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Development of a Light Emitting Diode Lighting System with Power Factor Correction for Domestic Applications

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Abstract

The incandescent and fluorescent lighting systems which have been the most prominent electrical lighting choice for over 150 years are gradually being replaced in most homes with Light Emitting Diode (LED) Lighting Systems. This is due to their relatively low power consumption and good luminous intensity. LED lighting systems have revolutionized energy – efficient lighting. The significant feature of LEDs is that the light is directional with very low lagging power factor (0.2 – 0.6) as opposed to incandescent bulbs which spread the light more spherically with high power factor almost approaching unity. New LED designs address the directional limitation by using diffuser lenses and reflectors to disperse the light more. Since LED lighting represents a green technology, the issue of high power factor becomes very important. Power factor, defined as the ratio of real power consumed by a load (expressed in Watts) to apparent power (expressed in Volt-amperes), is a figure that ranges from zero to unity, it indicates the degree of distortion and phase shift in the current waveform. The work reported here proposes LED lighting system equipped with power factor correction driving circuit fed with dc – dc converter circuit. The power factor correction function is achieved by using switching converters circuit that operate directly from a full-wave rectified DC bus on a passive valley fill (PVF) circuit operating in Discontinuous Inductor Current Mode (DICM) for Power Factor Correction (PFC). This converter is simple to control, easy to construct and attractive for low cost application for domestic lighting. The results obtained have shown a LED lighting system with a lagging power factor of 0.85 that is energy – efficient compared to its conventional counterpart in domestic lighting applications.

Keywords: luminous intensity, Domestic lighting applications, Energy efficient, LED, Microcontroller, Power factor correction

1. Introduction

Lighting is a very important resource in the world without which majority of our daily activities cannot be accomplished. The unique capabilities of LED lighting made it possible for some new government directives to create an enormous opportunity for the adoption of LED lighting development around the world [1]. These have enabled rapid investment in the development of truly green and sustainable LED solutions in the lighting industry. With the current push to limit or phase out energy-wasteful incandescent lamps in over 40 countries by 2015 [2], energy-saving alternatives such as LED will become not only desirable but necessary. The first LEDs came to market in the 1960s and the technology has improved tremendously since then. LEDs are now the industry standard in a variety of specialty lighting systems and the popular LED bulbs are rapidly taking over the illumination market. LED lightings have the good features of energy efficiency, long lifespan, and pollution free. This makes them more attractive in their use in lighting applications compared to other lighting systems such as the incandescent bulbs, halogen lamps, and fluorescent bulbs.

The semiconductor junction in the LEDs requires a specific amount of voltage in order to operate optimally. Since low voltage at junction leads to lower current (poor illumination) and high voltage presence at the junction will give rise to high current. Higher current results in wasted energy in transmission lines as well as generators and transformers consuming more fossil fuels and generating more pollution at higher cost. A constant current driver is therefore needed to regulate the current flowing through each LED string of the lighting system to the rated current in order to maximize the illumination level and lifespan of the LEDs for their optimum performance and reliability [3].

Low lagging power factors in LED lighting systems are now prevalent, and this can lead to increased reactive power requirements on existing grid networks [4]. Real power is defined as the apparent power multiplied by the power factor, where the apparent power is the product of (rms) voltage and current. This relationship indicates that more current is required to provide the same amount of real power for lower power factors. Higher power factor is very beneficial in all electrical products that operate from the AC power grid. The US Department of Energy mandates that power factor for LED drivers must be at least 0.7 and 0.9 for domestic and industrial applications respectively [5]. In addition to choosing LED products that genuinely represent green technology, selecting LED lights with higher power factor minimises the current capacity requirements of components in lighting systems. In this paper, a proposed design approach for improved power factor in LED driver circuits operating directly from a full-wave rectified DC bus on a passive valley fill (PVF) circuit operating in Discontinuous inductor current Mode (DICM) for power factor correction (PFC) with microcontroller based dimming control capabilities for domestic lighting applications is adopted.

2. **Design procedure using passive valley** fill **converter**

Minimum diode current is $(\mathrm{I} - \Delta i_l)$ [3]

DC component I = V/R

Current ripple is $\Delta i_L = \frac{(V_g - V)}{2L}\mathrm{DT_S} = \frac{V_g DD'T_S}{2L}$

From the above it is seen that I depends on load but Δi_L doesn't.

