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A Single Switch Low Cost LED Driver with Wireless Dimming Controls

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Abstract*— In order to nullify the source and light output power and to minimize the low frequency LED current ripple, electrolytic capacitors are generally used for energy efficient residential, industrial and commercial lighting. The life of an electrolytic capacitor is at least 13 times less than that of an LED bulb which affects the life of the LED lamp. To increase the age of the LED lighting fixture, an offline LED driver that does away with electrolytic capacitors or intricate input current control techniques to reduce the low-frequency (i.e., 100 or 120 Hz) output ripple is presented here. The single switch circuit reduces the energy storage capacitance to a few microfarads range, so that reliable film capacitor can be used instead of unreliable electrolytic capacitor. Simulation and hardware results are given on a 8-W LED lamp to validate the novelty of the circuit. The remote controlling mechanism enables to automatically turn ON ,OFF and dim even the non dimmable LED lighting system. Moreover, the system is suitable for any industrial. commercial and industrial lighting applications. The LED driver system also operates with high power factor of 0.99 in accordance with Energy star criteria for Solid State Lighting Luminaries and low Total Harmonic Distortion of 20% which is within the limits of IEC 61000-3-2 Class C standards. There is no flickering as the switching occurs at high frequency.

Keywords*— Current Ripple, Electrolytic Capacitor, Light Emitting Diode (LED), Power Factor, Total Harmonic Distortion,Flickering

I. INTRODUCTION

Over 25% of the worldwide energy consumption comes under lighting industry in the form of industrial, residential and commercial lighting. To improve the energy efficiency, solid light emitting diode (LED) lamps are used as they are eco friendly, mercury-free, durable and long lasting. LEDs are thermally susceptible devices and their working is determined by the driving current in the LEDs. A current limiting control by changing the duty cycle ensures proper LEDs operation. Harmonic content of the AC source current due to lighting loads such as the LED lamps should be within the IEC 6100032 Class C standards for residential or industrial lighting applications operating at 50Hz AC frequency [2]. In addition, the Energy Star Criteria for Solid State Lighting Luminaries states that the input line power factor of the LED lighting in commercial and residential lighting purposes should be higher than atleast 0.9 and 0.7 respectively [3].

Active power factor correction incorporated LED driver circuit [3] can be a single-stage switch-mode DC/DC converter (i.e., buck, buck-boost or flyback) or a dual-stage converter that consists of a front-end boost converter [4] for power factor correction (PFC) as shown in Fig. 1. The dual stage driver reduces energy storage capacitance (C_d) due to larger input impedance of the second stage DC/DC converter, but the increases the electronic components leading to bulkier size and higher cost of the driver circuit increases causing lower efficiency. Operation at high power factor with a sinusoidal AC-input current leads to pulsating input power. There is a need to compensate the energy difference between the fluctuating source power and the output DC power delivered to the LED load by incorporating large output capacitor. Large deviation in the low-frequency ripple of the LED current causes visible flickering irritating human vision causing malaise, seizures, headaches etc [5].

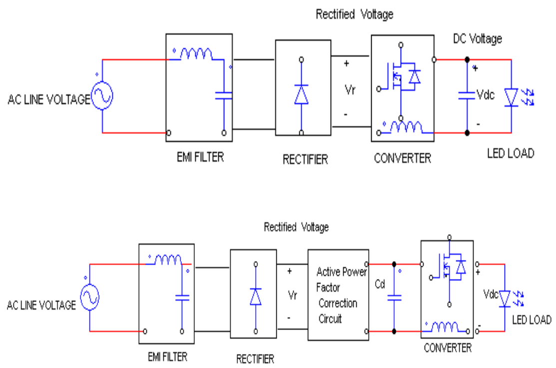

Fig. 1. Common offline AC/DC one stage and dual stage LED driver

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II. PROBLEM IDENTIFICATION AND SOLUTION

