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Single Stage Converter for Supplying LED Street Lighting Module

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ABSTRACT: A single stage AC-DC converter is proposed to drive a LED street lighting module. This converter consists of AC-DC full wave rectifier combined with a half-bridge LLC resonant DC-DC converter. The proposed resonant converter has lowered switching losses since it is operated in ZVS condition obtained on the two power switches. Since this converter is operated in high frequency, the volume of converter parameters is less. The proposed driver features cost effectiveness and high efficiency. Voltage mode control method is adapted to achieve feedback control. This converter is designed and simulated for Indian utility-line input voltage $230V_{rms}$. It is simulated using MATLAB simulink software for driving a 40watt LED module (40V and 1A).

KEYWORDS: LED, half-bridge LLC resonant converter, rectifier, ZVS, voltage mode control

I. INTRODUCTION

Street lighting plays an important role, keeping pedestrians, vehicles and other roadways safe at dark hours. Providing street lighting to an area is a most important, expensive and responsible job for government. Since, installation of street lamps is closely associated to development of one area or region, which in turn affects the financial status of a city. Among total annual power consumption worldwide, twenty percent of electrical power is consumed by global lighting. International energy agency (IEA) conducted a survey on global electricity utilized by street lighting. In India there are about 27.5 million street lights. Bureau of energy efficiency (BEE) conducted a survey on street lights, which says 80% of street lights were installed in haphazard manner without taking into consideration of pole distance, type and height of luminance. And thus the survey revealed that not only the lighting source but each and every aspect of street lighting must be overhauled.

LEDs (light emitting diode) have favourable features such as smaller in size, long lifetime, less maintenance cost, greater strength against breakage. Since it is mercury free it is less harmful to environment compared to traditional lighting sources. Due to several drawbacks of traditional lighting sources, LEDs have become popular and commonly been used as new lighting source for many application such as street lighting, domestic lighting, commercial lighting, vehicle and traffic lights. With excellent improvement in power capacity, conversion efficiency and reduction in price, LEDs are becoming more popular in many applications. With increasing popularity and rapid growth in electronics technology of LED has challenged electronic engineers to come up with more efficient and cost effective design of driver circuits. Since they must be driven from DC source, many types of driver circuits can be adapted according to the requirement of the LED. Many DC-DC converters have been proposed based on conventional DC-DC topologies. If the primary source is an AC source, then some type of AC-DC converter must be designed in between line and load accordingly. Nevertheless, it is necessary to design converters which perfectly fit the characteristics of LEDs. The key issues of these driver topologies are high reliability, high efficiency, power factor correction in case if AC-DC converters and in some cases galvanic isolation between line and load. According to the number of stages, these converters can be classified into one, two or three stage solutions.

Firstly, the two-stage topology is the most popular one to drive LED power supply over 100 Watt. It provides high power factor and good electricity isolation. In general, it can easily drive over 500 W. The first stage of the two-stage topology is a power factor correction circuit, such as Boost power factor collection (PFC) converter or Buck PFC converter, and the second stage is a dc-dc converter which have electricity isolation, such as LLC resonant converter or Asymmetrical Half-Bridge Converter. Nevertheless, the two-stage topology has the problems of poor efficiency, more high stress components requirement, high cost, and complex control circuits. One of the main disadvantages apart from

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the cost and size of the transformers is that the reliability problem still exists, i.e. the output capacitor has to be an electrolytic one, especially if the output voltage is relatively low. Therefore we go for single stage topology which reduces the size and cost of the driver.

This paper proposes a single stage driver consisting of a full bridge rectifier and half-bridge LLC resonant converter to supply a 40watt LED module. The proposed converter was designed to operate in Indian utility-line input range. It is designed and realized using MAT LAB simulink software.

II. PROPOSED HALF-BRIDGE LLC RESONANT CONVERTER

It is a single stage conversion consisting of a rectifier and a half-bridge resonant converter. Since it is a single stage converter, the rectifier and half-bridge LLC resonant converter are combined together to form a single stage conversion.

