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An Approach on Single-Stage High Power Factor Electronic Ballast for Metal Halide Lamps- A Survey

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Abstract

This paper presents single-stage high-power-factor electronic ballast for metal halide lamps. By integrating two buck-boost typed power-factor-correction converters, a full-bridge inverter and a bidirectional buck converter, a single stage electronic ballast with symmetrical circuit topology is derived. The proposed electronic ballast can output a low frequency square-wave voltage to drive metal halide lamps. The problematic phenomena of acoustic resonance can be eliminated.

Keywords – Acoustic Resonance, Electronic Ballast, HID lamp.

1. Introduction

Electric lamps have been known for more than 100 years. This is true not only for incandescent lamps, which are still widely used, but also for gas discharge lamps for street lightning. However, these could not hold their own in the long run. The carbon electrode which is between the electric discharges took place had to be regularly renewed, which is very expensive. Because gas discharge lamps generate much less heat while emitting lights, they are more efficient than incandescent lamps. Present-day lighting techniques are inconceivable without the wide variety of members of the gas discharge lamp family. In buildings, parks, offices, and factories, we find many thousands of tubular fluorescent lamps. Beside these fluorescent lamps, this can be categorized as low-pressure gas discharge lamps. There are a broad range of high intensity discharge lamps (HID). The HID lamps have excellent characteristics with high lighting efficiency, good colour rendering (eg. Metal Halide (MH) lamps), and longer lifetime [1].

HID lamps are used to satisfy high quality lighting fields and commercial lighting system. The HID lamps are used to satisfy high quality lighting fields and commercial lighting system. The HID lamp is gas discharge tubes which are filled with high- pressure gas. According to the gas composition, existing HID lamps are usually classified into three types, high pressure mercury lamps, high-pressure sodium lamps, and metal halide lamps.

One of the most important aspects of light generation, certainly from the application point of view, is the luminous efficacy of a lamp. The luminous efficacy is the ratio of the luminous flux of a light source to the power dissipated in it and expressed in lumen per watt (lm/w). Another important factor for choosing HID lamps is the colour properties of the light source, which is referred as colour rendering. In good colour rendering, the spectral energy distribution in the visible part of the electromagnetic spectrum, and thus close to daylight. Due to the negative incremental impedance characteristics of the HID lamps, a ballast device must be used to stabilize the operation of the lamp.

Conventional electromagnetic ballast is used to drive HID lamps because of simple structure, robust, and cheap. The conventional electromagnetic ballast is operated at 50 - or 60 – hz mains power frequency [5]. The structure of the ballast system is simple, robust, and reliable. It can be used under hostile working environments and has a very long service life. The disadvantages of electromagnetic ballast are poor power regulation ability, large size, heavy weight, and high power loss caused by the iron and copper losses in the magnetic chokes. These disadvantages can be overcome by the electronic ballast with the plenty of higher cost [12].

2. Electronic Ballast

Electronic ballast for high intensity discharge lamps have attracted attention, compared to electromagnetic ballast, because of their advantages: lighter weight, smaller size, higher efficiency, higher immunity to supply voltage changes, optimized performance, digital control and supervision etc [11]. Electronic ballast has been promoted as replacements ballast for the last decade. Electronic ballast are more efficient (10% - 15%) than electromagnetic ballast [5]. The lifetime of electronic ballast, which is mainly limited by the lifetime of the electrolytic capacitors, is relatively short when compared with that of electromagnetic ballast. However, metal halide lamps driven by a high frequency electronic ballast may suffer from problematic acoustic resonance which may lead to arc instability, light fluctuation or extinguishment, and even cracking the arc tube [2][14][9].

3. Acoustic Resonance

Acoustic resonance could happen when the lamps are driven by ac currents with frequency between a few KHz and a few hundred KHz. It hampers the electronic ballast from being wide applied to drive the metal halide lamps at higher frequency [8].

The acoustic resonance phenomenon depends on the lamp geomentry, gas temperature and pressure inside the lamp bulb. Although the acoustic resonance frequency can be calculated [14], it may vary due to the manufacturing tolerance and the lamp's condition.

Therefore, the HID lamp is not recommended if it is to be operated at high frequency [9]. Although the ballast can be operated at extra high frequency (up to several MHz) which does not cause acoustic resonance of the lamp. Many alternative approaches have been presented to eliminate the acoustic resonance. The most reliable solution to avoid the problem of AR is to supply the lamp with a low- frequency square-wave voltage [8][10][16].