$$I < \Delta i_L(t) \qquad \text{for CICM (Continuous Inductor Current Mode)}$$

$$\mathrm{I} > \Delta \mathrm{i_L}(t) \qquad \text{for DICM}$$

Insert buck converter expressions for I and $\Delta \mathrm{i_L}$:

$$\frac{DV_S}{R} < \frac{DDT_S V_g}{2L}$$

$$\frac{2L}{RT_S} < D$$

This expression is of the form

$$K < K_{crit}(D) \qquad \text{for DICM}$$

$$\text{where } \mathrm{k} = \frac{2\mathrm{L}}{RT_S} \text{ and } \mathrm{K_{crit}}(D) = D$$

Solve K_{crit} equation for load resistance R to give

$$\mathrm{R} < R_{crit}(D) \qquad \text{for CICM}$$

$$\mathrm{R} > R_{crit}(D) \qquad \text{forDICM}$$

$$\text{where } R_{crit}(D) = \frac{2L}{D'T_S}$$

In Summary

$$\mathrm{K} > K_{crit}(D) \text{ or } \mathrm{R} > R_{crit}(D) \qquad \text{for CICM}$$

$$\mathrm{K} < K_{crit}(D) \text{ or } \mathrm{R} > \mathrm{R_{crit}}(D) \qquad \text{for DICM}$$

The main advantage of using switching converters operating in DICM for PFC applications is the simplicity of the control method. Since there is no need to continuously adjust the duty – cycle D to perform PFC, only a voltage loop is needed to regulate the voltage across the storage capacitor. The bandwidth of the voltage loop has to be low (e.g. 10 – 15Hz), in order to filter out the output voltage ripple at twice the line – frequency. The simple control of the converters with inherent PFC makes them attractive for low – cost application. The only main disadvantage of using switching converters operating in DICM for PFC application is the input current that is normally a train of triangle pulses with nearly constant duty ratio. As a result, the high – frequency Electromagnetic Interference (EMI) is very high. In this case, an input filter is included for smoothing the pulsating input current into a continuous one.

2.1 Design specifications of the LED lighting system

The system takes an input voltage range of 220 – 240 V_{ac}, at a frequency of 50Hz, a power rating of 15-watts (Max) and a power factor rating of 0.8(Min). The system description using the passive valley fill method for power factor correction is explained as follows:

2.2 LED System

The LED lighting system takes its initial supply free of harmonics from the 230-V alternating current (AC) mains through an EMI filter as shown in the block diagram of figure 2.1. The operational sequence of the overall system design as shown in the circuit diagram of figure 2.2 is here described in this section.

The transformer, TR1 transforms the mains AC supply into an electrically isolated 15-V AC supply. A rectification process, using the Bridge rectifier, converts the new supply voltage level to a pulsating direct current (DC) supply. Through a protecting fuse, the PVF method is adopted for power factor correction purpose to the system [6]. The PVF circuit comprises diodes D7, D8, D9, C5, C6 and resistor R7. The capacitor C1 filters the pulsating DC to achieve a steady DC voltage supply. U1 is a fixed voltage regulator internally trimmed to 5-V for the microcontroller supply voltage.

U2 is also a fixed voltage regulator that is used to provide a 12-V supply to drive the LED strings. Due to the sizeable current of the load, a means of improving the current handling capacity of the 12-V regulator is required. The current boost is achieved by connecting an out-board pass transistor Q1 across the regulator. Current flowing through the resistor R1 develops a potential difference across it, which is used to bias the PNP transistor Emitter – Base Junction. A current of 70 mA through R1 develops a potential of 700mV which is applied between the emitter and base of the high-current transistor Q1.

Any current greater than 70 mA will have the excess diverted through Q1 to the 12-V output. Therefore, the output voltage remains un-altered but the current capacity improves.

A similar operation is found in the third regulated power source. The resistor R2 and transistor Q2 are out-board pass components for the adjustable regulator U3. The output voltage of U3 is adjusted by the variable resistor RV1 which forms a voltage divider network with resistor R3.

Capacitors C2 and C4 are filter capacitors which provide improved DC voltage stability. The output of the adjustable voltage regulator is used to charge the battery. B1.

The circuit is designed such that the battery comes on when mains AC power fails. This is achieved with the relay RL1. U5 provides a 5-V DC back-up power for the microcontroller.

The microcontroller U4 is used to control the brightness of the LEDs. Brightness control is achieved by a Pulse Width Modulation (PWM) approach [7]. When the push button is pressed, the microcontroller decreases the pulse-width in steps until it is at its lowest.

Since the microcontroller operates on 5-V DC, and is to drive a MOSFET with a gate-to-source threshold voltage of 4V DC, a voltage level translator is required to ensure that the MOSFET will be turned “ON” fully. This is achieved with resistors R4, R5 and bipolar junction transistor (BJT) Q3. The MOSFET drives the LED strings as controlled from the microcontroller.

