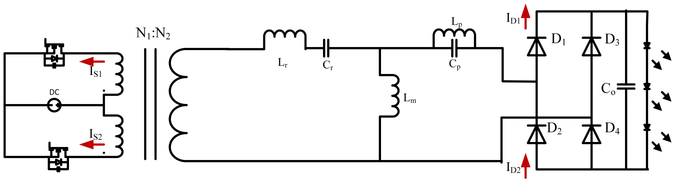

Fig. 2. Proposed LLC-LC Multi-resonant Converter

the input impedance of the converter and the isolation and temperature conditions duty ratio of the switches in the push-pull inverter are varied, till the operating point is changed to maximum power point. The block diagram in Fig. 1 depicts the complete working.

In low and medium voltage applications, a push-pull configuration is more efficient as compared to a full bridge configuration. There will be a reduced number of switches owing to fewer conduction losses, which is important to reduce in high switching DC-DC converters to increase its efficiency. So a push-pull configuration is used before Multi-resonant converter in this paper.

Fig. 2 illustrate the proposed LLC-LC Multi-resonant converter. The output of push-pull inverter is fed to a LLC resonant converter, which is cascaded with a notch filter. The output of the resonant circuit is given to uncontrolled bridge rectifier and LED strings are connected to it.

B. Equivalent circuit of Proposed LLC-LC Multi-resonant Converter

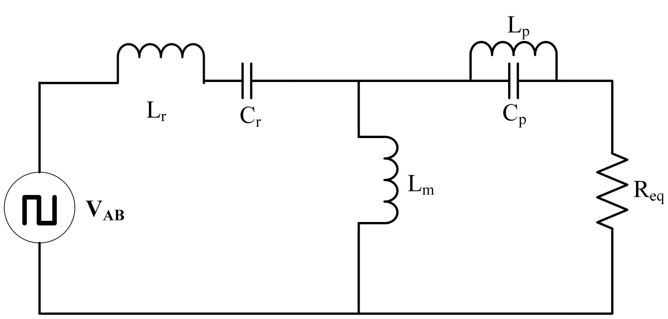

Fig. 3. Equivalent model of Proposed LLC-LC Multi-resonant Converter

The Equivalent model of Proposed LLC-LC Multi-resonant Converter is shown in Fig. 3.The output from the push-pull converter is a stepped-up square voltage V_{AB} . The DC voltage gain of the topology is calculated by using KCL and KVL equations.

$$\frac{V_0}{V_{AB}} = \frac{(K\_1//X_{Lm}) * R_{ac}}{(X_{Lr} + X_{Cr} + K\_1//X_{Lm}) * K\_1} \tag{1}$$

where

$$K\_1 = [R_{ac} + (X_{Lp}//X_{Cp})]$$

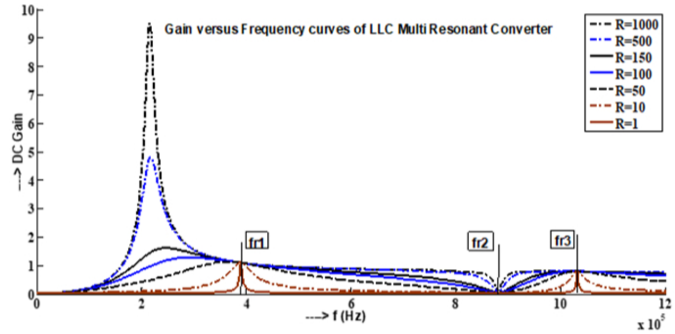

Fig. 4. DC Gain Characteristics of the LLC-LC multi-resonant converter

C. Characteristics of Proposed topology

The dc gain characteristics with respect to frequency at various loads are shown in Fig. 4. The characteristics show different operating regions. The preferred switching frequency f_s range is $f_s < f_{r1}$, in which case ZVS and ZCS can be obtained for the primary side active MOSFETs and the secondary side diodes, respectively. The maximum switching frequency f_{smax} is recommended to f_{r2} . It can be observed that, when $f_s = f_{r2}$ and the output short circuit occurs, the current in the resonant tank is limited.

$$v_{in}(t) = \frac{4}{\Pi}.V_{in}.\sum_{n=1,3...}^{\infty} \frac{\sin(n\omega_s t)}{n} \tag{2}$$