To enable compact LED driver size and low cost, aluminium electrolytic capacitor is the most commonly preferred energy storage device due to its high energy density and low cost. Lifetime of electrolytic capacitor is only 5000 hours compared with the life span of an LED lamp, which lasts 100000 hours thus hampering the natural life of overall LED system [6]. Aluminium based electrolytic capacitors are vulnerable to their operating temperature, ripple current, internal equivalent series resistance and have low electromagnetic immunity and low overvoltage capabilities and are therefore unreliable. As a literature survey, various AC/DC driver alternatives devoid of electrolytic capacitors for LED lighting was analysed. In [7], flyback converter using a bidirectional buck-boost converter at its output was used to absorb the pulsating component of the LED current to eliminate low frequency component of the output current and the output energy storage capacitor used in the conventional flyback converter. In [8], a modified flyback converter with an additional auxiliary winding and three switches was presented to provide almost constant current to the output. In [9], a coupled inductor PFC single-switch LED driver circuit is proposed but the switch suffers very high current and voltage stress as the switch needs to handle both PFC inductor current and LED current resulting in low efficiency. In [10], an isolated single-switch AC/DC electrolytic capacitor-less LED driver was proposed but the three winding transformer increases the cost and size. In [11], a electrolytic capacitor-less LED driver based on two flyback converters was proposed but it doesn't have the dimming feature for current control.

Usual driver circuits incorporate intricate power circuit topologies (multiple switches or many working levels), feedback current control methods to minimize bulkiness of the energy storage capacitor or involving large sized high voltage film capacitors. A simple, reliable aluminium capacitor-less driver with a remote controlled feature to implement automatic ON,OFF and dimming controls for even the non dimmable LED bulbs is projected here. It is a one-stage one-switch circuit that produces high frequency pulsating output current without any current regulating method to control the low-frequency ripple in the output current.

III. DERIVATION OF THE PROPOSED CIRCUIT

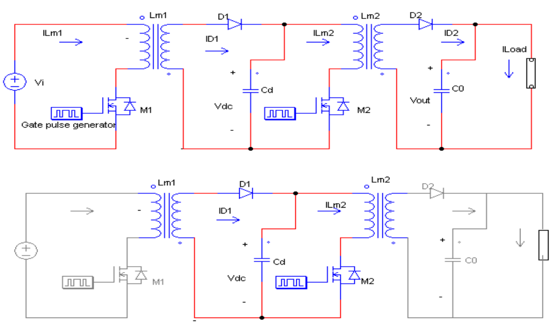

Fig. 2. Development of novel driver circuit from cascaded flyback converters

The energy storage section is transferred from output to the intermediate rectifier stage of the converter to reduce the energy storage capacitance. Two Discontinuous Continuous Mode (DCM) flyback converters are cascaded in series illustrated in Fig. 2. Suppose switches M_1 and M_2 has the identical switching frequency, duty ratio and same turns ratio for L_{m1} and L_{m2}, then winding currents I_{Lm1} and I_{Lm2} both increase in a linear fashion when the switches are on and diode currents I_{D1} and I_{D2} both freewheels the current when the switches stop conducting. There will be magnetic coupling between the secondary winding of L_{m1} and the primary winding of L_{m2} as shown in Fig. 2. Load will be driven by a high frequency pulsating triangular current when it is connected in series with the primary winding of L_{m2} and a voltage source in series with the secondary winding of L_{m1} acts as the energy source.

The final LED driver circuit is composed with MOSFET switch (M), ultra fast-recovery diode (D_1), an energy capacitor for storing energy (C_d), high frequency filtering capacitor (C_1) and a coupled inductor with primary and secondary windings (N_p and N_s) and with inductance (L_m), where L_m represents inductance with respect to primary winding as shown in Fig. 3. Input current flows through the diode instead of the switch. Diode carries the input current instead of the switch. The capacitance necessary to lessen the output ripple gets minimized due to energy feedback process of coupled inductor L_m to the dc-link capacitor (C_d). Small size film capacitor can be used instead of electrolytic capacitor. A high frequency pulsating current drives the LED output due to the operation of series connected L_m and the switch (M).

