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Single Phase AC to DC Isolated ZETA Power Factor Correction Converter fed LED drives

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ABSTRACT

This paper deals with PFC-isolated Zeta converter fed LED drive to overcome the power factor problems. The proposed circuit topology consists of diode bridge rectifier and isolated Zeta converter with high frequency transformer. A single –phase supply is used to feed a DBR followed by a filter to avoid any switching ripple in DBR and the supply system. An isolated Zeta converter is operated to work under DCM mode. This combination of DBR and PFC converter is used to feed a LED drive. This converter is simulated in MATLAB platform. This converter provides better results such as unity power factor and less current harmonic distortion.

Keywords : Power factor, THD, Isolated Zeta converter

I. INTRODUCTION

Traditional light emitting diode (LED) drivers with diode bridge rectifier suffer the problem of low circuit efficiency, low power factor and low reliability. LED drivers connected to alternating current (AC) line source generally needs an additional power factor correction (PFC) stage to overcome the problem on power factor (PF) and total harmonic distortion (THD). It leads to more circuit loss in PFC stage.

In conventional converter like three phase ac-dc boost are used to increase the power factor system [1-3]. But, three phase boost converter only suitable for high power applications. Single phase AC-DC boost converters are used for LED drivers [4-5]. These converters require bulky inductance. Cuk converters are used to improve the power quality of LED driver [6-8]. Cuk converter provides negative output voltage and require current and voltage sensor. Modified Sepic converters are used as power factor correction [9-13]. These converters also require two sensing units and only provide boost operation. Three level AC-DC converters also employed as LED drivers in marine applications [14-18]. But these converters require two switches and complex control circuit. Luo converters are developed to improve the power quality the LED lighting system [19-23]. These converters are non isolated converter and it provides negative output voltage. Single phase Zeta converter is used as LED Street lighting [24-26]. This paper deals with isolated AC-DC Zeta converter for LED lighting system for improvement of power quality. So we are in the need of converter to overcome these issues to drive the LED for better performance. Hence the objective of the problem is to improve the power factor and to minimize total harmonic distortion and maximize the efficiency with the help of PI controller to generate the PWM to turn on/off the switches used in the converter. For this process, MATLAB software version 2016a is used. Converter is designed using blocks available at library in power SIMULINK. It is a simulation and model based design environment integrated with MATLAB.

Recently Zeta converter attains major role in DC/DC converter topology. It is a fourth order DC/DC converter made up of two inductor and two capacitors. It is capable of increase and decreases the input voltage levels without inverting the polarities. Zeta converter, which is originally, comes under the buck boost type and it can be regarded as a fly back converter. High frequency transformer is incorporated in Zeta converter to form isolated Zeta converter. The isolated Zeta converter has some advantages than the normal Zeta converter.

II. BLOCK DIAGRAM

The proposed isolated PFC Zeta converter is fed to LED. A single phase AC supply is feed to the diode bridge rectifier the followed by LC filter and an isolated Zeta converter. The purpose of the filter is to avoid the ripples in the input side due to switching. The proposed isolated converter is designed to operate in continuous mode. Output voltage is controlled with the help of PI controller. The repeating sequence and PI controller is used to generate PWM pulses for the MOSFET switches. A simple block diagram represents the proposed design as shown in the Fig. 1.

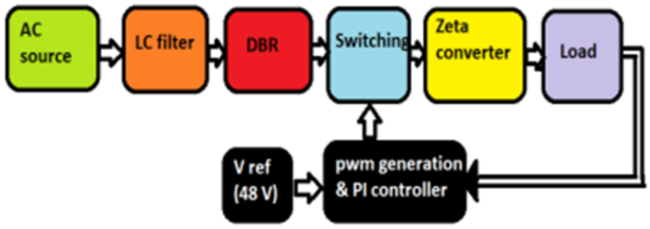

Fig. 1 : Block diagram

MODES OF OPERATION

MODE 1 : SWITCH ON MODE

Fig. 2 represents switch of the MOSFET is in ON condition. During this operation region, the diode is in reversed bias condition i.e, the diode is in off condition. The magnetizing inductor stores energy from the power received from the rectifier. The capacitor c_1 delivers energy to the load resistor via the inductor L_o and the capacitor. The current through the magnetizing inductor and the output current is linearly increasing.