For the conventional LLC resonant converter, only the fundamental component of contributes to delivery power and the higher-order harmonics show evidence of reactive power. By means of notch-filter, high-order current harmonics can be injected to the Multi-resonant tank circuit. As a result, reactive power and conduction loss can be reduced. Thus, the resonant frequency f_{r3}, which provides a .0low impedance for the higher order harmonics is preferable to be designed three times of f_{r1}. In this case, the third harmonics can be utilized. However, it should be noted that, with variable frequency operation, the third harmonics injection will become weak once the switching frequency is far away from f_{r1}. The main function of the notch filter is to provide excellent voltage regulation ability of the LLC resonant converter. The resonant frequencyf_{r2} of the notch filter is designed to achieve overload protection and soft start. According to Fig. 4 f_{r2} is in the range of $[f_{r2}, f_{r3}]$. To avoid the notch filter affecting the power transfer of fundamental and third harmonics, fr2 should be not too close to f_{r1} and f_{r3}. On the other hand, to reduce the size, volume, and power loss of the notch filter, f_{r2} should be designed as high as possible. In practice,$1.5f_{r1} < f_{r2} < 2.5f_{r1}$ is recommended Similar to the multi-resonant converter, four resonant frequencies, $f_{r0}f_{r3}$, can be obtained as well with the proposed LLCLC multi-resonant converter. These resonant frequencies are given as follows,

where

$$f_{r0} = \frac{1}{2\pi\sqrt{(L_r + L_m)C_r}}$$

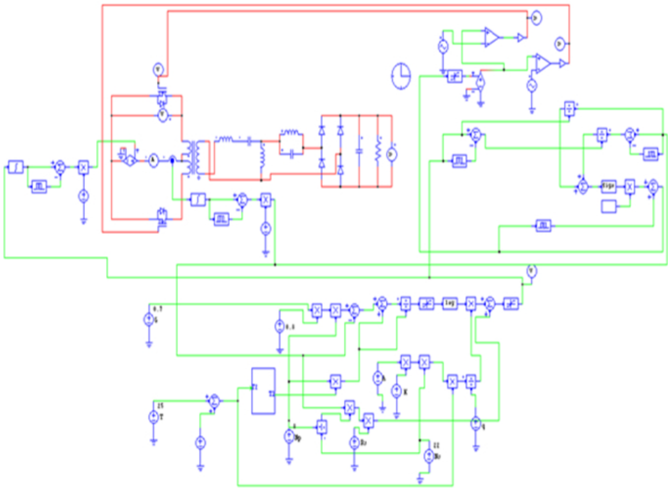

Fig. 5. Schematic file of proposed topology with MPPT control

$$f_{r1} = \sqrt{\frac{1+A+B-\sqrt{(1+A+B)^2-4B}}{2B}} * f_r$$

$$f_{r2} = \frac{1}{2\pi\sqrt{L_P C_P}}$$

$$f_{r3} = \sqrt{\frac{1+A+B+\sqrt{(1+A+B)^2-4B}}{2B}} * f_r$$

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}}, A = \frac{L_p L_m}{L_r(L_p+L_m)}, B = \frac{C_p L_p L_m}{L_r C_r(L_p+L_m)}$$

The converter is designed for a PV-sourced renewable power system. The maximum open-circuit voltage of the input source is 12.5V, while the maximum power point tracking voltage range is 7 to 9.25 V. Rated output power P_o = 50W. Lm and Lr is designed to be63.2 H and 19.8 H respectively, Cr=6.6nF according to ZVS conditions and the voltage gain requirement. Lp= 4.8H and Cp= 6.8nF are obtained. The transformer turns ratio n = 1:6 (turns of primary and secondary windings are 7 and 42, respectively). In this case, the optimized operating frequency $f_{sw} = 300KHz$.

D. SIMULATION RESULTS ANALYSIS

The proposed topology with MPPT control is simulated in PSIM as shown in Fig. 5 In the simulation LED is replaced with an equivalent resistance.

PV panel is simulated and its characteristics (Vpv, Ipv, P) at G=1000W/m2 and T=250C are shown in Fig. 6 .Output voltage and output current waveforms of the LED load is shown in Fig. 7 (a),(b). By observing MOSFET voltage and current waveforms ZVS is observed and it shown in Fig.7(c). Current through the inductor Lr and Lm on the secondary side of the transformer is shown in Fig.8 Output voltage and source current waveforms of the LED load for G=900W/m2 is