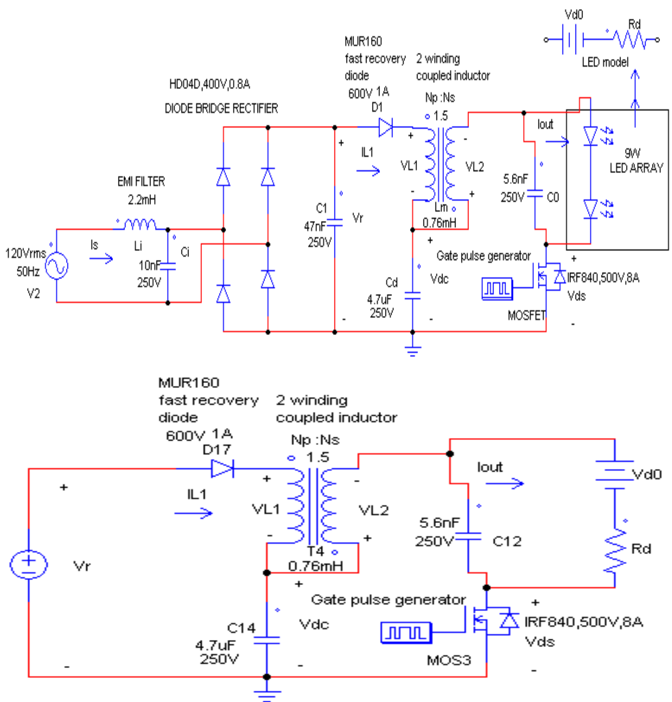

Fig. 3. LED driver circuit and Simplified circuit with rectified voltage source

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A. Working of the driver circuit

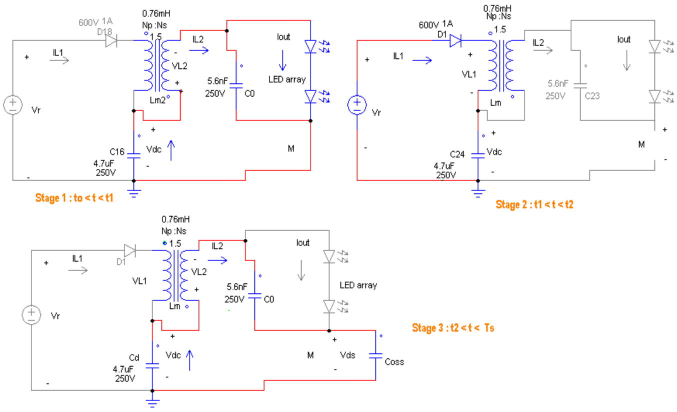

Fig. 4. Working stages of driver circuit

[Stage 1: $t_0 < t < t_1$]: When the gate pulse(V_g) is applied and MOSFET starts conducting, output current (I_{out}) flowing through the lamp rises and LED bulb glows.

[Stage 2: $t_1 < t < t_2$]: When the gate pulse (V_g) is with-drawn, MOSFET stops conducting and the switch voltage (V_{ds}) increases and I_{out} drops to zero. The polarity reversal between the two windings of L_m turns D_1 in conduction and the energy retained in L_{sec} gets transferred to C_d through the primary side of L_m. Rectified voltage V_r is lesser than V_{dc} which makes V_{L1} negative leading to linearly reducing I_{L1} (is the discharging phase of L_m current). Voltage across C_d is increased from V_r .

[Stage 3: $t_2 < t < T_s$]: As switch and diode are OFF, V_{dc} remains unchanged. Output capacitance C_o enables current flow between L_m and junction capacitance (C_{oss}) of the switch when the switch is OFF. Owing to resonance between L_m and C_{oss} ,high frequency oscillation is observed in V_{L1} and V_{ds}. Output capacitance C_o decreases the output high frequency voltage ripple but C_o shouldn't become large which can cause significant oscillation on V_{ds} .

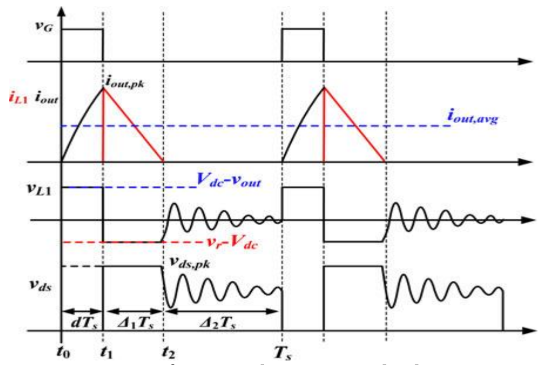

Fig. 5. Main Waveforms involving proposed pulsating current LED driver

B. Input Power Factor Correction

As the magnetizing inductance (L_m) of the transformer works in Discontinuous Conduction Mode (DCM),input side PFC is obtained. This is when the switch (M) conducts, secondary winding of L_m coupled inductor stores energy and this is coupled to the primary winding as the MOSFET stops conducting. The current carried by D_1 traces the low frequency voltage waveform given by the variation between V_r and V_{dc}.