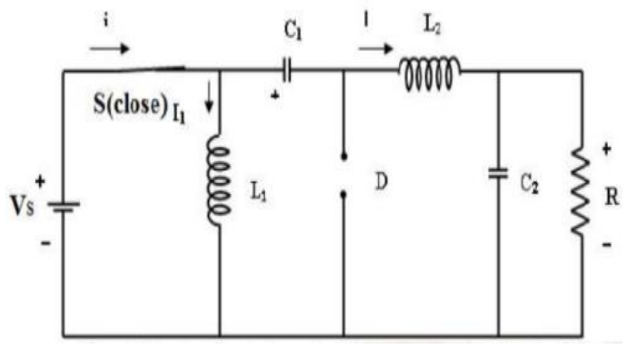

Fig. 2: Mode 1

MODE 2 : SWITCH OFF MODE

Fig. 3 represents the switch off MOSFET is in off condition. During this operation region, the diode is in forward bias condition i.e, the diode is in on condition. This is due to the reversed polarity of the magnetizing inductor. The stored energy in the magnetizing inductor is transferred to capacitor c_1. The load R receives energy from the output inductorL_o.

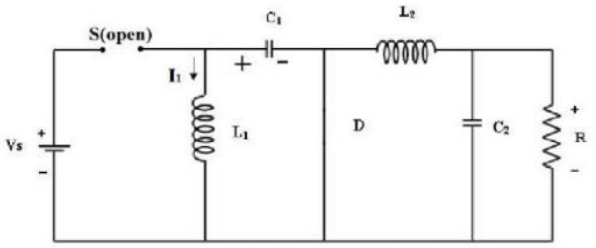

Fig. 3 Mode 2

ADVATAGES OF ZETA CONVERTER

- High frequency transformer provides input and output isolation.
- Due to high frequency operation, core area of the transformer is low. Hence the size of the converter becomes low.
- Provide buck-boost capability. Therefore, the level of the input voltage can be amplified or decreased according to the requirement of the load.
- It provides better efficiency and better voltage gain than the conventional buck-boost converter.

INTRODUCTION OF PI CONTROLLER

In general PI controller is a combination of proportional and integral controller. The output of the PI controller is the summation of proportional and integral of error signal. The error signal is generated from the comparator i.e. (comparator function is performed by subtract block). The input to the subtract block is output signal and the reference signal). The reference signal is set with the help of constant block. The value of k_p and k_i is selected by trial and error method. The value chosen for k_p and k_i value were 0.001 and 0.24 respectively for proper action. The output of the PI controller is compared with the repeating sequence generator with the switching frequency of 40 kHz. It would generate PWM pulse which controls the switching actions.

III. DESIGN OF PFC BASED ISOLATED ZETA CONVERTER

The Zeta converter is operated in discontinuous mode of operation. It involves the design of various elements such as magnetizing inductor, intermediate capacitor, dc link capacitor, LC filter value. This will be discussed in below:

1) Duty ratio for an isolated converter can be found by the equation below

$$\text{Duty ratio} = \frac{V_{DC}}{\left(\frac{n2}{n1}\right)V_{IN}+V_{DC}} \quad (1)$$

Where V_{DC} is DC link voltage, $V_{IN}$is supply voltage, $V_{IN}$is supply voltage, $\frac{n2}{n1}$is transformer turns ratio.

2) The magnetizing inductance value is obtained by using below expression:

$$L_m = \left(\frac{v_{dc}^2}{p_1}\right)\left(\frac{\{1-D\}^2}{2Df_s\left(\frac{n2}{n1}\right)}\right) \quad (2)$$

Where p_i is rated power
f_s is the switching frequency of the PFC converter.