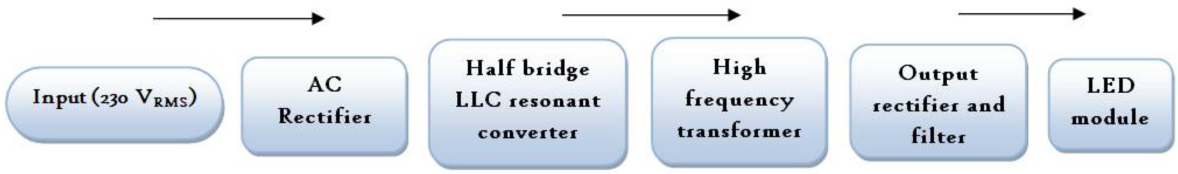

Figure.1 Basic block diagram of proposed converter

The basic block diagram of the proposed converter is given above. Since we are using AC input, there is need of designing an AC-DC converter. Therefore we need a rectifier at input side. Half bridge LLC resonant converter is an excellent choice for DC-DC application due to its best features. A step down transformer is designed to step down the high voltage to appropriate voltage required by the LED module. A synchronous rectifier and a low pass capacitor filter are used at the output stage to convert the pulsating DC to constant DC to supply the LED module. To supply constant voltage to the LED module, we select and design appropriate voltage mode control feedback loop.

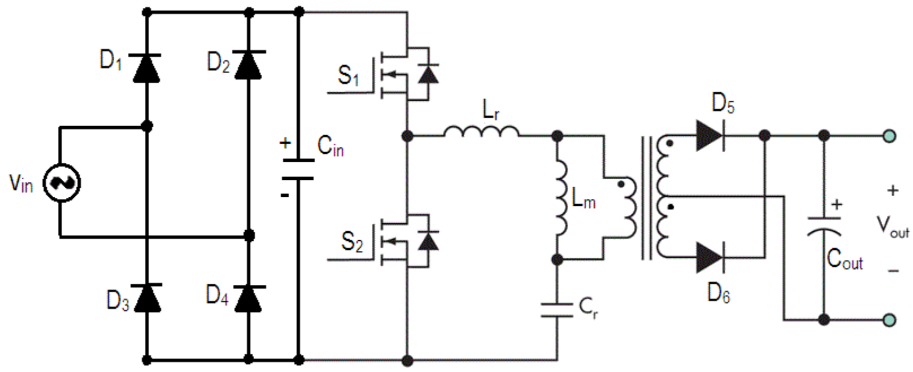

Figure.2 Single stage half-bridge LLC resonant converter

The circuit diagram of half bridge LLC resonant converter is given below. As we saw in previous chapter, the issues faced in other topologies are high circulating energy, regulation at no load condition and high input voltage due to which high switching losses and conduction losses occurs. Even it affects the converter efficiency also. The LLC resonant converter has excellent characteristics which can overcome these limitations. This converter has two resonant frequencies, higher resonant frequency determined by resonant tank circuit L_r and C_r.

$$f_0 = \frac{1}{2\pi\sqrt{L_r C_r}} \quad \text{……………(1)}$$

And the lower resonant frequency is determined by L_m and L_r, which is given by:

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$$f_p = \frac{1}{2\pi\sqrt{(L_r + L_m)C_r}} \quad \text{……………..(2)}$$

Advantages of LLC resonant converter:

i. Regulation of output over wide line and load variations with small variation of switching frequency.
ii. This converter can operate in ZVS region over entire operating range.
iii. Smaller circulating energy compared to other topologies.
iv. Essential parasitic elements including intrinsic capacitance of power MOSFET and magnetizing inductance of the transformer are used for achieving soft-switching.

The primary MOSFETs S_1 and S_2 conduct complimentary to generate a symmetrical square waveform. The resonant inductor L_r, resonant capacitor C_r, and magnetizing inductor L_m forms the resonant tank circuit which is used to shaping the waveform and filtering purpose. At the output side, a center-tapped rectifier is used for rectification purpose. The center- tapped rectifier is formed by diodes D_3 and D_4 which is connected to the secondary winding of the main transformer.