IV. DESIGN OF THE DRIVER CIRCUIT

To authenticate the driver topology working , LED driver was simulated in MATLAB using 8-W LED bulb with source voltage of 120 V_{rms} and switching frequency of 100 kHz. LED model used is Philips 8W LED lamp. The driver circuit was designed for an peak output current of 350 mA. Driving LED with pulsed-current improves the constancy of the luminous power of the LED while high DC current leads to saturating luminous level [12]. Each of the ten LED in the array has a forward voltage slump of 10.2 V which gives output power wattage of 8.06 W. With the output wattage of 8 W and assuming 88% efficiency, the average source power is obtained as 9.37 W. As input voltage is 120 V_{rms} , peak input volage V_p is 170 V using $V_p = 1.414 * V_{rms}$. The optimized source current outline is obtained when V_p/V_{rms} lies between 0.6 and 0.8. A ratio of $\beta = V_p/V_{dc} = 0.7$ is chosen to give V_{dc} = 245 V. V_p must be lesser than V_{dc} as β influences the input power. Power factor reduces as V_{dc} nears V_p . As V_{dc} rises, β becomes smaller and power factor rises. On again reducing β, power factor also minimises slightly.As β decreases, configuration of source current resembles a square shape and input power factor decreases. With V_{dc} = 243 V and $P_{i,avg}$ = 9.48W and a 10% ripple in V_{dc}, the minimum value of C_d is 4.7 F. As total LED voltage = 102 V, increasing turns ratio n lowers switch voltage stress V_{ds} . Turns ratio is chosen as n = 1.5 and magnetising inductance L_m becomes 0.76 mH. Capacitor (C_o) of 5.6 nF acts as output filter added by reducing the high frequency output voltage ripple across the LEDarray

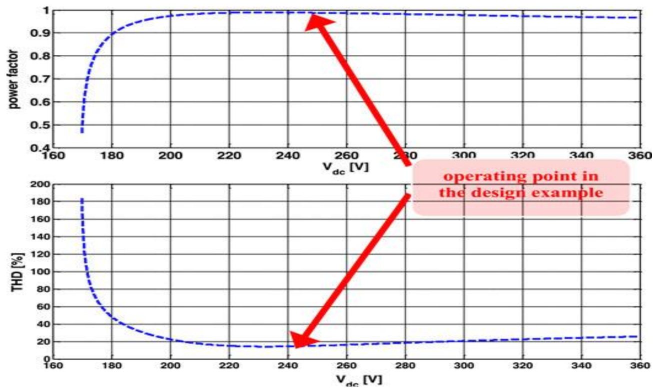

Fig. 6. Variation of source side power factor and input current THD with capacitorvoltage

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V. SIMULATION MODEL AND RESULTS

Simulation of the novel driver topology was done using MATLAB software as the power factor and total harmonic distortion can be directly obtained using the SIMULINK tools as illustrated in Fig. 11. Waveforms of the MOSFET switching pulse, diode current, primary winding voltage, capacitor voltage, LED output current, MOSFET switch voltage and LED output voltage are given in Fig. 12. The peak LED load current was obtained as 0.4A .The voltage across the primary winding was obtained as 50V and the LED output voltage as 85V for a duty ratio of 0.37. The capacitor voltage is measured as 200V and the maximum voltage stress as 320V. The input side waveforms of source current, source voltage and power factor is shown in Fig. 13.It can be seen that the input current is almost in phase with the input voltage. The achieved input power factor is 0.994 at the source side in accordance with Energy Star LED qualifications and the Total Harmonic Distortion of the input current is 20.34% which is within the limits of IEC 61000-3-2 Class C standards. The source current is almost sinusoidal with a value of 0.18A and the source voltage is 170V.