3) The output inductor is calculated by using the expression mentioned below

$$L_o = \frac{V_{dc}\{1-D\}}{f_s k I_o} \quad (3)$$

Where, k is the output inductor current ripple and I_o is the output inductor current

4) Intermediate capacitor can be calculated below expression

$$\frac{DV_{dc}}{V_{dc}\sqrt{V_s}}\left(\frac{P_i}{V_{dc}}\right) \quad (4)$$

5) The expression for the dc link can be determined by the equation (5)

$$c_d = \frac{1}{2w(pv_{dc})}\left(\frac{p_i}{v_{dc}}\right) \quad (5)$$

Where c_d is the capacitance of dc link capacitor.

IV. BLOCK PARAMETERS

Table 1 Design parameters

DESIGN PARAMETER	VALUES
L_f (filter)	$16e^{-3}$ H
C_f (filter)	$470e^{-9}$ F
L_m (magnetizing inductor)	$200e^{-6}$ H
C_1 (intermediate capacitor)	$250e^{-9}$ F
C_D (DC link capacitor)	$4600e^{-6}$ F
L_O (output inductor)	$3e^{-3}$ H
Output voltage	48
Resistor	100 Ω

The values for the magnetizing inductor, dc link capacitor, output inductor, intermediate capacitors, inductance and capacitance of inductor and capacitor are calculated by keeping ripple values of output current and output voltage. The switching frequency is chosen as 40 kHz. The specification used in the design model is tabulated as shown in the table 1

V. OPEN LOOP CONFIGURATION

It consists of source voltage which is fed to the diode bridge rectifier. The output of the diode bridge rectifier is fed into the isolated Zeta converter with the resistive load. The ripple in the input current can be minimized by choosing the optimum LC filter between the input and diode bridge rectifier. Switching frequency for the MOSFET switch would be 40 kHz.

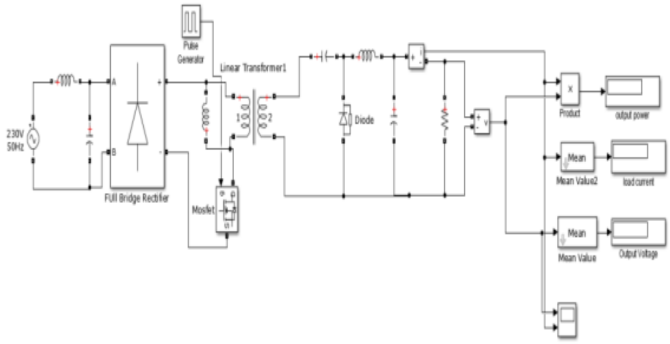

Fig. 4 Open loop Simulation

VI. CLOSED LOOP CONFIGURATION

The open loop configuration of the converter is changed to closed loop controlled converter with PI controller. The comparator, repeating sequence, PI controller is used to generate the PWM pulse for MOSFET switches to regulate output voltage constant for varying supply voltage and for varying load. Closed loop configuration is shown in Fig.5.

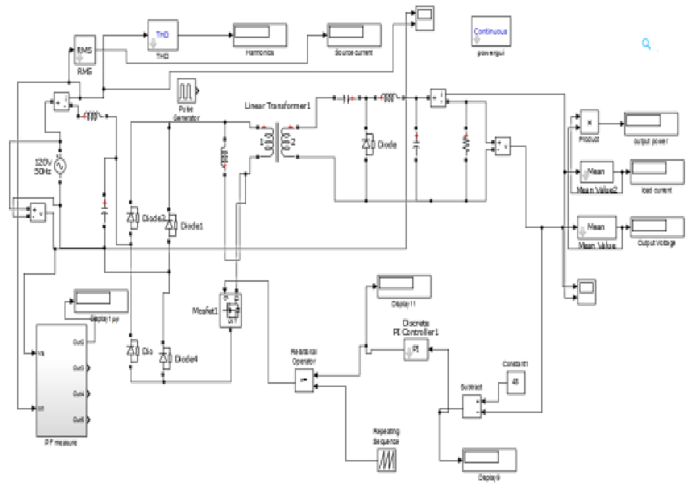

Fig. 5 Closed loop Simulation

VII. ANALYSIS of VARYING INPUT VOLTAGE

By keeping the load constant, the input voltage is varied widely to understand the performance of the converter for varying input voltage. Input current, power factor, output current output voltage, total harmonic distortion readings are noted and tabulated as in table 2. Output power, input power, efficiency values are calculated and mention in table 2.