III. DESIGN PROCEDURE FOR HALF-BRIDGE LLC RESONANT CONVERTER

This section presents the design procedure for the proposed converter which supplies a 40watt LED module, which has been rated with 40v and 1a. The specification of for the presented converter is given below:

- Input utility-line voltage V_{in} (RMS value) = 230 V_{ac}
- Rated power of LED module P_o = 40watt
- Rated voltage of LED module V_o = 40v
- Rated current of LED module I_o = 1 A
- Estimated efficiency η = 90%

A. TRANSFORMER TURNS RATIO:

The turns ratio n of the transformer T_1 is given by:

$$n = \frac{np}{ns} \geq \frac{D\,Vdc\_max}{Vo+Vf}$$

B. EQUIVALENT LOAD RESISTANCE:

The equivalent circuit of the LLC resonant converter is given in the figure below, where V_{ab} is the input square wave of amplitude V_{dc}, which is obtained by switching action of the power switches S_1 and S_2. From the diagram the equivalent load resistance is given by:

$$Req = n^2\frac{Vso}{Iso} = \frac{8n^2Vo}{\pi^2 Io} = \frac{8n^2}{\pi^2}Rl$$

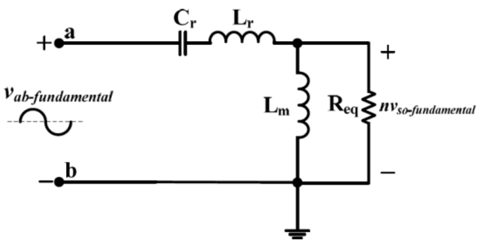

Figure.4 Equivalent circuit of LLC resonant converter

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C. DETERMINE MAXIMUM AND MINIMUM VOLTAGE GAIN:

Referring to the LLC resonant circuit, the quality factor is given by

$$Qr = \frac{\sqrt{Lr}}{Req\sqrt{Cr}}$$

The main resonant frequency and secondary resonant frequency are given by

$$\omega_{r1} = 2\pi fr1 = \frac{1}{\sqrt{Lr\ Cr}}$$

$$\omega_{r2} = 2\pi fr2 = \frac{1}{\sqrt{(Lm + Lr)Cr}}$$

Using fundamental approximation method, the voltage gain of the LLC resonant network is given by

$$Mv(\omega_s) = \frac{2n.Vo}{Vdc}$$

When switching frequency is taken equal to the main resonant frequency, then the minimum voltage gain of the resonant tank is considered as unity.

$$Mv_{min} = 1$$

And the maximum voltage gain of the resonant network is given below

$$Mv_{max} = \frac{Vdc_{max}.Mv\_min}{Vdc\_min}$$

Selecting the switching frequency and quality factor for the proposed converter, the inductance ratio L_n is chosen from the graph of voltage gain versus normalized frequency.

D. DESIGNING THE RESONANT NETWORK PARAMETERS

From above equations, we arrive at formulas for the resonant network parameters,

Resonant inductor, $Lr = \frac{Qr.Req}{2\pi fr1}$

Magnetizing inductor, $Lm = Ln.Lr$

Resonant capacitor, $Cr = \frac{1}{(2\pi fr1)^2 Lr}$

IV. SIMULATION MODEL AND RESULTS

The proposed converter is realized using MATLAB simulink software. The simulink model of the whole circuit is given below. It is driven by an AC source of 230 Vac, which is converted to DC using a full bridge rectifier. The two power switches are used to generate square wave which is then shaped and filtered using resonant circuit.

