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Research on Active Power Factor Correction of the Electronic Ballast for High-pressure Sodium Lamps Based on L6563

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***Abstract*—In the recent years, there has been a growing interest in the design of high-pressure sodium lamp electronic ballast. Two measures are proposed to improve the power factor of high-pressure sodium lamp electronic ballasts from the definition of harmonic and power factor. And the basic principle of active power factor correction is also discussed in this paper. The active power factor correction circuit of the electronic ballast for high-pressure sodium lamps is successfully designed based on L6563 integrated chips. Experiment results show that the power factor of this electronic ballast is above 10% and its total harmonic distortion is lower than 0.990.**

Keywords—high-pressure sodium lamps; electronic ballast; active power factor correction; L6563

I. INTRODUCTION

High-pressure sodium (HPS) lamp has been the third representative new powerfrugal light source due to its merits such as high optical efficiency, powerful fog penetrability, long life, wide power bracket and so on. There are two kinds of high-pressure sodium lamp ballast. One is inductive ballast and the other is electronic ballast. Conforming to the energy conservation and environmental protection times, electronic ballast is predominant for it is smaller in bulk, light in weight, quiet in noise and efficient in power. In the home market, compared to the standard of International Electro technical Commission, disparity of most high-pressure sodium lamps electronic ballasts rests with higher electric current harmonic content and lower line power factor which undoubtedly causes pollution to the power system and seriously influence normal operation of other power facilities. Leading in filter capacitor causes more serious current distortion in traditional rectifier bridge structure whose power factor is generally less than 0.65. Power factor correction must be taken into consideration with the increase of high power supply quality and the technology development of integrated circuit.

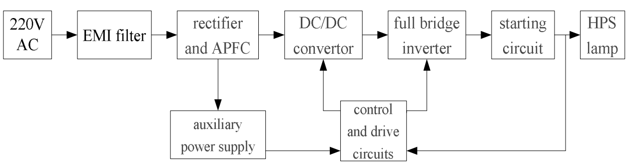

Figure1. Schematic diagram of HPS electronic ballast

Generally speaking, power factor correction circuits can be divided into passive power factor correction （PPFC) and active power factor correction（APFC）. Only inactive components such as inductances, capacitances, diodes and resistances are used in PPFC circuit. Besides inactive components, active components are also used in APFC circuit such as discrete transistor components and control integrated circuits which contain numerous transistors. PPFC circuit has simple topology, lower cost, and upper power factor which is higher than 0.9. But it is difficult to achieve low electric current harmonic distortion. Control integrated circuit is needed in APFC circuit and one individual section must be constituted before the system which lead to the increase of the cost. But APFC circuit can achieve low harmonic distortion and a very high power factor which is higher than 0.99. With the constantly lowered IC price, APFC circuits have been widely applied not only because it is small in bulk, light in weight, high in power factor which is close to 1 but also its input current total harmonic wave factor is less than 10%.

II. THE BASIC PRINCIPLE OF ACTIVE POWER FACTOR CORRECTION

Based on the power factor IC controller, using passive components and switching device such as MOSFET or IGBT, active power factor correction can make phase position of the commercial power input current be consistent with voltage waveform. Thus the current waveform distortion and phase aberration can be eliminated which can achieve a high power factor similar to 1. At the same time the dc voltage output can be adjusted stably.

Active power factor correction converter is essentially a kind of DC/DC converter. Almost electronic ballast active PFC circuits use boost converter because it is easy to design the driving circuit whose input current is just the inductance current, easy to implement current mode control, easy to solve electromagnetic interference problem and easy to provide greater power output. The basic structure of booster active PFC circuit is shown in figure 2.

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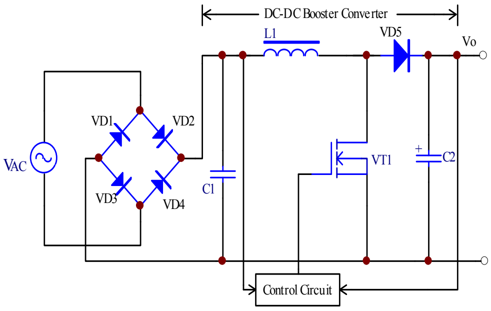

