Implementation of Pulse Ignition Circuit in Electronic Ballast for 70W High Intensity Discharge Lamp

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Abstract-High-Intensity-Discharge (HID) lamps are widely utilized in a variety of lighting circumstances that need high luminance. Because of high lighting efficiency, good colour rendering, long lamp life time, HID lamps have become an attractive lighting source for outdoor lighting, road lighting, stadium, park, building, shopping mall etc. Hid lamps should need a high voltage peak at the ignition phase of the lamp and rated lamp power should be needed at the steady state running operation of the lamp. Therefore, a ballast is needed to fulfill these conditions. In this paper, in addition to design of an electronic ballast a novel pulse ignition circuit is proposed for electronic ballast with the zero-voltage-switching quasi-square wave (ZVS-QSW) converter; the voltage pulse of the proposed igniting circuit contains both a high frequency part and a low frequency part; the high frequency part made it easy to exit the gas in the ionization conduction state in the high-intensity discharge lamp, and the low frequency part makes it easy to lower the igniting potential and provides the continuous pulse energy. The circuit is with few components, low cost high reliability, and easy to control. A digital control is proposed here for controlling the electronic ballast by using pic controller. A zero-voltage-switch quasi-square-wave(ZVS-QSW) dual Buck converter is adopted here. Also this digital control method is proposed to achieve ZVS for the converter. A hardware prototype of electronic ballast with pulse ignition circuit for 70W lamp is implemented in this work. Experimental results show that the electronic ballast works reliably. Furthermore, the efficiency of the ballast can be higher than 92%,with an increased power factor.

Keywords: ZVS-QSW converter, pulse ignition, electronic ballast, PIC controller, HID lamp.

PFC is usually higher than the operating voltage of MH lamp, an additional buck converter should be cascaded after the PFC to comply with the lamp

INTRODUCTION

As a high-efficacy long-lifetime lighting source, the high intensity discharge (HID) lamp plays an important role in the modern life. The metal halide (MH) lamp belongs to the HID lamp and has a distinct characteristic of negative impedance. Therefore, it cannot be connected with the power line directly and must be used with the ballast. Traditional electromagnetic (EM) ballasts operating under the line frequency have a big volume, a high weight, and a low efficiency. The MH lamp using the EM ballast may flick with the line frequency, its power fluctuation follows the line voltage, and it extinguishes easily. The MH lamp used with the electronic ballast gets the advantages of characteristics for controllable operation, lighting quality, and economical benefit over those used with the EM ballast. Therefore, the electronic ballast will gradually take the place of the traditional EM ballast[9].

However, MH lamps driven by a high-frequency electronic ballast may suffer from problematic acoustic resonance that may lead to arc instability, light fluctuation, or extinguishment, and even cracking the arc tube. Many approaches have been proposed to solve the problem of acoustic resonance. Among them, driving MH lamps with a low-frequency square-wave (LFSW) voltage has been considered the most effective method to eliminate the occurrence of acoustic resonance for its high reliability and control simplicity[1],[2]. On the other hand, in order to improve the power factor, an ac/dc converter that performs as a power-factor corrector (PFC) is required in ballast circuits. A boost converter or a buck-boost converter is preferred to serve as a PFC. Since the output dc voltage of the voltage[5]. For these reasons, many proposed electronic ballasts consist of three stages, which are

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the PFC, the buck converter, and the half-bridge inverter.

But nowadays, electronic ballast for Hid lamps are slowly replacing the electromagnetic ballast. Electronic ballast is superior to Electromagnetic ballast in respect of compactness , energy saving light weight , better ignition circuitry , and control during steady state operation .Basically Electronic ballast for Hid lamp are mainly classified upon what frequency range the lamps are to be operated . High frequency driven electronic ballast has been widely adopted for low pressure lamps as it offers a compact light weight lamp-ballast system. Though the technology has been turned to low-frequency square wave driven electronic ballast considering factor of acoustic resonance[9],[10] .The probability of occurring of acoustic resonance is much higher when operated at high frequency range for high pressure lamps and probability is null when operated at low frequency range (200- 500Hz) . An effort has been made in this work to develop electronic ballast for high pressure discharge lamp operated at low frequency range as well as high frequency range .Cost Reduction for electronic ballast is another objective of our study.