S.no	Vin (V)	Is (A)	Vo (V)	PF	Is THD (%)	η (%)
1.	120	0.921	48.0	0.997	3.3	90.8
2.	150	0.779	47.9	0.993	2.8	86.2
3.	180	0.606	48.0	0.996	2.7	91.9

Table 2 : Analysis of Input voltage

VIII. ANALYSIS OF VARYING OUTPUT LOAD

For determining the input current, THD, power factor, output current, output voltage for varying load, keep the input voltage at constant 120V. The resistive load is varied and readings are tabulated as in the table 4.2 and in the table 3.Load resistive value 23.04ohm and 50 ohm equivalent value of the LED drive is considered for this analysis. Input power, efficiency were calculated and mentioned in the table 2 and in the table 3.

S.no	Vin (V)	Vo (V)	THD (%)	PF	R_L
1.	120	48.01	3.31	0.997	23.04
2.	120	48	3.33	0.9996	50

Table 3 : Analysis of Load Variation

IX. SIMULATION WORK RESULTS

Simulation is performed in the MATLAB for the proposed converter design. Power factor is maintained almost unity.THD is maintained below 4% which is the acceptable range of value. Parameter values used for the simulation work are found out from equation available.. Source voltage and source current is simulated and graph is obtained in the scope of SIMULINK which is shown in the Fig. 6 and Fig. 7. Fig. 6 represents the input voltage waveform. The input 120 V, 50 Hz is given to the circuit. The power factor is maintained almost unity.

Fig. 6 Input voltage waveform

Fig. 7 represents the input current waveform. The current waveform attains its steady state value after 0.3 sec. The mean value of the input current is 0.921 A. The harmonics in the input current waveform is removed by LC filter. The source current THD is less than 4%.

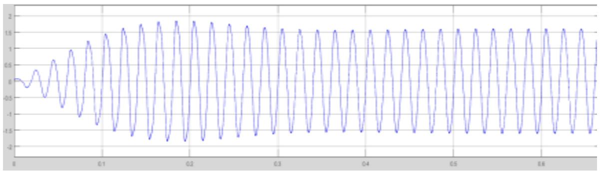

Fig. 7 Input current waveform

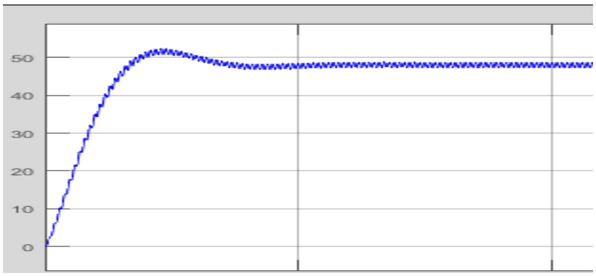

Fig. 8 Output voltage waveform

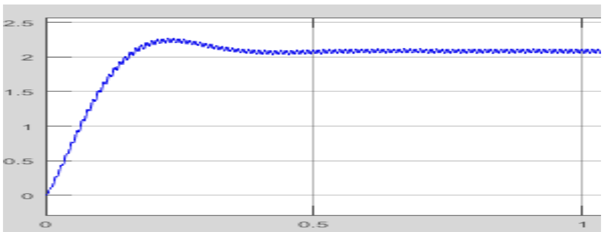

Fig. 9 Output current through the load resistor

Output voltage and output current also obtained in the scope of the MATLAB software as shown in the Fig. 8 and 9.

X. CONCLUSION

The proposed converter is to reduce the power factor, total harmonic distortion and to improve the efficiency of the converter. Various analyses have been done to compare the converter with the conventional converter. The power factor at the input side is maintained almost unity. Total harmonic distortion is maintained below 4% which is lie within the acceptable limit as stated by the standards. Efficiency of the converter is maintained almost around 90%. As high frequency transformer is included in this topology, it provides complete isolation between the input and output side. Thus the low power circuitry system is separated from the high power AC mains. This converter has attention towards the low power application because of the compatible size. The proposed converter is suitable for LED drives to operate efficiently.

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