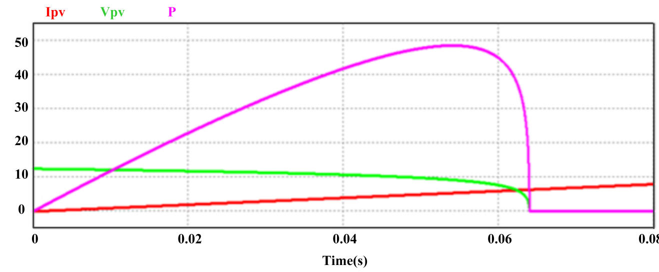

Fig. 6. PV module characteristics at G=1000W/m2 and T=250C

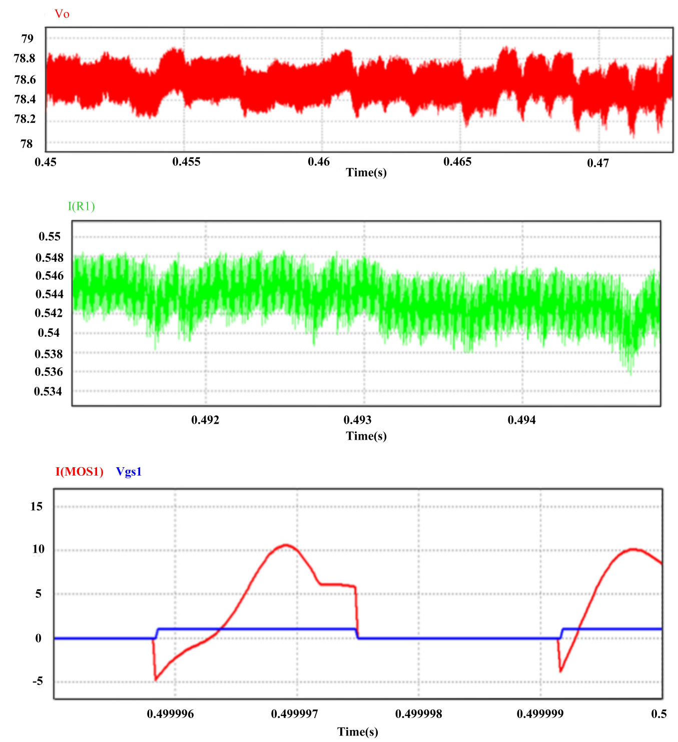

Fig. 7. waveforms for G=1000W/m2 (a) output voltage (b) output current (c) MOSFET switch current and gate-source voltage

shown in Fig. 9(a) and MOSFET switch current, gate source-voltage, and drain-source voltage is shown in Fig.9(b). Current through the inductor Lr and Lm on the secondary side of the transformer is shown in Fig. 10. Output voltage, source current and MOSFET switch current and voltage across gate-source during the over-current conditions is shown in Fig. 11. MOSFET gate-souce voltage and drain-source volatage during overloading conditions is shown in Fig. 12. Current through the inductor Lr and Lm on the secondary side of the transformer are shown in the Fig. 13 and it can be seen that, when $f_s = fr_2$ and the output short circuit occurs, the current in the resonant tank is limited.

III. CONCLUSION

This proposed topology combines all the advantages of conventional PWM Push-Pull converters which is best used for medium power applications, Multi-resonant converters for

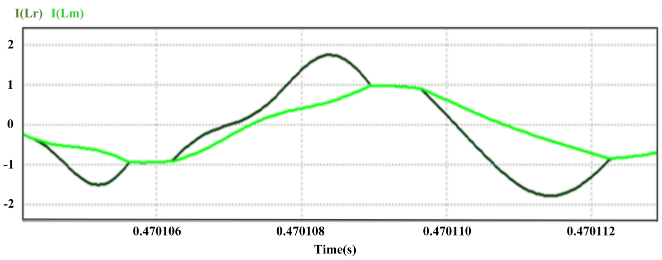

Fig. 8. current in Lr and Lm at G=1000W/m2

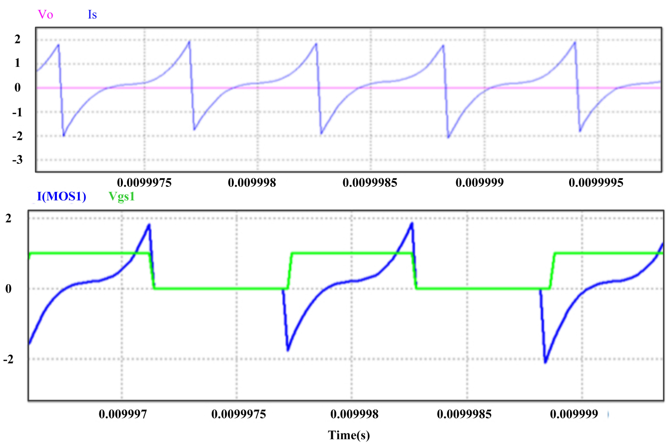

Fig. 9. Waveforms during over current condition (a) output voltage and source current (b) MOSFET switch current and the voltage across gate-source