I. ELECTRONIC BALLAST AND ITS COMPONENTS

Electronic ballast is a device which controls the starting voltage and the operating current of lighting devices built on the principle of electrical gas discharge. Basic structure of proposed electronic ballast is shown below. There are basically 8 functional blocks in the electronic ballast of HID lamps as shown in fig. 1.

A typical HID ballast performs eight basic functions. An electromagnetic interference (EMI) filter blocks ballast-generated noise. A full-wave rectifier converts ac to dc and provides the high-voltage bus power. A power-factor-correction (PFC) block ensures sinusoidal input current. A buck converter controls the lamp current. A half-bridge output stage provides the ac lamp drive. An ignition circuit strikes the lamp. Control circuitry manages each stage. Finally, driver activates all the mosfet switches for the operation. Currently, this is one of the most popular approaches to powering HID lamps with a low-frequency ac voltage. The PFC stage is a boost converter that operates in critical- conduction mode with a free-running frequency.

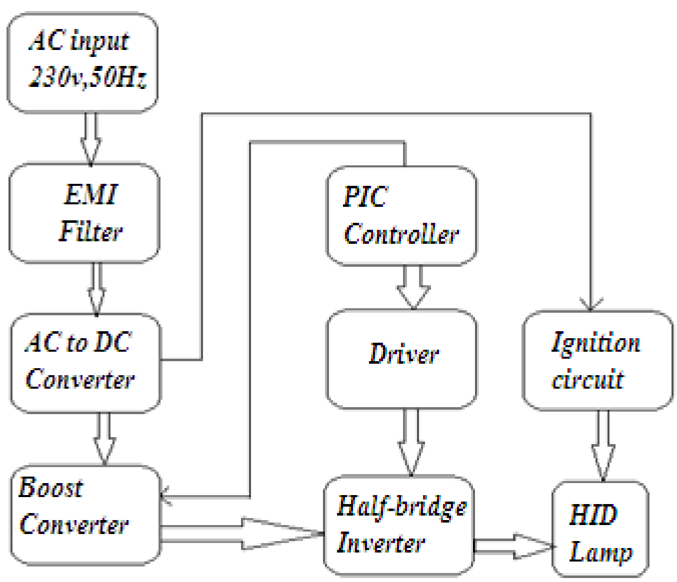

Fig 1. Block diagram of electronic ballast for HID lamp

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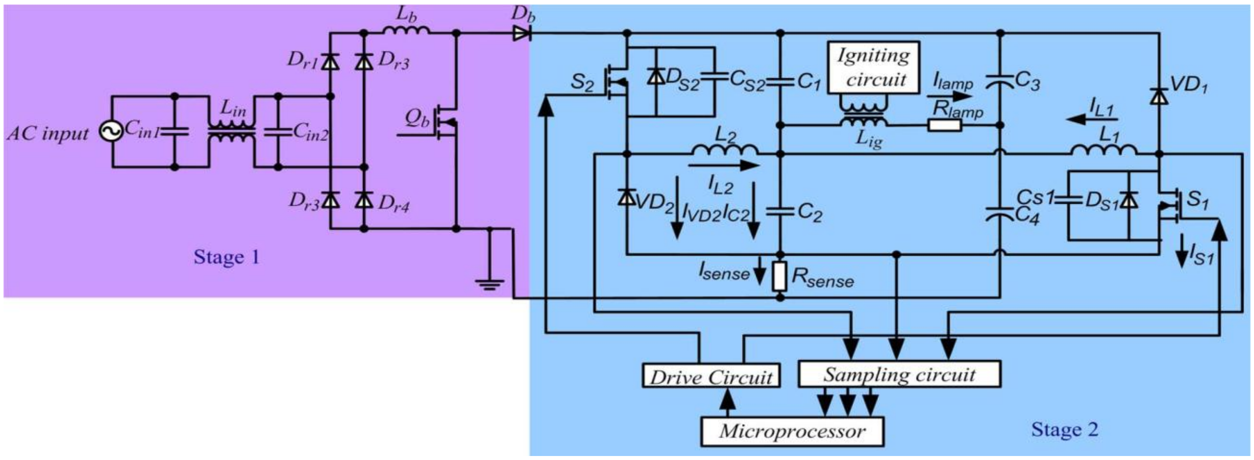

