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Improved Charge Pump Power Factor Correction Electronic Ballast Based on Class DE Inverter

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Abstract

This paper proposes fluorescent electronic ballast with high power factor and low line input current harmonics. The system performance can be improved by a charged pump circuit. Details of design and circuit operation are described. The proposed electronic ballast is modified from single - stage half bridge class D electronic ballast by adding capacitor parallel with each power switch and setting the circuit parameter to operate under class DE inverter condition. By using this proposed method the DC bus voltage can be reduced around by 50% compare with conventional class D inverter circuit. Because the power switches are operated at zero voltage switching condition and low dv/dt of class DE switching. The experimental results show that the proper frequency of the prototype is around 50 kHz with input power factor of 0.982, THD_i 10.2% at full load and efficiency of more than 90%.

Keywords*: electronic ballast, Current-source Charge-pump (CS-CP)*

NOMENCLATURE AND CONVENTIONS FOR SYMBOL

Capital italic letters, like as L_m, represent constant variables. Small italic letters, like as i_{ds}, represent instantaneous variables depends on time.

Symbol	Description [Units]
P_{in}	Power input [Watt: W]
P_o	Power output [Watt: W]
V_{in}	Input voltage [Volt: V]
V_B	Bus voltage [Volt: V]

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V_P Peak voltage [Volt: V]
f_s Line frequency [Hz]
I_x Rectifier current [Amp: A]
ω_L Switching frequency [Hz]
C_{in} Capacitor of charge pump circuit [Farad: F]
L_r Inductor of resonant circuit [Henry: H]
C_r Capacitor of resonant circuit [Farad: F]
η Efficiency of power conversion

1. INTRODUCTION

Nowadays, the fluorescent lamps are used worldwide because it provides good colour and lighting more than incandescent lamp. Traditional electromagnetic ballast for fluorescent lamps has several drawbacks, including low efficiency and low power factor. High power factor high efficiency electronic ballast for fluorescent lamp applications has been developing very fast recently due to its obvious advantages, such as high power factor and high efficiency [1]. In the early part of research work electronic ballast make use of electric current for electricity with dc to ac inverters which are used for electronic ballast. The disadvantage is electrical current has to use large capacitor to compensate ripple which make the current in short term resulting to harmonic current and low electrical current. From the mentioned problems, [2-5] then charge-pump is applied as power factor correction circuit by using output resonant circuit acting as a high frequency current source to charge and discharge electric charges through charge - pump delivering power from input to output. As a result, the input current will flow continuously according to the change cycle of high frequency. By this method, no matter how much input voltage is; high or low, input current waveform will be closed to sinusoidal and in phase with input voltage leading to higher power factor and lower THD. But still there is some disadvantaged in terms of the class D inverter circuit therefore, it is necessary to use the capacitor and the high switch instrument due to the duty cycle at 50%. Besides, there are some electrical current flows through diode within the switch while both switches stop bringing the electrical current. So, there is some loss and also affect to the highest efficiency of the circuit at 89.4% [6]. Regarding all those problems, the Class D inverter has been chosen in order to solve the problem by reducing the DC bus voltage as into 50%. The control of the Mosfet process Q_1,Q_2 can control the constant duty cycle at 25% [7-8] which can reduce the bus voltage. In terms of the characteristic of class DE the switch can be designed to the power switch are operated at zero voltage switching condition and low *dv/dt* which can promptly switch again so that can reduce the loss of Mosfet. As a result, the new electronic ballast has efficiency over 90% and improves the power factor and also reduces the harmonic current. Therefore this can be proved to be the perfect single-stage ballast.

2. CONCEPT OF ELECTRONIC BALLAST

Electronic ballast will produce the signal driving itself from internal circuit frequency and resonant circuit feeding to half-bridge inverter circuit. The frequency fed to electronic ballast will be converted from 50 Hz to 50 kHz to trigger the electronic ballast fluorescent lamp. Block diagrams of basic structure of electronic ballast and conventional ballast are shown in Figure 1.

