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Buck Converter Based LED Driving Topology for Solid State Luminaire

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ABSTRACT

This Paper deals with the practical implementation of 20W LED power driving circuit for domestic lighting. In this work, buck converter topology is implemented using controller IC MT 7834. It has integrated MOSFET which is used to provide constant output current with Single-stage active power factor correction, and benefits like higher efficiency, overvoltage protection, overcurrent protection & overtemperature protection. The circuit is operated in Quasi-Resonant mode to achieve higher efficiency. This paper also consists of test report which is carried out over the actual hardware of 20W LED power driving circuit. Finally experimental results shows that proposed LED power driving circuit is best suited for the household lighting applications.

Keywords **—** Buck converter, MT 7834 with integrated MOSFET, Quasi-Resonant mode, Test report and related graphs.

I. INTRODUCTION

Solid-State lighting (SSL) is an emerging technology with potential to greatly exceed the efficiency of traditional lamp-based lighting systems. Whereas energy efficiency is the primary motivation behind SSL, LEDs are also anticipated to bring entirely new functionalities to lighting systems, greatly enhancing the ways in which we use light. LEDs have already replaced traditional lamps in a number of lighting systems, including traffic lights, signs, and displays [1]. About 25% of total electrical power generated is consumed for residential, commercial and industrial lighting applications throughout the world [2]. Hence development of green technology is highly demanded as energy crises and the environmental issues are considered on priority. As energy consumption by illumination equipment is significantly high so there is a need to implement cost effective and energy saving solution over conventional lighting sources. LEDs has many merits over conventional lighting sources i.e. light in weight, energy saving, small in size, high luminous efficiency, environmental friendliness and longer life time. The implementation of LED lighting is based on constant current at the output side, so it is prime important to develop driving circuit for LED string [3]. Hence switch mode power supply in various configurations are used for LED power driving. In recent years, many integrated-stage topologies are designed for the sake of efficiency and cost, as shown in Fig.1 [6]

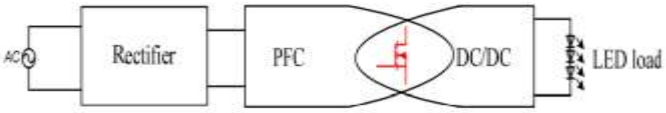

Fig.1 Block diagram of LED driver with integrated MOSFET

In order to obtain high PF and low THD, a topology which performs power factor correction characteristics as PFC stage is usually chosen, and a DC/DC stage is selected according to the power level of the system. Due to the integration technology, the PFC stage and DC/DC stage can be simplified into one stage by sharing active power switches and control circuits. Therefore, cost and size of the system is reduced while ensuring high efficiency, high reliability, and fast output dynamics [6]. In low power applications, single stage buck and flyback PFC converter topologies are most suitable because of low component count and cost [4]. But high voltage stress across the MOSFET switch experiences ringing effect in flyback converter. When the peak and average current of flyback is relatively high, the energy loss of switch will be increased. Hence additional snubber circuit is needed.

Buck topology is the most typical step-down circuit. The output voltage of Buck circuit is lower than input voltage peak value. Therefore, for DC-to-DC converter stage, the bus capacitor of low voltage stress can be selected. It suits the situation of high voltage ratio between input voltage and output voltage. Buck circuit has few components and simple structure. For the integrated-stage LED driver, when front-stage PFC Buck circuit works in discontinuous conduction mode (DCM), a natural PF function will be achieved [6].

In practice, the topology of LED driver can be selected according to the requirements-indoor or outdoor use, including performance parameters like power factor, harmonic distortion, cost, galvanic isolation, lifetime, temperature and applications. For indoor applications, such as general lighting, ballasts should be compact, low cost, and of minimal component counts Ballast is common term used for all type of lamp drivers, also known as starter. e.g.

Electronic ballast or magnetic ballast [5].

In general purpose lighting applications, a popular type of switched mode power supply buck converter is suggested for high efficiency & power factor correction with low component count and reduced cost [4],[6]-[8].

The proposed project work consists of Single-stage active power factor corrected 20 watts buck converter based LED driver operating in QRM mode. The proposed project is based on quasi resonant mode of operation. According to driving method using MT 7834 circuit is assembled and tested to verify its current stability over input voltage range

This paper is divided into six different sections. In section I, basic introduction about LED power driving circuit is discussed. In section II, necessity of LED power driving circuit and methodology of proposed project work are presented. In section III, proposed technique of QRM based buck converter for LED power driving is explained. In section IV, experimental results are discussed with test report of 20W LED power driving circuit & their related graphs are also being plotted.