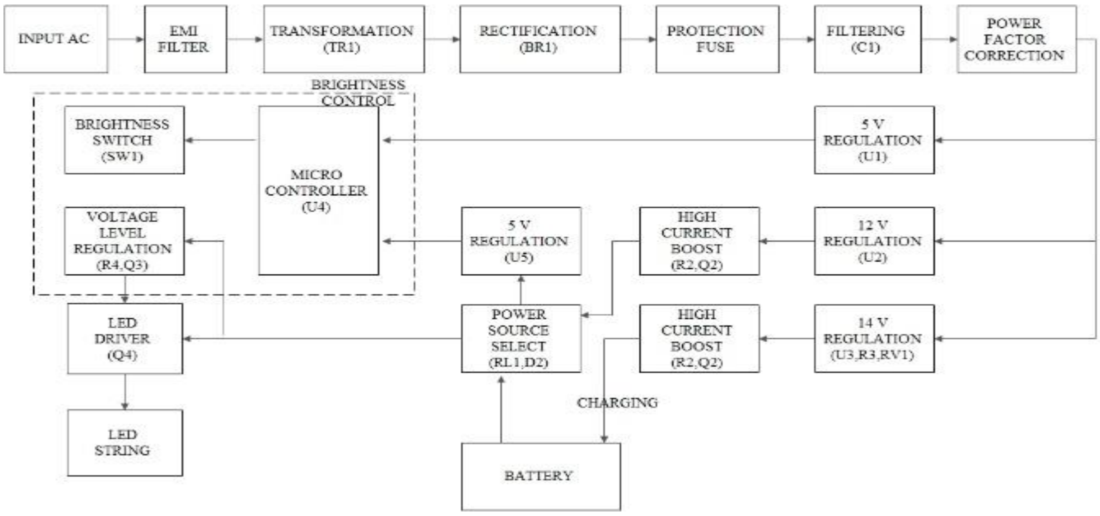

Figure 1. Block Diagram of the LED Lighting System

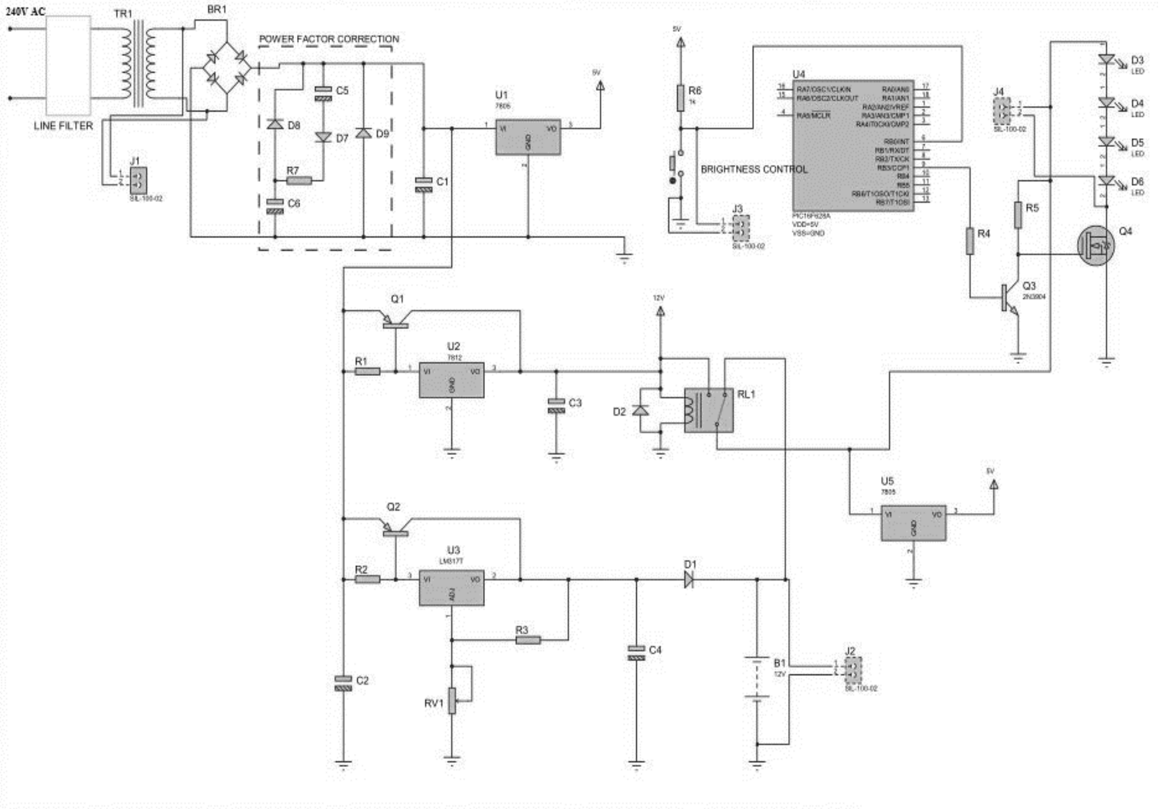

Figure 2. LED Lighting System Circuit Diagram

3. The Research outcome

The results showing the energy-efficient capabilities of the LED lighting system designed are highlighted as follows:

- A significant improvement in power factor correction was achieved. A higher power factor (pf) rating in the LED driver circuit of 0.85 lagging was measured as compared to 0.2 lagging pf without the LED driver circuit.