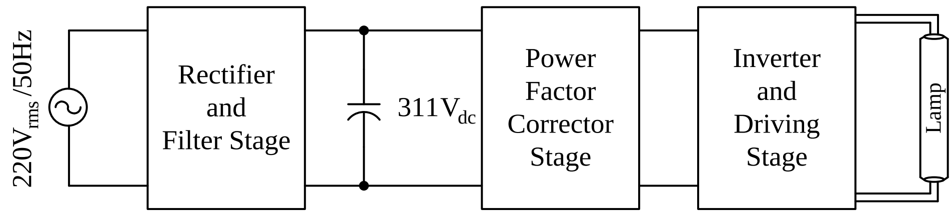

Figure 1. General block diagram of electronic ballast.

The functions of each part are as follows.

1. Rectifier and Filter Stage (or Rectifier stage): this stage converts AC to DC voltage using bridge circuit.

2. Power Factor Collection Stage: this stage acts as power factor correction circuit by means of various methods.

3. Inverter and Driving Stage: this stage acts as high frequency inverter (DC-to-AC converter) by using half bridge inverter at frequency of 25-50 kHz which will be tested to find the proper frequency. This circuit is for triggering fluorescent lamp and controlling the lamp in the stead state by using DC-to-AC inverter to produce high frequency for resonant circuit.

3. DESIGN OF ELECTRONIC BALLAST CIRCUIT

3.1 Power Factor Correction

This paper uses A Combination of Current Source Charge Pump Power Factor Correction (CS-CPPFC) technique for shaping the input current of the electronic ballast. This charge pump will feed signal from output resonant circuit to help charging and discharging electric charges to reduce DC voltage ripple from DC rectifier and fulfill DC waveform with Valley-Fill passive circuit. This leads to absolute DC current fed to inverter and also causes the current to be pulled when ballast is started which makes input current be sinusoidal and in phase with input voltage resulting in higher power factor, closed to 1.

From the Figure 2, charge pump C_{in} should be designed properly according to the power of the lamp. So input power is constant being the product of input voltage at any time and average rectified input current in one switching cycle as stated in equation 1.

$$p_{in}(t) = \left(\frac{I_x}{\pi} - C_{in} f_x V_B\right)\left|v_g(t)\right| + C_{in} f_x \left|v_g(t)\right|^2 \quad (1)$$

By averaging the above equation (1) in a line input cycle if $v_g(t) = V_p \sin \omega_L t$, where ω_L is the line frequency, the average input power P_{in} is

$$P_{in} = \frac{2}{\pi} V_p \left(\frac{I_x}{\pi} - C_{in} f_x V_B\right) + \frac{1}{2} C_{in} f_x V_p^2 \quad (2)$$

Under the operation of power factor correction closed to (1), the first term of equation (2) is zero. So we get equation (3).

$$P_{in} = \frac{1}{2} C_{in} f_x V_p^2 \tag{3}$$

Based on the power balance between the input and output that is,

$$P_{out} = \eta P_{in} \tag{4}$$

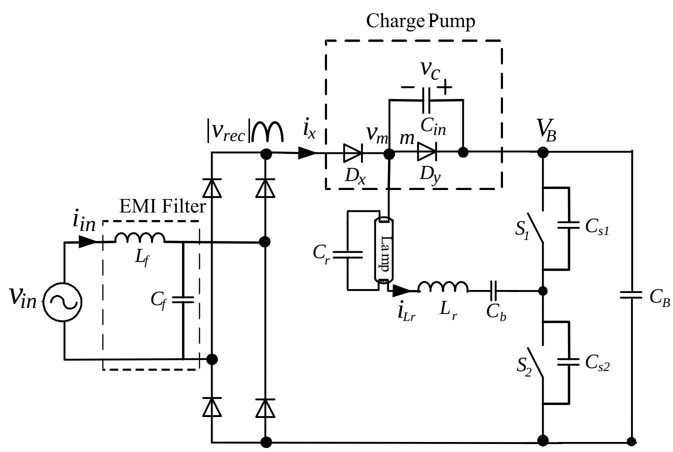

Figure 2. Basic circuit of charge pump ballast based on Class DE

Where P_o and η are the output power and the conversion efficiency, respectively. The charge capacitor C_{in} can be determined by

$$C_{in} = \frac{2P_{out}}{\eta f_s V_p^2} \tag{5}$$

3.2. Inverter Circuit

This circuit exploits Class DE Half-Bridge Inverter Circuit as shown in Figure 2, using 2 switches to drive circuit with continuous alternate operation, namely switch1 is on while switch 2 is off and vice versa.