II. METHODOLOGY

Based on the electrical characteristics of LEDs and variation in ac power supply , a constant current driver is needed to support the LED working performance [6]. Constant current makes the stability in the brightness of all LEDs which are connected in the string.

For most non-isolated converters, including Flyback converter, switches are operated in hard switch mode, which decreases the efficiency of system. Therefore, innovative soft switch technologies are put forward to solve the problems, such as quasi-resonant switch control method [6].

Quasi-resonant technology is used to reduce the Switching loss of MOSFET [13]. In order to meet power quality norms, active power factor correction (PFC) is needed. The cost and efficiency are prime concern for LED driver market. In order to address these concerns, a solution using a single stage single switch in quasi-resonant active switching mode (QRASM) is proposed. The single stage and single switch AC-DC power converter uses a single active switch preferably metal-oxide field effect transistor (MOSFET) for PFC as well as for constant current control QRASM is used to increase efficiency of power converter by reducing switching losses using a low cost control system [9].

Comparing to conventional buck converter, resonant buck converter includes a resonant tank equipped with resonant inductor and capacitor. To solve the problem occur during switching, the zero-current switching (ZCS) and zero-voltage switching (ZVS) techniques have been introduced. switching loss could be significantly decreased with ZCS. In ZVS technique, the voltage on the switch is forced to be zero with resonant before turn-on. When the current reaches to zero, switching signal is applied to turn-on the switch. Hence, the loss arises during the turn-on greatly decreased [18]. Basic arrangement of full wave quasi resonant topology is shown in fig.2 below.

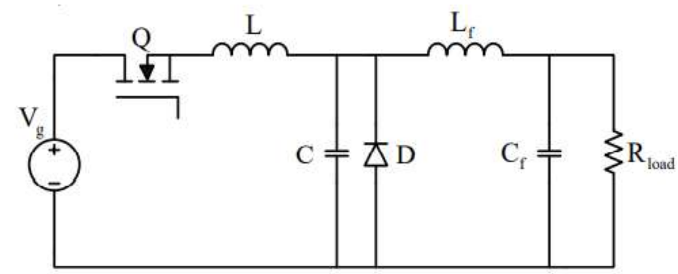

Fig.2 Full wave quasi resonant circuit Topology

Ref. [18], full wave buck converter quasi resonant circuit is a special version of traditional buck converter which uses resonant intervals to ensure soft switching of the semiconductor device like MOSFET. Ref. [21], inductor must have higher current rating than the maximum current drawn by LED load. Four important parameters are considered to design the power stage in buck converter. They are input voltage range, nominal output voltage, maximum output current, the type of integrated circuit used to operate the buck converter. Hence some parameters are selected directly from the data sheet.

III. PROPOSAL OF QR MODE BUCK CONVERTER

Proposed LED power driver circuit consist of a surge protection circuit, rectifier, filter and QRM based buck converter. The output of this buck converter is connected to four parallel strings of 24 series LEDs each.

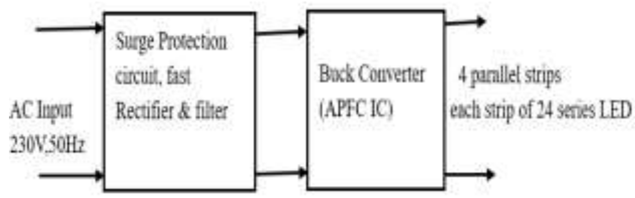

Fig.3 Block Diagram of proposed LED Power Driving Circuit

The surge protection Circuit, fast diode Rectifier: Surge Protection circuit made up of Fusible resistor and MOV. A Fusible Resistor (0.47 ohms) is a wire-wound resistor that is designed to burn or open easily when the power rating of the resistor is exceeded.

The main purpose of rectifier circuit and filter is to provide the raw DC voltage from the input AC voltage. Usually, the rectifier is a diode bridge which is available as a single four-terminal module.Diode ES 1J are used to achieve superfast recovery time for high efficiency.