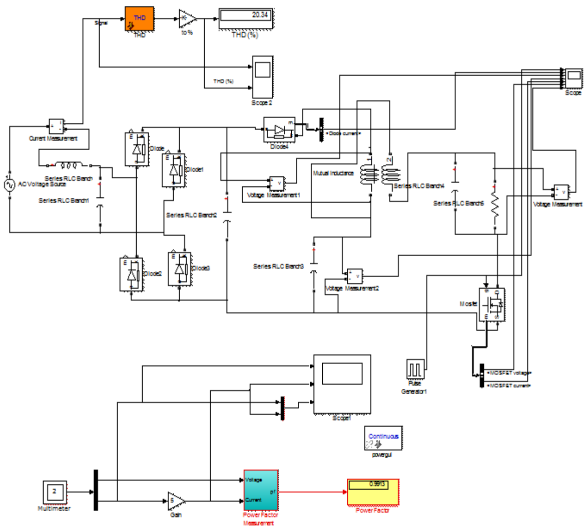

Fig. 7. MATLAB Simulink model of the proposed LED driver circuit

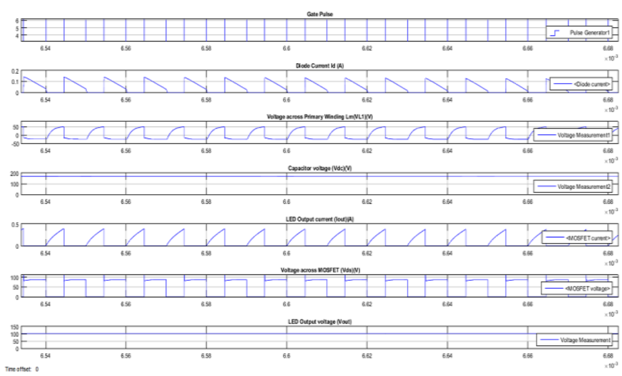

Fig. 8. Key waveforms of the MATLAB Simulink model

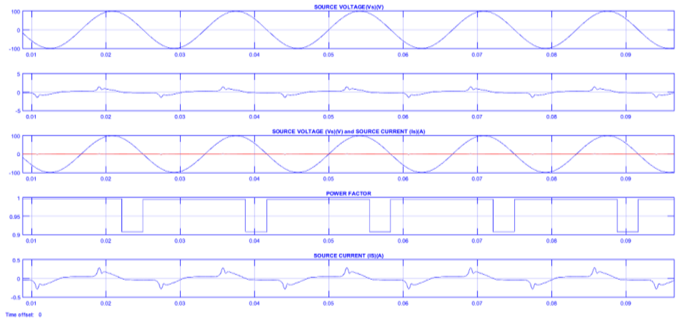

Fig. 9. Key waveforms of the MATLAB Simulink model in the source

VI. HARDWARE IMPLEMENTATION

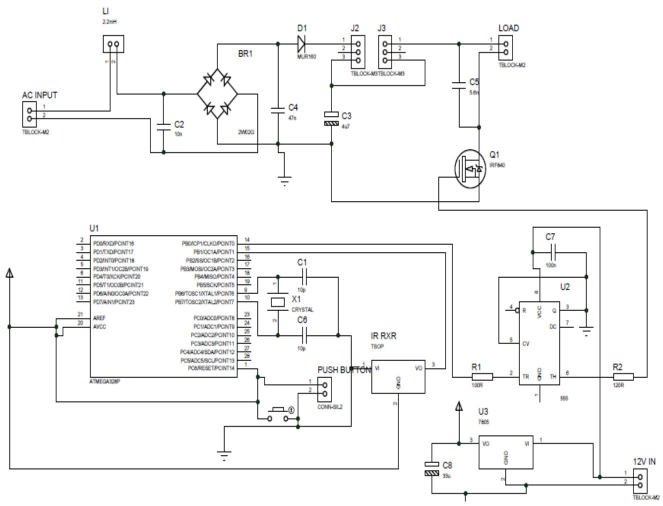

Fig.10. Complete Hardware Circuit

The complete hardware diagram is shown in Fig. 14. The hardware of the circuit was implemented in lab using the MOSFET driver TLP250 to trigger the MOSFET and Philips 9W LED lamp was used. Due to the high switching frequency of 100kHz, no flickering was observed. Atmega328P was used as the controller to produce the switching pulse for the MOSFET. As the duty cycle increases, the conduction period of the MOSFET switch increases and the LED output voltage increases leading to higher luminous intensity as indicated by Fig. 15. As the duty ratio decreases, conduction period of the MOSFET switch reduces and the LED output voltage reduces leading to low level dimming as shown in Fig. 16. An IR remote is used to ON,OFF and provide dimming from 0 to 100%. IR sensor TSOP 31256 demodulates the IR signals and gives it to the microcontroller Atmega328P which decodes the signal and performs the ON,OFF and dimming operation according to the program.

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Fig. 15. LED bulb with full brightness

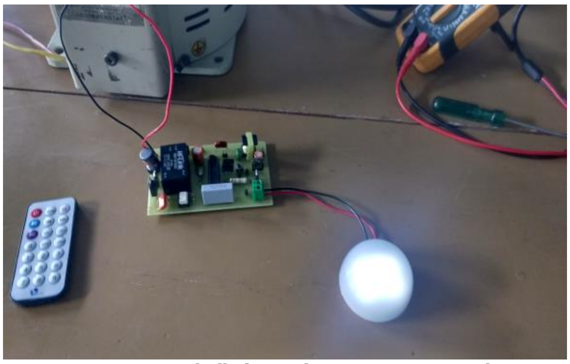

Fig. 12. LED bulb dimmed using remote control

As a next experimental test, a flukemeter is used to measure the operating voltage, current drawn, power consumption, energy consumed, power factor and the Total Harmonic Distortion(THD) as given by Fig. 18. The power factor was obtained as 0.98 which is within the Energy Star Energy Star LED qualifications while harmonic content in source current is 21%. Flickering was obtained as 20% which is within the stipulated limit of Alliance for Solid State Illumination Systems and Technologies(ASSIST) .The flicker rate remains below 30% due to the high frequency switching of the switch at 100kHz.

Fig. 13. Flukemeter for Power quality indices measurement

VII. NOVELTY OF THE PROPOSED LED DRIVER