4. Three stages of electronic ballast

The electronic ballast widely found in industrial market consists of three stages which are 1) PFC stage, 2) dc-to-dc conversion stage, and 3) full-bridge inverter stage. The buck converter is usually performs the dc-to dc stage to regulate the lamp voltage and thereby the lamp power. The switches of the full bridge inverter stage are alternatively turn on and off to achieve a low-frequency square-wave voltage to drive the lamp. In spite of their good performance, such three stage approaches require more circuit components and complex control, resulting in higher cost and lower efficiency.

To overcome the disadvantages of three-stage approaches, two-stage electronic ballast have been developed by integrating the dc-to-dc conversion stage and the full-bride inverter stage [15][7] can be achieved by two stage approach and it eliminates the occurrence of acoustic resonance by driving the metal halide lamp with a low-frequency square wave voltage. Since stage electronic ballast is developed in order to reduce the circuit component count [6][3][4][13].

5. Proposed Circuit Configuration

Fig. 1 shows the proposed single state electronic ballast. The Diodes D_1, D_2, D_3, and D_4 represent the intrinsic body diodes of the MOSFETs S_1~S_4. For improving the switch-utilization factor, two buck-boost converters (PFC1, PFC2) are adopted as the PFC circuit.

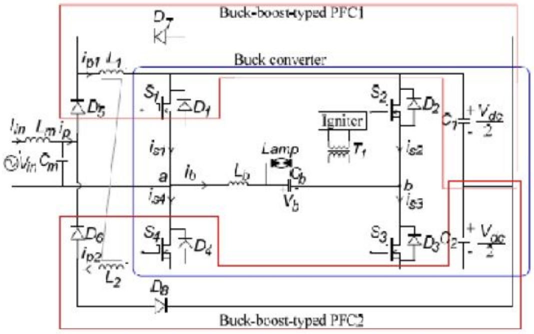


Fig 1 Single Stage HPF electronic ballast for metal halide lamp

It results in a symmetrical circuit topology. PFC1 consists of diodes D_5 andD_7, active switch S_1, inductor L_1 and dc-link capacitor C_1. PFC2 consists of diodes D_6 and D_8, active switch S_4, inductor L_2 and dc-link capacitor C_2. PFC1 operates in the positive half-cycle of the input line voltage, while PFC2 operates in the negative half-cycle. Since PFC1 and PFC2 never conduct current simultaneously, the inductors L_1 and L_2 can be made by two windings in one magnetic core.

The buck converter consists of inductor L_b, capacitor C_b and all the switches S_1~S_4. Actually, it complies with the operation of the full-bridge inverter to be a bidirectional buck converter and outputs a square-wave voltage. An igniter and the transformer T_1 generate a high voltage to start-up the lamp. A small low-pass filter, L_m and C_m, is used to remove the high frequency current harmonics at the input line.

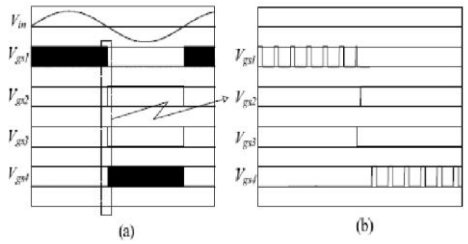


Fig 2 Gated signals for active switches. a) Gated signals in line voltage period b) Expanded waveforms in the rectangular region

The four active switches, S_1, S_2, S_3 and S_4 are controlled by four gated signals, V_{gs1}, V_{gs2}, V_{gs3}, and V_{gs4}, respectively. Fig. 2 shows these gated signals. V_{gs2} and V_{gs3} are non overlapping rectangular-wave voltages with a short dead time at a low operating frequency equal to that of the input line voltage. On the contrary, V_{gs1} and V_{gs4} are high-frequency rectangular-wave voltages which happen when V_{gs3} and V_{gs2} are at high voltage level, respectively.

6. Circuit Operation

In order to obtain a high power factor, the circuit is designed to meet the following conditions:

(a) Both the PFC1 and PFC2 perform as buck-boost converters and operate in DCM.
(b) The buck converter operates in DCM.
(c) During the time when S_1 or S_4 are turned off, the currents *ip1* and *ip2* should decline to zero before *ib* does.

Since the circuit operates symmetrically, the operation modes in the negative half-cycle of the line voltage are similar to those in the positive. Hence, the operation modes only in the positive half-cycle of the line voltage are discussed. For simplifying the circuit analysis, the input filter and the igniter circuit are omitted. At steady state, the circuit operation can be divided into four modes in accordance with the conducting power switches within one high-frequency cycle. Fig.3 shows the operation modes in the positive half-cycles of the line voltage. Fig. 4 illustrates the theoretical waveforms for each mode. The circuit operation is described as follows:

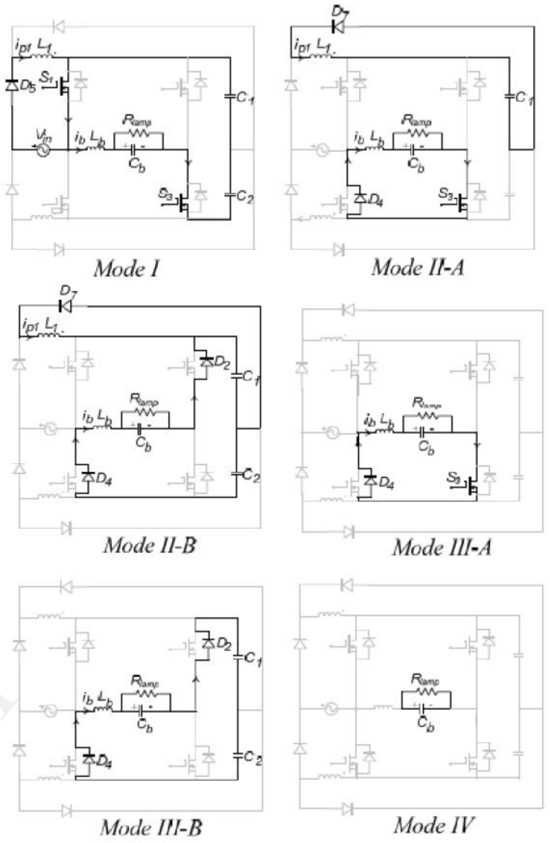


Fig 3 Operation modes in positive half-cycle

Mode I (t0<t<t1):

Mode I begin at the instant of turning on switch S_1. The rectified input voltage is across the inductor L_1. Current i_{p1} increases linearly from zero with a rising slope which is proportional to the line voltage.

Meanwhile, the voltage across the inductor L_b is equal to V_{dc} minus V_b. Capacitors C_1 and C_2 supply current to charge L_b. Same, the buck inductor current i_b rises from zero.

Mode I end when S_1 is turned off. There could be two different operation modes following Mode I. If, switch S_3 is on, the circuit operation enter Mode II-A. Otherwise, the circuit operation will enter Mode II-B.

Mode II-A (t1<t<t2):

Mode II-A begins when S_1 is turned off. For making PFC1 and PFC2 perform as buck-boost converters, both the voltages across C_1 and C_2 should be higher than the amplitude of the ac input voltage.

Diode D_5 is reverse-biased. Current i_{p1} will freewheel through diode D_7 to charge C_1. Meanwhile, current i_b

flows through S_3 and diode D_4 to supply current to C_b and the lamp. The voltages across L_1 and L_b are equal to $-V_{dc}/2$ and $-V_b$, respectively. Therefore, both currents decrease linearly.

Mode II-B (t1<t<t2):

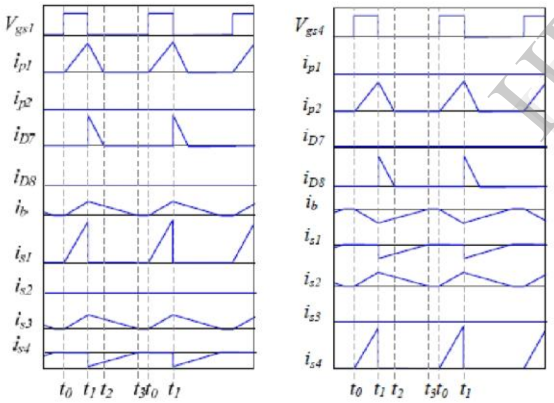
The difference between Mode II-B and Mode II-A is only the current loop of i_b. Since both S_1 and S_3 are turned off, i_b will freewheel through diodes D_2 and D_4 to charge capacitors C_1 and C_2. The voltage across L_b is $-V_{dc}$ plus $-V_b$. Hence, i_b decrease faster than it does in Mode II-A.

Mode III-A & Mode III-B (t2<t<t3):

As stated above, i_{p1} should decline to zero before i_b does. When i_{p1} reaches zero, Mode III-A and Mode III-B follow Mode II-A and Mode II-B, respectively. Only i_b and lamp current keep flowing.

Mode IV (t3<t<t4):

The operation enters Mode IV when i_b reaches zero. During this mode, only the lamp current supplied from C_b exists. When V_{gs1} goes back to high level to turn on S_1, the circuit operation returns to Mode I of the next high-frequency cycle.



(a) (b)

Fig.4. Theoretical waveforms in a) positive and b) negative half-cycles of input line

7. Conclusion

A novel single-stage electronic ballast for MH lamps is presented. The proposed circuit is derived by integrating two buck-boost converters a buck converter and a full-bridge inverter. The buck-boost converters perform as power factor correction circuits and operate at DCM to achieve high power factor and small total current distortion. The lamp was driven by a low frequency square wave current to avoid the occurrence of acoustic resonance.

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