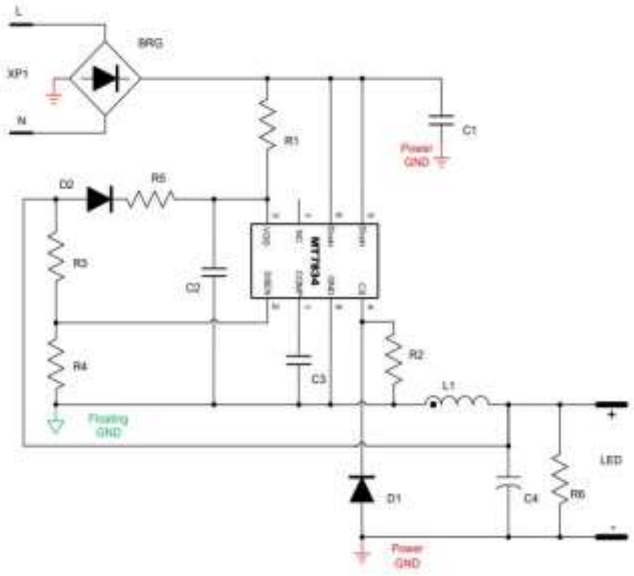

Fig.4 Application circuit of Buck LED driver (www.maxictech.com)

The MT7834 integrates power factor correction function and works in Quasi-Resonant Mode (QRM).

Refer fig.4, internally start up circuit accurately regulates LED current through sensing the inductor current signal. The LED current can be easily set by:

$$I_{LED} = \frac{V_{FB}}{R_S}$$

Where V_{FB} (=200mV) is the internal reference voltage and R_S (Here R2) is an external current sensing resistor which is connected between CS pin 4 and floating ground. The diode which is used in output side must handle power dissipation which is a product of forward current & Forward voltage.

During start-up, the capacitor C2 at VDD pin3 is charged through the resistor R1 which is connected to main line voltage. The internal control logic starts to work when VDD reaches 18V. The COMP pin 1 is, therefore, pre-charged during this process. The internal control loop is established. Once the voltage of COMP pin1 reaches 1.4V, the whole system works in normal operation mode. As the VDD supply goes below 9V, the system is considered to be undervoltage lockout, the PWM signal to MOSFET gate goes low, and the voltage of COMP pin1 is discharged to 0V. The voltage waveform of the inductor is sensed during PWM OFF period for switching logic control, short-circuit protection (SCP). The DSEN pin 2 senses the inductor voltage through a resistor divider R3 & R4.

When overvoltage or short circuit condition is detected, the PWM signal disables the internal MOSFET and start up sequence is initiated again. If the fault condition is removed the LED driver goes back to normal. This process is known as hiccup mode.In case of overcurrent, the voltage at CS (current sense) pin 4 exceed 1.4V, the internal drive signal turns off the MOSFET. Thus internal MOSFET, inductor and output circuit components prevented from damage.

Table 1: Test Report of proposed scheme

Vin (Volts)	90	170	230	250	270
Iin (Ampere)	0.215	0.13	0.094	0.087	0.082
Pin (Watts)	18	21.4	21.2	21.1	21.2
Vout (Volts)	71.1	73.8	73.8	73.8	73.8
Io (Ampere)	0.186	0.27	0.266	0.266	0.266
Pout (Watts)	13.22	19.6	19.63	19.63	19.63
Efficiency (%)	73	91.7	91.72	91.72	91.72
Power Factor	1	0.99	0.99	0.98	0.98
Athd (%)	31.81	17.7	16.1	16.15	16.14
Vthd (%)	4.25	2.96	2.59	2.74	2.74

The test report of proposed scheme is presented in Table 1. LED power driving circuit is assembled and tested with 96 light emitting diodes. The measurements are carried out on SONIT dpm101 meter. The setup is shown in fig. 9

IV. EXPERIMENTAL RESULTS

Following graphs are obtained on digital storage oscilloscope. It shows behaviour of rectifier and MOSFET.

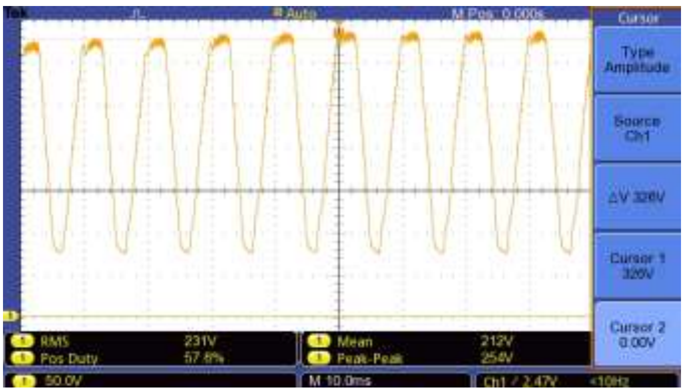

Fig. 5 Rectifier output

Instead of electrolytic capacitors, we have used plastic film capacitor to the output side of rectifier. Plastic film capacitors handles large voltage, offer high stability, long shelf life, low equivalent series resistance, low self-inductance, and a high ability to absorb power surges. Fig. 5 shows rectifier output voltage waveforms. Rectifier output waveforms is modified due to feedback detection and PWM controller. Fig. 6 shows output voltage waveform across external current sensing resistor R2 (pin 4 and pin 8). Fig. 7 shows the switching frequency & voltage waveform across MOSFET.

