High Efficiency Unity Power Factor Compact Fluorescent Lamp with Energy Conservation Dimmer for Commercial Applications

S. Sivaram

Abstract: This paper presents unity power factor single switch ballast for CFL with intensity controlled dimmer. The circuit topology comprises of single switch electronic ballast and an intensity controlled dimmer. This single switch is operated at ZVS and it carries only input current which leads to high efficiency. This circuit will operate in energy conservation mode during activation of Dimmer otherwise it operates in constant power mode. PSIM simulation results are provided which highlights the merits of proposed work.

Keywords: compact fluorescent lamp, electronic ballast, Dimmer

1. Introduction

Energy is the most essential factors in people’s life. Every day, people deal with the price of energy and think about saving of energy in their life. To save the energy, fluorescent lamps have been increasingly accepted in residential, industrial and commercial lighting applications. In commercial office applications, this lamp will glow continuously with constant intensity, which may leads to over illumination and energy loss.

The fluorescent lamp has negative resistance characteristics which lead to increase in current with decrease in lamp voltage. A lamp current stabilization element called ballast is required in order to provide sufficient voltage for proper lamp ignition and to stabilize lamp current once the lamp arc is established.

To provide a compact and lightweight solution for CFLs, high-frequency electronic ballasts operating at higher frequency than 25 kHz are more suitable than magnetic ballasts. For minimizing the cost, commercial CFL’s normally do not include a power factor correction circuit in their ballasts. It consists of a diode rectifier and a self-driven half bridge parallel resonant inverter with a DC link capacitor. The major drawback of this circuit is highly distorted line current and produces a large amount of unwanted harmonics, hence results in very poor power factor [1 – 4].

To improve the power factor, power factor correction circuit is introduced. The regulation of the PFC stage output DC voltage is achieved by controlling the duty cycle. However the circuit requires extra switching devices which increase the complexity size and cost of the device [5 – 11].

To reduce the number of MOSFETs required in the ballast power circuit, single-switch electronic ballasts were proposed in [12]-[17] by using the class-E resonant inverter. These electronic ballasts use only one switch to simultaneously achieve PFC while providing the lamp current stabilization at the inverter stage. The disadvantage of using the class-E resonant inverter is that the switch needs to suffer a high voltage stress of about 3–5 times of the input dc voltage [17].

2. Description About Proposed System
The completed ballast circuit with the proposed controller is shown in Fig. 1. The electronic ballast power circuit studied in this paper is a single-switch single-stage resonant inverter with SEPIC PFC.

**A. Constant Lamp illumination with DC-Link Voltage Control**

From the circuit it is clear that the dc-link capacitor \( (C_d) \) serves as the main energy storage element in the ballast circuit. The output lamp power is approximately equal to the DC-link power at the input of the inverter stage. Hence, by controlling the DC-link voltage \( V_{dc} \), output lamp power can be indirectly controlled, thereby maintaining almost constant light intensity at the output as the input voltage fluctuates. Therefore this paper uses a DC voltage regulation loop which compares the DC link voltage with respect to the reference voltage and generates an error signal which is given to PWM generator. This generator will decide the duty ratio of the switch. Hence during line fluctuations the DC link voltage decreases and to maintain the constant DC voltage, the duty ratio increases. Thus by using this regulation loop constant illumination is maintained.

**B. Proposed Controller with Dimmer operation.**

During daylight condition, in commercial offices the lamp will glow with constant intensity. This will create over illumination which leads to energy loss. During over illumination, the energy can be conserved by using a dimmer which can be controlled by firing angle \( \alpha \). When \( \alpha \) is varied (ie. \( \alpha \geq \alpha_{\text{min}} \)), the DC voltage regulation loop will get deactivated. The logic circuit will produce pulses with constant duty ratio and hence the DC link voltage varies with respect to firing angle of the dimmer. Therefore the illumination can be varied and controlled which leads to conservation of energy.

As \( \alpha \) increase during dimming, it can be observed from Figure 4 that \( V_{\text{ripple}} \) becomes less sinusoidal and can be described as consisting of two portions: a partly sinusoidal waveform and the discharge of the DC-link capacitor during the discontinuous period of the line voltage. The DC-link voltage during the discontinuous period of the line voltage can be obtained by noting that the DC-link capacitor must discharge its stored energy to the inverter side during this period.

**C. Design Specifications**

The resonant circuit is designed based on the steady state lamp resistance. The formula is shown in (Eq. 1). Then the resonant circuit components are designed for the chosen \( Q \) value so that the proper lamp ignition voltage will be provided for the lamp start-up process. The switching frequency should be chosen to be below the corner frequency to ensure high voltage gain. At the same time, it should be above the resonant frequency to minimize the voltage and current stress of the switch.

\[
R_{\text{lamp}} = \frac{P_{\text{out}}}{I_{\text{out}}^2} \quad (1)
\]

\[
L_r = \frac{QR_{\text{lamp}}}{2\pi f_0} \quad (2)
\]

\[
C_r = \frac{1}{(2\pi f_0)^2L_r} \quad (3)
\]

The corner frequency is chosen to be 90 kHz to minimize the resonant inductor size and the \( Q \) is chosen to be 0.9. The final values of \( L_{\text{rand}} \) and \( C_r \) are then calculated as shown in (Eq. 2) and (Eq. 3) respectively. The starting inductor for lamp ignition, \( L_p \), is then selected to be 2.2 mH. The switching frequency is chosen to be 70 kHz for this design.