Figure2. The basic framework of APFC circuits

This circuit structure consists of control circuit based on IC, input capacitance C1, boost inductor L1, VT1 (MOSFET) used as switch, booster diode VD5 and output storage capacitor C2. It is placed between the full wave bridge rectifier and the inverter in the electronic ballast. When the control circuit drives VT1 to be conductive, diode VD5 will be in its off condition, output capacitor C2 will supply power to the load alone and current through L1 will increase linearly and will entirely return to the electric power source through VT1. Once VT1 turns into off condition, the energy in L1 will release, diode VD5 will be conductive, capacitance C2 will be charged and electric current in L1 will linearly decline from its peak. If booster converter works in discontinuous conduction mode, electric current in L1 will decline until zero during the off condition of VT1. The inductance current will be high frequency triangle wave or saw teeth wave and will be power frequency current wave after the high frequency components are filtered. One of the important reasons that the input current can become frequency current wave is that inductance peak current is continuously tracking the alternating current input voltage in every switch cycle.

III. HARMONIC AND POWER FACTOR

The power factor of electronic ballast generally is generally defined as the ratio of active power P and apparent power S:

$$PF = \frac{P}{S} = \frac{V_1 I_{1rms} \cos\theta_1}{V_1 I_{rms(total)}} = \frac{I_{1rms}}{I_{rms}} \times \cos\theta_1 = r\cos\theta_1 \quad (1)$$

In the above formula, I_{1rms} stands for input current fundamental RMS, $I_{rms(total)}$ stands for input current total RMS, r stands for input current distortion coefficient, $\cos\theta_1$ stands for the phase shift factor between fundamental voltage and fundamental current. So the power factor (PF) can also be defined as the product of input current distortion coefficient r and phase shift factor $\cos\theta_1$.

The total current harmonic distortion (THD) is defined as following:

$$THD = \frac{\sqrt{I_{2rms}^2 + I_{3rms}^2 + \cdots + I_{nrms}^2}}{I_{1rms}} \times 100\% = \frac{\sqrt{\sum_{n=2}^{\infty} I_{nrms}^2}}{I_{1rms}} \times 100\% \quad (2)$$

In formula (2), I_{nrms} stands for the nth harmonic current RMS, so the power factor can be shown as following:

$$PF = \frac{I_{1rms}}{\sqrt{I_{1rms}^2 + I_{2rms}^2 + \cdots + I_{nrms}^2}} \times \cos\theta_1 = \frac{I_{1rms}\cos\theta_1}{\sqrt{\sum_{n=1}^{\infty} I_{nrms}^2}} = \frac{\cos\theta_1}{\sqrt{1+(THD)^2}} \quad (3)$$

Formula (3) shows that the following two methods can be used to improve the power factor:

- Inhibiting the input current waveform distortion to the utmost to achieve the minimum THD.
- Making the phase shift factor between fundamental voltage and fundamental current to zero as far as possible. Thus power factor correction can be achieved for $\cos\theta_1$ is equal to 1.
- The existence of harmonic current is the fundamental reason which causes the power factor decline. So it is uniform to eliminate harmonic current and improve the power factor. How to turn a narrow pulse current into a better uniform phase sine wave current has become the main way of power factor correction [2] .

IV. THE DESIGN OF AFPC CIRCUIT OF THE ELECTRONIC BALLAST FOR HIGH-PRESSURE SODIUM LAMP BASED ON L6563

L6563 is a kind of transition-mode power factor correction control IC which is manufactured by ST corporation. Besides the general characteristics of traditional standard TM PFC controller, L6563 can also implement the following additional functions:

- THD optimization circuit

A high-frequency filter capacitor between 0.22 μ F and 1 μ F is placed after the bridge rectifier in the PFC boost pre-regulator. Near the zero-crossing of AC line voltage, it is impossible to discharge completely for this filter capacitor on which a rudimental voltage exists. So a dead-angle appears in the AC input current which is called cross over distortion. Yet a highly linearized multiplier is combined with a THD optimization circuit which is used to minish AC input current cross over distortion in L6563. Thus a THD level less than 5% can be achieved as low as current continuous-conduction mode PFC converter. Also the circuit structure of L6563 can be as simple as CCM-PFC.

- Tracking boost function

In some applications it may be advantageous to regulate the output voltage of the PFC pre-regulators so that it tracks the RMS input AC voltage rather than at a fixed value like in conventional boost pre-regulators. This is commonly referred to as “tracking boost” approach.

With this IC the function can be realized by connecting a resistor (R_T) between the TBO pin and ground. The TBO pin presents a DC level equal to the peak of the MULT pin voltage and is then representative of the mains RMS voltage. The resistor defines a current, equal to V (TBO)/R_T, is internally 1:1 mirrored and sunk from pin INV (pin 1) input of the error amplifier. In this way, when the mains voltage increases the voltage at TBO pin will increase as well and so will do the current flowing through the resistor connected between TBO and GND. Then a larger current will be sunk by INV pin and the output voltage of the PFC pre-regulator will be forced to get higher. Obviously, the output voltage will move in the opposite direction if the input voltage decreases.