The duty cycle is given by D= Ton/T

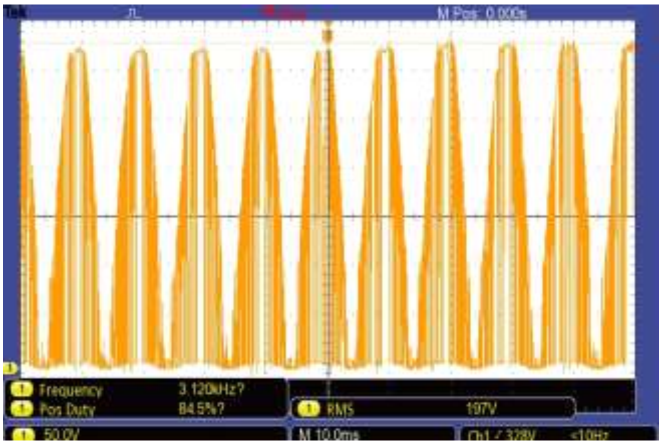

Fig. 6 Rectifier output with carrier

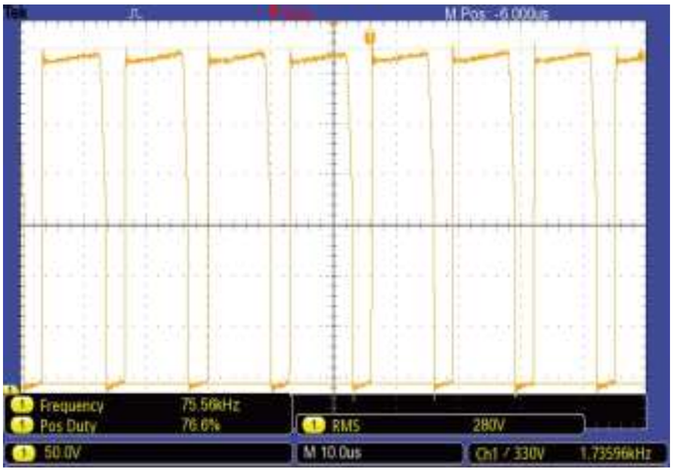

Fig 7 Voltage V_{DS} across Internal MOSFET

Fig. 8a Experimental Setup for Obtaining Test report

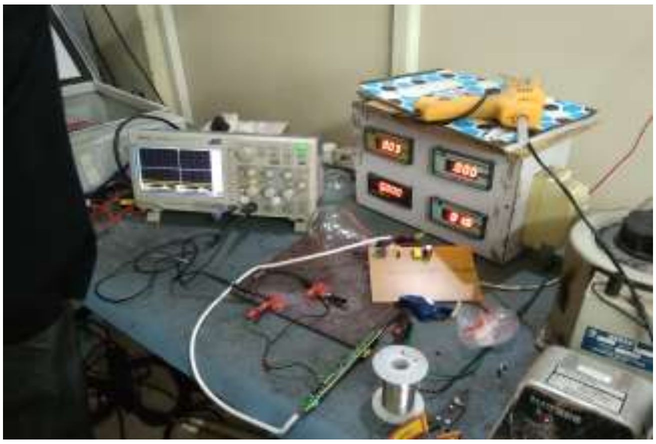

Fig. 8b Experimental Setup for Obtaining Test report

Fig. 9a Front side of LED Driver board

Fig. 9b Rear side of (SMC) LED Driver board

Following are the graphs which are obtained from the test report.