3.3. Ballast Design

The Class-DE resonant parallel-load inverter is shown in Figure 2 using the design procedure defined elsewhere. For the steady-state lamp operation, the rms value of the lamp voltage and current are V_{lamp} = 100 V and I_{lamp} = 0.36 A. Thus, the lamp resistance is $R_{lamp} = V_{lamp} / I_{lamp}$ = 278 Ω, and the output power is 36 W. We assume that the corner frequency $f_o = f_s$ for full power. The relationship among loaded quality factor Q_L, dc bus voltage V_B, and rms lamp voltage V_{lamp} is described by

$$Q_L = \frac{\pi V_{lamp}}{\sqrt{2} V_B} = \frac{\pi ?\ \ 00}{\sqrt{2} ?\ \ 11} = 0.714. \tag{6}$$

The characteristic impedance Z_o is

$$Z_o = \frac{R_{lamp}}{Q_L} = \frac{278}{0.714} = 389.35\ \Omega. \tag{7}$$

The resonant inductor L_r is

$$L_r = \frac{Z_o}{\omega_o} = \frac{389.35}{2\pi ?\ \ 0 ?\ \ 0^{3}} = 1.24\ \text{mH}. \tag{8}$$

The resonant capacitor C_r is

$$C_r = \frac{1}{\omega_o Z_o} = \frac{1}{2\pi ?\ \ 0 ?\ \ 0^{3}\ 389.35} = 8.20\ \text{nF}. \tag{9}$$

Therefore, a standard value of 10 nF is select for C_r. And components of the circuit in resonant with the capacitor C_{S1} and C_{S2} series are calculated using equation 10, calculated the C_{S1}, C_{S2} allows the *dv/dt* is low, and switch on. The voltage switch is in the start of the next state, which is given by

$$C_{s1} = C_{s2} = \frac{1}{2\pi\, \omega R_L} = \frac{1}{4 \times \pi^2 \times 50 \times 10^3 \times 278} = 1.8\ \text{nF}\,. \tag{10}$$

4. EXPERIMENTAL RESULTS

To experimentally verify the theoretical derivation, an electronic ballast for 220-Vac input and a 36 Watt fluorescent lamp was implemented. The detailed circuit is shown in Figure 2. The circuit parameters are as follows :

L_r = 980 μH C_r = 10 nF C_d = 0.22 μF
$C_{1,2}$ = 10 μF C_{in} = 15 nF C_{S1} = C_{S1} = 1.5 nF
D_1 = D_2 = 1N4007
S_1 = S_2 = IRF840
D_3 = UF4007
The switch frequency f_S is 50 kHz

In the experiment of electronic ballast with frequency of 50 kHz, output power is closed to 36 watt when 220 ACV and 50 Hz are supplied to a 36-watt fluorescent lamp. Signal waveforms of input voltage and current are sinusoidal and in phase with power factor of 0.982 as shown in Figure 3.

Table 1. Measured line input current harmonics and IEC 61000-3-2 Class C requirement (λ: Power factor) [8]

Harmonics order (n) THD_i	IEC 61000-3-2 CLASS C	Measured (%)
3rd	30%*λ	5.71
5th	10%	4.18
7th	7%	2.16
9th	5%	1.90
n ≥ 11th	3%	1.29

Digital oscilloscope and current probe used in this experiment were Tektronix model TDS2014 and Tektronix TCP312, respectively. The experimental results of electronic ballast are compared with the IEC 61000-3-2 Class C standard and showed in Table I.