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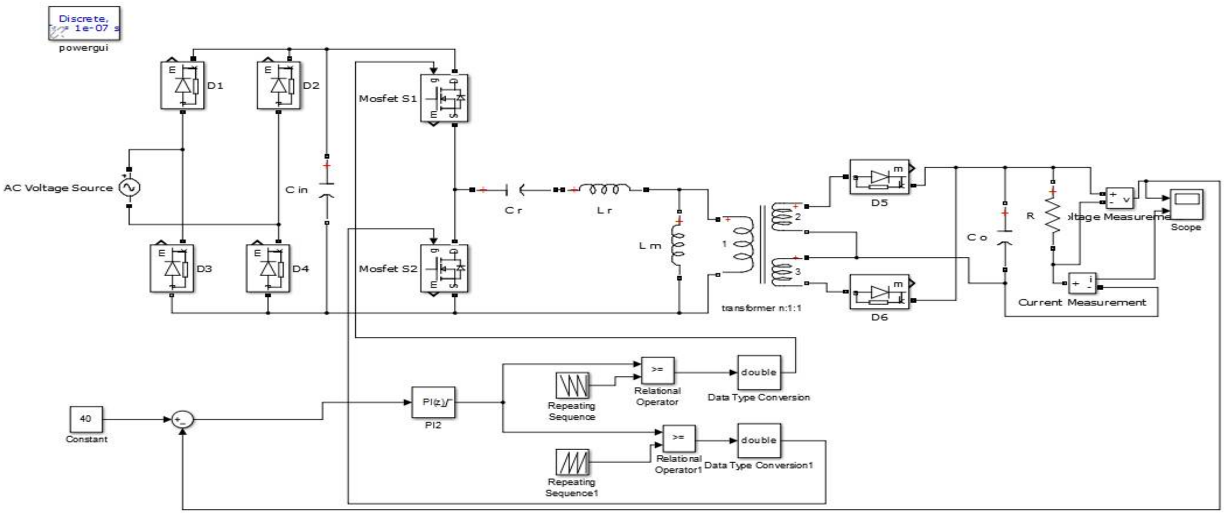

Figure.5 Simulink model

The transformer used here is designed in such a way that it steps down the voltage in order to drive the LED module. A centre tapped rectifier with a low pass capacitor filter is used at the output side to convert the pulsating DC voltage to constant DC voltage, since LED requires a constant voltage for its operation.

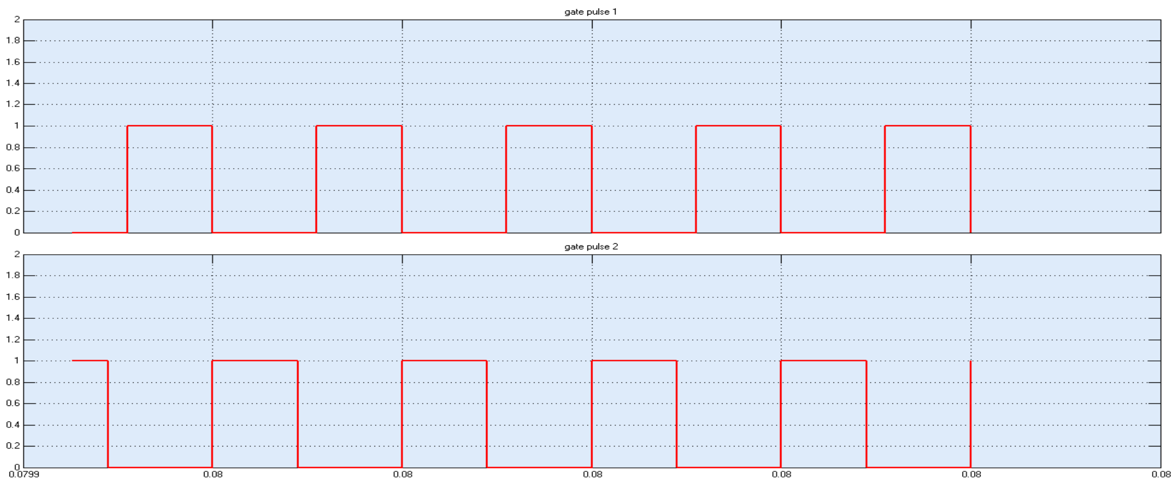

Figure.6 Gate pulses of power switch S1 and S2

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Figure.7 shows the gate pulses for switch S1 and S2 generated by voltage mode control technique. Here voltage mode control is used as a feedback control, where the output voltage is sensed and subtracted from a reference voltage in order to generate a difference signal. This difference signal is then fed to the PI controller to produce error signal, which is compared with a repeating sequence to generate gate pulses. This kind of feedback technique is easy to understand and implement, since there is only one loop. The two gate pulses are complementary with 50% duty cycle.