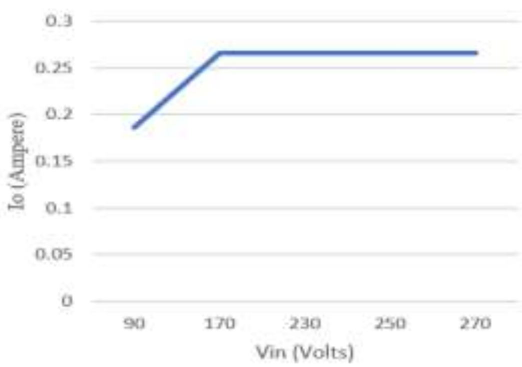

Fig.10 Output current (I_0) Vs Input Voltage (V_{in})

Figure 10 shows Output current (Io) Vs Input Voltage (Vin) response. This load regulation curve shows that output LED current is constant for input voltage range of 170 to 270 V ac. Figure 11 shows Efficiency (%) VS Input Voltage (Vin) curve which shows that efficiency of proposed LED driver circuit is 91.72% for input voltage range of 170 to 270 V ac. Efficiency is constant for this desired voltage range. Figure 12 gives the relation of power factor Vs input voltage curve. This curve shows that power factor changes from 0.99 to 0.98 over the input voltage range from of 170 to 270 V ac.

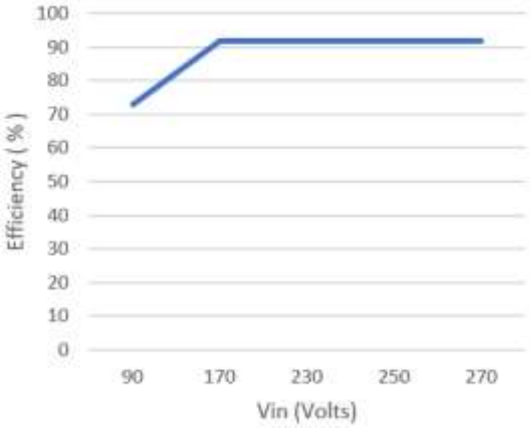

Fig.11 Efficiency (%) Vs Input Voltage (Vin)

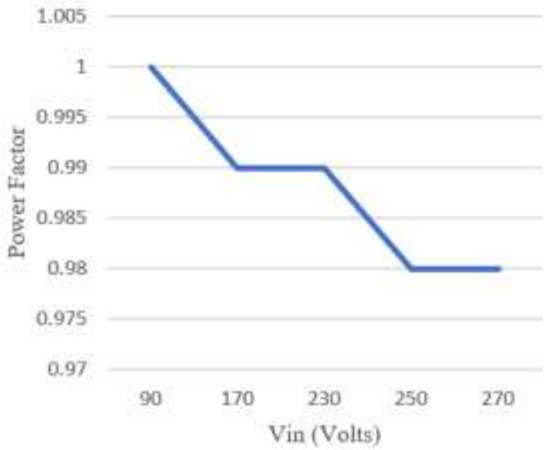

Fig.12 Power Factor Vs Input Voltage (Vin)

Fig. 13 shows total harmonic distortion curve. The curve shows that low THD (less than 21%) is obtained. The results are within the acceptable limits indicates the proposed scheme is best suited for lighting applications (Maxic Technology) [11],[19]

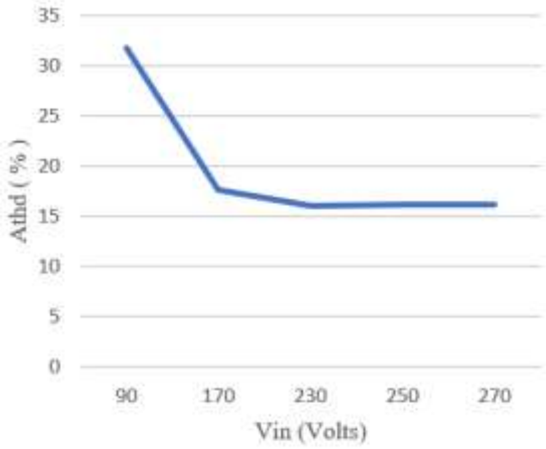

Fig.13 Athd (%) Vs Input Voltage (Vin)

V. CONCLUSIONS

An LED power driving circuit with having improved power factor for lighting applications has been presented in this paper. The buck converter based topology in quasi resonant mode is used to satisfy present standard requirements. The controller IC MT7834 is used in this driving circuit which improves the power factor of the proposed circuit. The proposed scheme has been implemented successfully, obtained experimental results and test report provides better performance parameters. The proposed topology works as a good solution to implement low cost, high power factor LED driving circuit for lighting applications.
Limitation of this circuit isolation is not provided. So cannot be used for outdoor (e.g. street light) applications. In future, an isolated buck converter with quasi resonant topology can be implemented for outdoor applications.

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