Fig 2. circuit diagram of dual buck converter based electronic ballast

A. Configuration of the Ballast

The electronic ballast which contains two stages is presented in Fig.5.1. In the first stage, the input EMI filter, the full-bridge rectifier, and the power factor correction (PFC) circuit work together, where the PFC circuit is a boost circuit working in the BCM. Where the bus voltage is 400 V with a 230-V ac input. In the second stage, the ZVS-QSW dual buck converter is adopted, and the correspondent signals of the ZVS-QSW dual buck converter are sampled by the sampling circuit. After sampling, the pic controller sends drive signals to the switches to control the working condition of the converter[9].

B. Working Modes of the Ballast

One buck circuit contains S_1, VD_1, L_1, C_1, and C_2, and the other contains S_2, VD_2, L_2, C_1, and C_2, as is shown in Fig.2. The functions of the components are described as follows. D_{s1} and C_{s1} are both the body diodes and the output capacitance of S_1. D_{s2} and C_{s2} are both the body diodes and the output capacitance of S_2. C_1 and C_2 are the filtering capacitances of the buck circuits. C_3 and C_4 are not only the half-bridge capacitances but also the output capacitances of the PFC circuit. The equivalent impedance R_{lamp} works in the steady state. The working modes are shown in Fig.3, where *TLF* is the low-frequency period of the ZVS-QSW dual buck converter.

In a one-half low-frequency period, S_1 works in the high frequency; in the other half low-frequency period, S_2 works with the high frequency.

Therefore, the low-frequency square wave is gotten by the lamp, and the HID lamp is in the low-frequency square-wave drive mode. As we know that from the references the lumen efficiency decreases slightly as the frequency of the square wave for the lamp increases, so the frequency of the square wave should be as low as possible, but if the frequency is too low, the flicker will be detected by our eyes. Here, 150 Hz is chosen to be the low frequency, and it is not changed for the whole working condition.

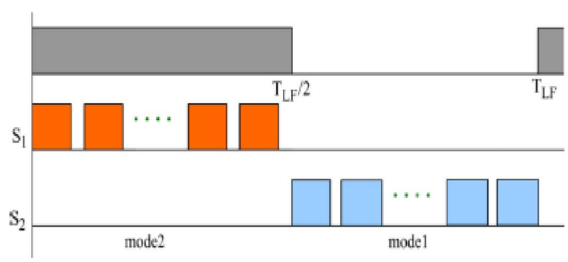

Fig 3. working modes of switches

C. zvs-qsw dual buck converter

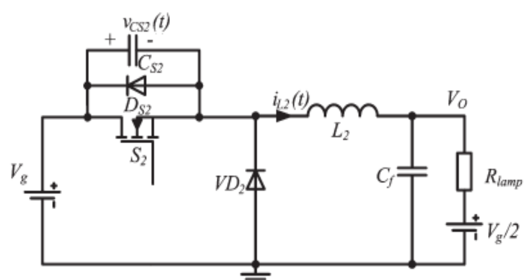

Fig 4, equivalent circuit of zvs-qsw dual buck converter operating in mode 1

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Mode1 and mode2 follow the same working principle, so only mode1 is analyzed in detail here. Fig. 4 shows the equivalent circuit in mode1. C_f is the equivalent capacitor of C_1 and C_2. Fig.5 shows the waveforms of the drive signals in one high-frequency period. Here, V_{GS2} is the voltage between the gain pole and the source pole of S_2, V_{DS2} is the voltage between the drain pole and the source pole of S_2, and I_{L2} is the current of L_2.