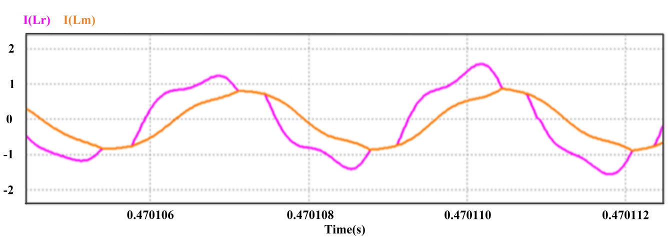

Fig. 10. current in Lr and Lm at G=900W/m2s

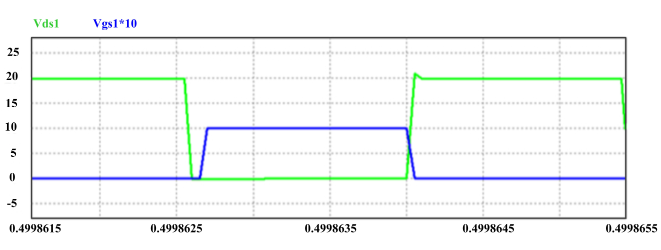

Fig. 11. Waveforms of Gate-source voltage (Vgs) and Drain-source voltage (Vds) of MOSFET during overloading conditions

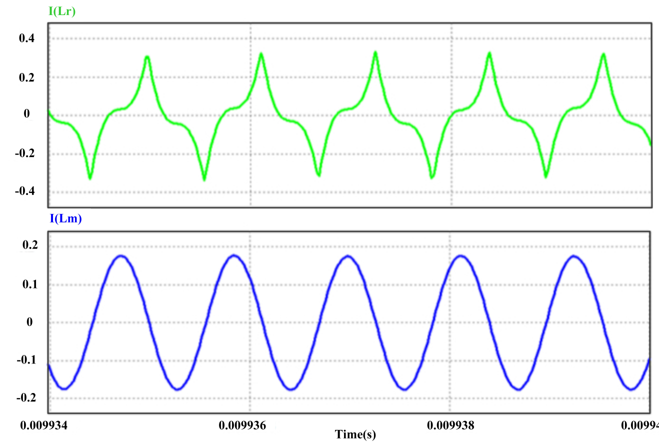

Fig. 12. current in Lr and Lm during overloading conditions

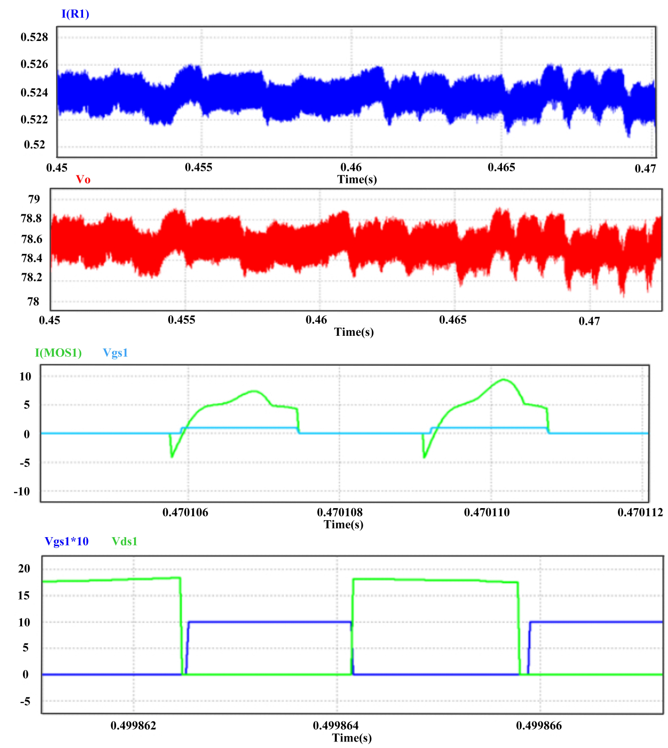

Fig. 13. Waveforms at G=900W/m2 (a) output voltage (b) output current (c) MOSFET switch current and gate-source across voltage (d) Gate-source voltage (V gs) and Drain-source voltage (V ds) of MOSFET

soft switching, notch filter for voltage regulation capability and Incremental Conductance method for MPPT control because it can achieve high accuracy for rapid changes in irradiance conditions with higher accuracy .Hence proposed method procures maximum efficiency for driving the LEDs with minimization of switching losses,so it is best suited for Street-light applications . In addition to that problem of over-current protection during overloading conditions is solved by using a notch filter.

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