The LED driver has longer lifetime and increased reliability as unreliable aluminium capacitors are not used.Harmonics injected in the input current are 20% which is within the stipulations of the IEC 61000-3-2 Class C standard leading to low Total Harmonic Distortion (THD). The circuit has a high efficiency, lower cost due to fewer components and smaller size. It operates at a high input power factor of 0.99 and since the MOSFET switch is in output side, it experiences lower stress life leading to low power loss. If the proposed LED driver is manufactured as a SMD PCB circuit, it can be used as a alternative to existing LED drivers for use in industries, commercial, domestic lighting applications. Light emitting diode (LED) lamps are eco friendly, rugged and emit more lumens per watt and increased shelf life (low maintenance cost) than other lighting technologies. In addition, they can be made to improve power quality by operation at high power factor and low THD at low cost and higher reliability. This will act as an incentive to the public and also leads to huge savings in cost and energy. When the switch turns off, a small voltage spike appears across the switch due to the leakage inductance on secondary winding of coupled inductor. A resistor-capacitor-diode combination acts as a snubber circuit to minimise the voltage spike by absorbing the extra energy. Duty cycle control is used to control peak current within the safe limit.

VIII. CONCLUSION

A novel high power factor, remote controlled long life LED driver with ON,OFF and dimming controls is proposed which eliminates aluminium capacitors in the circuit and makes the driver more compact and simple without difficult techniques to synchronise the switching operation. It minimises the flickering of the output and fluctuations in the output current. Owing to the discontinuous mode operation of coupled inductor,power factor correction is achieved at input side and MOSFET triggering at fast switching rate provides driving current pulses to the LED. The working of the proposed driver circuit was studied. Simulation models in MATLAB SIMULINK and hardware of the basic circuit was realised to validate the novelty of the driver circuit by implementing a 8 W, 120 V_{rms} model .

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