**3. Simulation Results and Performance**

The performance of the proposed control circuit is validated through PSIM simulation and the results are shown below.

Figure 6 shows the gate pulse generated for MOSFET switch and the switching frequency is 70 KHz with duty cycle of 0.5.
Figure 7: Rectifier Voltage

Figure 7 shows the rectifier output voltage. The peak value is 110 V and the average DC voltage is 70 V.

Figure 8: DC link voltage

Figure 8 shows the DC link capacitor voltage. It is clear that \( V_{ripple} \) is sinusoidal during normal operation and the average capacitor voltage is 90 V.

Figure 9: Output Voltage and Current waveforms

Figure 9 shows the output voltage and current during steady state operation. The RMS voltage is 106 V and the RMS current is 0.17 A.

Figure 10: input voltage and output voltage

Figure 10 shows the input and output voltage during transient operation. The input voltage given is 85 V and the RMS output voltage is 106 V. During line fluctuations from 85 V to 135 V, the constant output voltage is maintained by the help of regulation loop.

Figure 11: input and rectified voltage (\( \alpha = 30^\circ \))

Figure 11 shows the input and rectifier voltage during dimming operation. The firing angle given to the dimmer is \( \alpha = 30^\circ \).

Figure 12: DC link voltage during Dimming

Figure 12 shows the DC link capacitor voltage during dimming operation. As \( \alpha \) increase, \( V_{ripple} \) becomes less sinusoidal and consist of two portions: a partly sinusoidal waveform continuous period and the discharge of the DC-link capacitor during the discontinuous period of the line voltage.

Figure 13: output voltage and current (\( \alpha = 30^\circ \))

Figure 13 shows the output voltage and current during dimming operation where firing angle \( \alpha = 30^\circ \). The RMS voltage is 88 V and the RMS current is 0.14 A.

Figure 14: input and rectified voltage (\( \alpha = 120^\circ \))

Figure 14 shows the input and rectifier voltage during dimming operation. The firing angle given to the dimmer is \( \alpha = 120^\circ \).

Figure 15: output voltage and current (\( \alpha = 120^\circ \))

Figure 15 shows the output voltage and current during dimming operation where firing angle \( \alpha = 120^\circ \). The RMS voltage is 50 V and the RMS current is 0.07 A.
regulation loop is deactivated and it will operate in constant lamp power. During dimmer activation, the feasibility of the proposed work. Future works will maintain constant dc link voltage which realizes the line fluctuations, the lamp is operated with voltage regulation reducing the switching losses and increase the efficiency of voltage stress across the switch is also less.

Switch transition is done with zero voltage switching and the energy can be conserved during over illumination.

Conclusion
A high efficiency unity power factor CFL with intensity controlled dimmer has been presented in this paper. During line fluctuations, the lamp is operated with voltage regulation loop maintaining constant dc link voltage which realizes the constant lamp power. During dimmer activation, the regulation loop is deactivated and it will operate in energy conservation mode. The switch is operated at ZVS, which reduces the switching losses and increase the efficiency of the system. Simulation results have also been given to support the feasibility of the proposed work. Future works will include implementing a novel yet cost-effective controller design using fuzzy logic that will able to change the Vdc reference according to the intensity of light in a room. Hence the energy can be conserved during over illumination.

Table 4: Energy Saved During Dimming Operation

<table>
<thead>
<tr>
<th>Dimmer</th>
<th>Time</th>
<th>V_{out} (RMS) V</th>
<th>I_{out} (RMS) A</th>
<th>P_{out} (RMS) W</th>
<th>Energy Saved W</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>6 pm – 8 am</td>
<td>106</td>
<td>0.17</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>30°</td>
<td>8 am – 9 am</td>
<td>88</td>
<td>0.14</td>
<td>12.32</td>
<td>5.68</td>
</tr>
<tr>
<td>60°</td>
<td>9 am – 10 am</td>
<td>71</td>
<td>0.13</td>
<td>9.23</td>
<td>8.77</td>
</tr>
<tr>
<td>90°</td>
<td>10 am – 11 am</td>
<td>60</td>
<td>0.11</td>
<td>6.6</td>
<td>11.4</td>
</tr>
<tr>
<td>120°</td>
<td>11 am – noon</td>
<td>50</td>
<td>0.07</td>
<td>3.5</td>
<td>14.5</td>
</tr>
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References