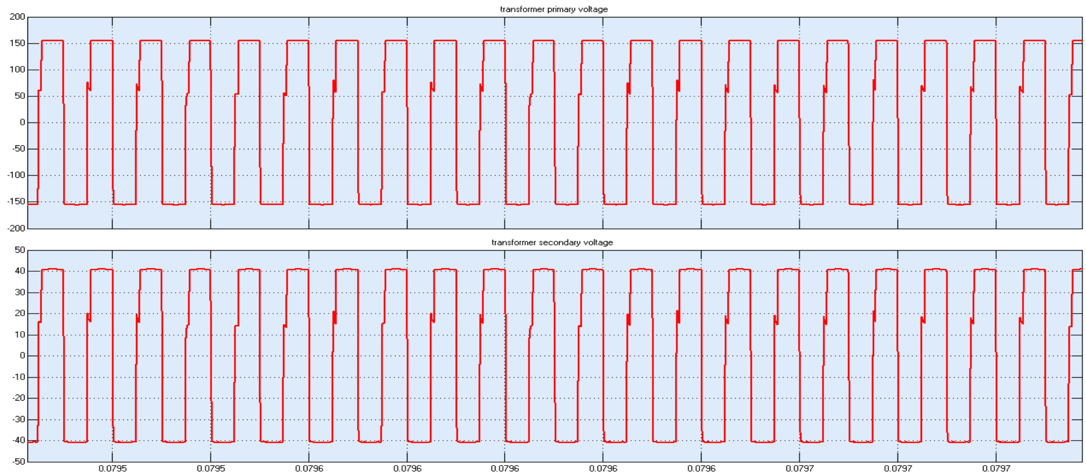

Figure.9 Transformer primary and secondary voltages

The above figure shows transformer primary and secondary voltages. Since the LED module requires 40v for its operation, the transformer is made to step down the primary voltage to 40v. We make use of a full bridge centre tapped rectifier in order to rectify the pulsating secondary voltage of the transformer.

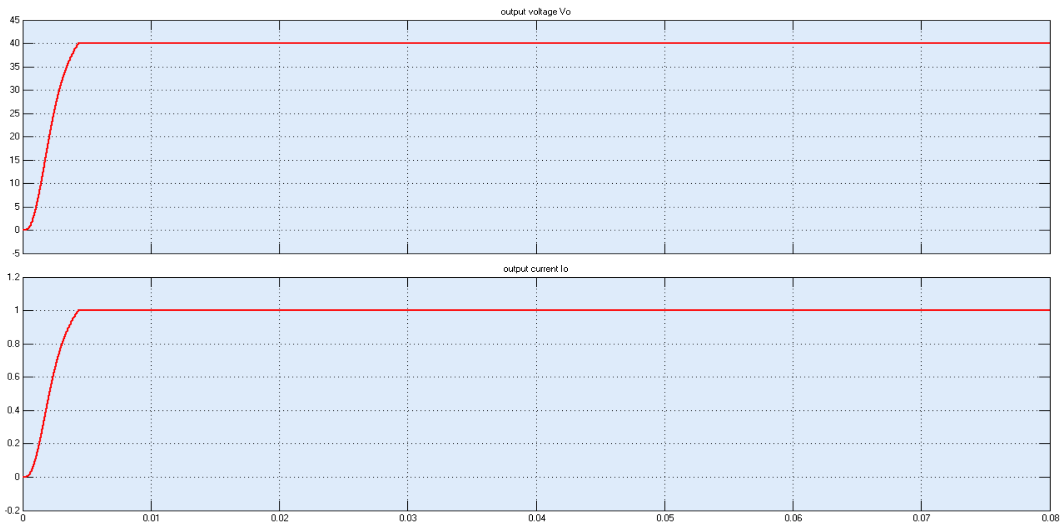

Figure.10 Output voltage and output current

The above figures are obtained simulation results of transformer voltages. Figure 10 shows the obtained output voltage and output current of the proposed converter which is used to drive 40watt LED module. In this simulation model we make use R load of 40 ohms.

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V. CONCLUSION

This paper has proposed a single stage half bridge LLC resonant converter for LED application. The presented converter is designed and realized using MATLAB which supplies the LED module. Simulation results were achieved according to the design. This converter is designed and it is suitable for Indian utility line input voltage. For feedback purpose voltage mode control technique is more convenient since there is only one loop and even easy to realize. Since it is operated in high frequency and soft switching technique is adapted, switching losses are much lesser. It can be easily realized using a experimental prototype using arduino, pic controller or integrated circuits which are readily available in market.

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