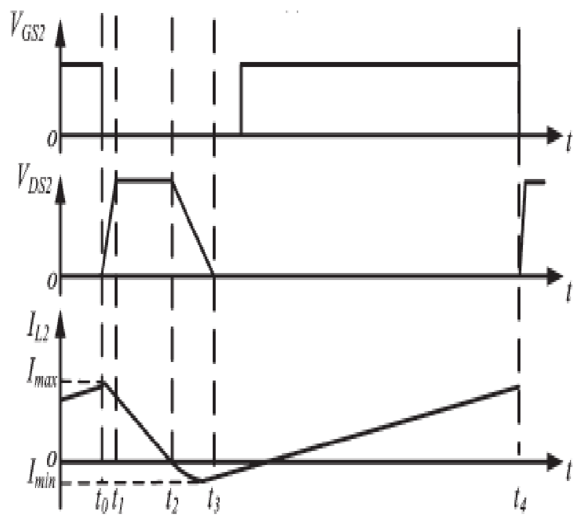

Fig 5 Working modes of ZVS-QSW converter.

The working conditions of the buck circuit are described as follows.

Mode1 (a) (t_0 ~ t_1): This mode starts at t_0. C_{S2} resonates with L_2, and VD_{S2} increases linearly, until it equals Vg.

Mode1 (b) (t_1~ t_2):When VC_{S2} (t) reaches Vg,VD_2 is turned on, and VC_{S2} (t) is clamped to Vg. iL_2 (t) runs throughVD_2 and decreases linearly until it reaches zero.

Mode1(c) (t_2~ t_3): At time t_2, the inductor current decreases to zero, and the diodeVD_2 is turned off. L_2 resonates with C_{s2}. The current of the inductor changes its direction so that the voltage of C_{s2} begins to decrease from Vg. When VC_{S2} (t) decreases to zero, this mode ends

Mode1 (d) (t_3~ t_4): At time t_3, VC_{S2} (t) decreases to zero, iL_2 (t) runs through D_{S2}, and VC_{S2} (t) is clamped in the ZVS state. At this time, if the turn-on signal of S_2 comes before iL_2 (t) changes its direction, S_2 will be turned on in the ZVS state, and iL_2 (t) will run through $S_2$and increase linearly. When $S2$ is turned off, iL_2 (t) reaches its maximum value I_{max}.

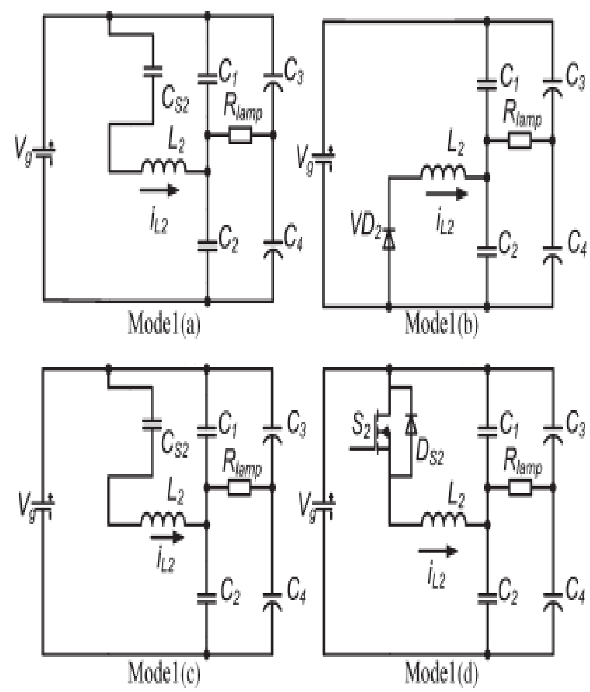

Fig. 6 working conditions of the converter in mode1

Mode 2 and mode 1 work alternately in the low frequency (150 Hz), so waveform of the lamp current is a low-frequency square wave. The current waveform is symmetrical and contains high-frequency harmonics. Choosing suitable working frequency, C_1 and C_2 can limit the high-frequency harmonic content in the range of not causing acoustic resonance.