- A considerable reduction in the reactive power demand by the LED lighting system due to the higher pf was achieved. As a result, the power losses on the supply lines will be reduced considerably.

It should be noted that Reactive power demands and power losses become a concern when there is a large deployment of the LED lighting system for lighting applications.

- A constant output voltage to the LED lighting system from the LED driver circuit is sustained, thereby increasing the lifespan of the LEDs used.

- A good and comparable illumination level with the least power requirement is achieved as the LEDs tend to possess a high lumen capability at very little power demands. LEDs are very low rated semiconductor devices.

- A brightness control with the microcontroller circuit is one way to regulate active power consumption of the LED lighting systems making it more energy efficient.

- A successful implementation of redundancy with the inclusion of a 12-volt battery backup to the LED lighting system ensures an uninterrupted illumination at any location of utilization.

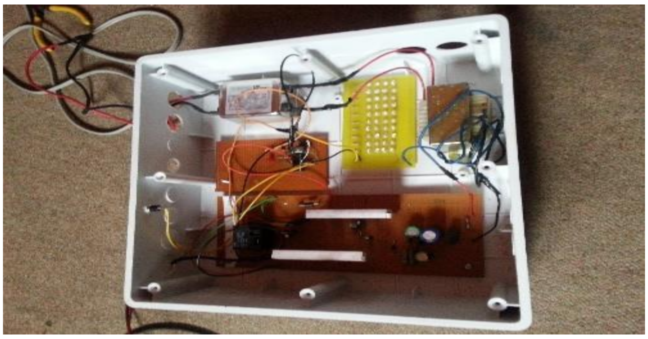

Figure 3. The Constructed LED Lighting with Power Factor Correction Circuit

4. Conclusion

The developed power factor correction unit for LED lighting application using valley fill circuit with a combination of flyback converter that operates on Discontinuous Inductor Current mode improved the power factor from 0.2 to 0.85 which satisfies the specified power factor requirement for domestic lighting application. This unit is small in size, cheap and also it includes the following unique features:

- Constant output voltage of the LED driver.

- Achieved brightness control in the microcontroller circuit.

- Successful coupling of the various units to function as a single system.

- With a 12-V lead acid battery it can serve as a backup power supply.

References

[1] C.S. Moo, Y.J. Chen, and W.C. Yang, "An efficient driver for dimmable LED lighting," IEEE Transactions on power Electronics, vol. 27, no 11, pp. 4613, 2012

[2] H.S. Aihab, D. D. C. Lu, A. Yazdani, B. Wu, "An efficient single-switch quasi-active PFC converter with continuous input current and low DC-Bus voltage stress," IEEE T transactions on Industrial Electronics, vol. 61. No.4, pp. 1735-1749, 2014

[3] H.S. Athab, D.D.C. Lu, K.Ramar, "A single-switch AC/DC flyback converter using a CCM/DCM quasi-active power factor correction front-end,"IEEE Transactions on Industrial Electronics, vol. 59, no. 3, pp. 1517-1526, 2012

[4] B. Akin, H. Bodur, "A new single – phase soft – switching power factor correction converter," IEEE Transactions on Power Electronics, vol. 26, no. 2, pp. 436-443, 2011

[5] Y.S. Roh, Y.J. Moon, J.C. Gong, C. Yoo, "Active power factor correction (PFC) circuit with resistor-free Zero-current detection," IEEE Transactions on power Electronics, vol. 26, no. 2, pp. 630-637, 2011

[6] A.E. Aroudi, R. Haroun, A. Cid-Pastor, L. Martinez-Salamero, "Suppression of line frequency instabilities in PFC AC-DC power supplies by feedback notch filtering the pre-regulator output voltage," IEEE Transactions on Circuits and Systems1: Regulator papers, vol.60, no. 3, pp. 796-809, 2013

[7] Yong-Nong Chang, "Self-Excited Single-stage power factor Correction driving circuit for LED lighting," Hindawi publishing Corporation, Journal of Nanomaterials,vol. 2014, Article ID 107939, 8 pages, March, 2014.