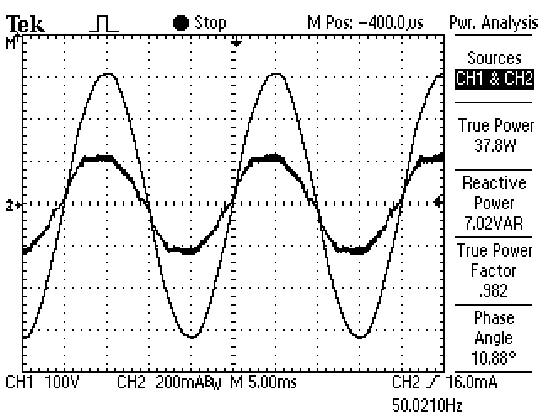

Figure 3. Experimental results of the input current and voltage waveform power factor 0.982.

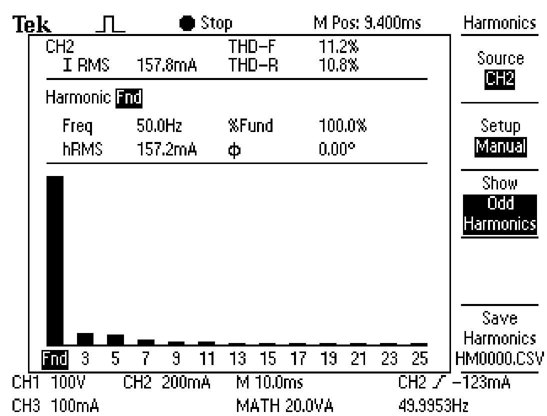

Figure 4. Experimental results of input current Harmonics(THD) is equal to 10.2%

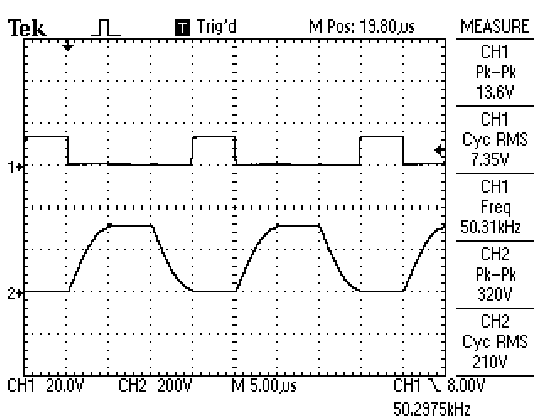

Figure 5: Switch voltage waveform at MOSFETs S_1, V_{g1} of circuit operate under class DE inverter Condition with voltage switching at zero; ZVS & Low *dv/dt*.

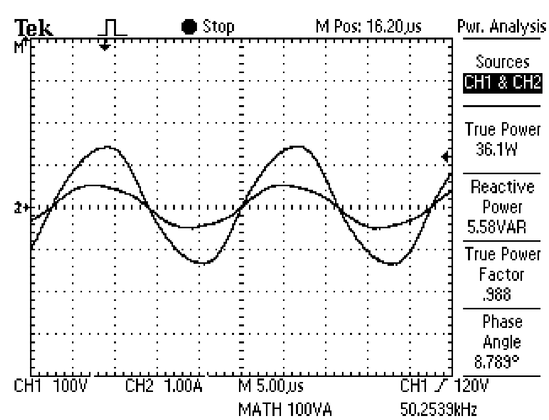

Figure 6: Experimental waveform of output voltage and current at fluorescent lamp.

4. CONCLUSION

In this paper, details of electronic ballast 36W/220V_{rms} 50Hz for fluorescent lamp are presented. The skeleton of power circuit is current source charge pump circuit so one part of half bridge inverter can be obtained. The prototype is designed at 50 kHz of switching frequency. Electronic Ballast Based on Class DE Inverter has been presented in the paper. While the duty cycle is 25%. The high - voltage stress problem was solved by the proposed low duty cycle operation. The resonant inverter switching at zero and turns off at low *dv/dt*. Therefore, the ballast operates at zero turn on losses. The experimental results show that input power factor is equal to 0.982 and THD_i is equal to 10.8 percent. So ballast supplies maximum output power at 37.8 watt and efficiency of more than 90% at full load.

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