To avoid undesired output voltage rise should the mains voltage exceed the maximum specified value, the voltage at the TBO pin is clamped at 3V. By properly selecting the multiplier bias it is possible to set the maximum input voltage above which input-to-output tracking ends and the output voltage becomes constant. If this function is not used, leave the pin open: the device will regulate a fixed output voltage.

- Input voltage feed-forward

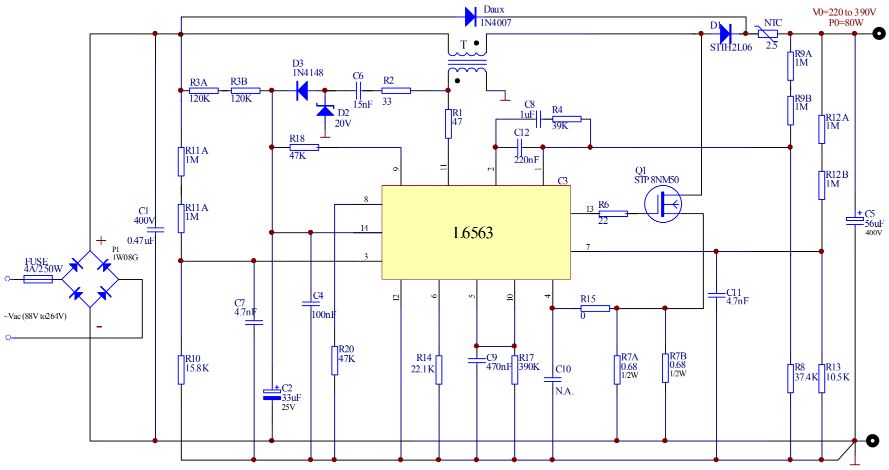

Figure3. The high active power factor correction circuit of the electronic ballast for 80W high-pressure sodium lamps based on L6563

Voltage feed-forward can compensate for the gain variation with the line voltage and allow overcoming all of the above-mentioned issues. It consists of deriving a voltage proportional to the input RMS voltage, feeding this voltage into a squarer/divider circuit ($1/V^2$ corrector) and providing the resulting signal to the multiplier that generates the current reference for the inner current control loop.

- Overvoltage protection and Feedback failure protection

Normally, the voltage control loop keeps the output voltage Vo of the PFC pre-regulator close to its nominal value, set by the ratio of the resistors R1 and R2 of the output divider. Neglecting the ripple components, under steady state conditions the current through R1 equals that through R2. Considering that the non-inverting input of the error amplifier is internally biased at 2.5V, the voltage at pin INV will be 2.5V as well.

The OVP function above described is able to handle "normal" overvoltage conditions, i.e. those resulting from an abrupt load/line change or occurring at start-up. It cannot handle the overvoltage generated, for instance, when the upper resistor of the output divider (R1) fails open: the voltage loop can no longer read the information on the output voltage and will force the PFC pre-regulator to work at maximum ON-time, causing the output voltage to rise with no control.

- Remote ON/OFF control

When voltage at the IO(RUN) pin is lower than 0.52V, the IC will power off. However the IC will power on again when the IO(RUN) pin is higher than 0.6V. So the remote ON/OFF control can be implemented.

- Providing interface for the cascade connected DC-DC converter

The major functions and effects of APFC control circuit based on L6563 are as following：

- Inhibiting the source current waveform distortion effectively which can completely reach and can be far less than L-level distortion index requirements.
- Raising the power factor to the level near to 1.
- Obtaining relatively stable dc voltage even though the input AC voltage fluctuates in a wide range which can keep invariable lamp output, reduce or eliminate the transient energy impact to electronic components and raise the reliability and safety of electronic ballasts. At the same time invariable lamp voltage and current can be ensured which can extend the lamp life.

Owing to above merits, L6563 is used to design a high active power factor correction circuit of the electronic ballast for 80W high-pressure sodium lamps as is shown in figure3.

V. CONCLUDING REMARKS

The high active power factor correction circuit of the electronic ballast for 80W high-pressure sodium lamps is successfully designed based on L6563 integrated chips. Experiment results show that the power factor of this electronic ballast is above 10% and its total harmonic distortion is lower than 0.990.

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