In the practical use, when the lamp is on, the output voltage of the buck circuit is always higher than $Vg/2$ because of the existence of the lamp voltage, so the ZVS condition is always satisfied. It is also evident that not only can the switch work in the ZVS state but also can the buck diode work in the zero current switching (ZCS) state, so the turn-on losses of the switches can be decreased a lot which increases the efficiency of the system.

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II. Pulse Ignition

There are usually two methods to ignite the metal halide lamp, the first method is the resonant igniting method, since no additional components are needed, the igniting method is very easy to be realized. But when the lamp is in the open-circuit state, the voltage and the current in the main circuit are both very high, so the protection function must be made. The second method is the pulse igniting method.

The pulse igniting method requires adding additional components to the system, so the costs increase, but there is no high current in the main circuit when the lamp is in the open-circuit state. For the pulse igniting method, there are usually two ways to realize it, one is the high-amplitude high-frequency method; the pulse voltage waveform of the high-amplitude high-frequency method is shown in Fig.7; the amplitude of the first pulse is usually very high to ignite the lamp, and the amplitude of the voltage pulse decays to zero quickly. The method is easy for the metal halide lamp to be ignited, but it introduces a high current between the main electrode and the auxiliary electrode, and if the amplitude of the pulse voltage is too high, the auxiliary electrode may be damaged. The second way is the low-amplitude low-frequency method, as can be seen in Fig.7, the frequency and the amplitude of the pulse voltage are both very low.

This method can improve the working life of the lamp, but the loop current of the resonant tank for the pulse igniting circuit in the primary side of the transformer is very high, which makes it hard to choose the components, and it's mainly for the magnetizing ballast. In my work a pulse ignition with low frequency square wave technique is used to ignite HID lamp[10].

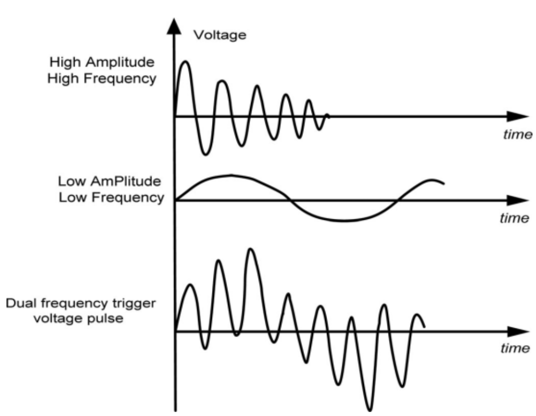
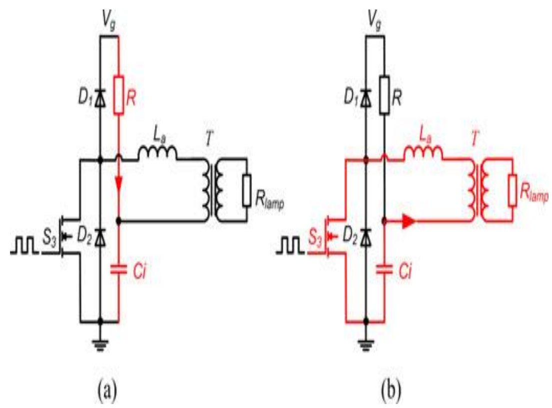


Fig 7 Waveform of ignition high-voltage pulse.

a) Pulse igniting circuit



(a) Charging process. (b) Discharging process
Fig 8 Working modes of the igniting circuit.

The pulse igniting circuit is made up of S_3,D_1,D_2,R, L_a, Ci and the transformer in Fig. 8. Here R is the current limiting resistance, D_1 and D_2 are the clamping diodes, which makes sure that the voltage between the drain pole and the source pole of S_3 is limited from Vg to 0 V. There is a high voltage pulse in a half-low frequency period to ignite the lamp. There are two working modes for the igniting circuit. First, S_3 is in turned off, Ci is charged until the voltage of Ci reaches Vg . Second, after the voltage of Ci reaches Vg, S_3 is turned on, Ci discharges through L_a and the transformer, one resonance tank is made up of the primary inductor L_p , the auxiliary inductor L_a and the energy storage capacitor Ci , the other resonant tank is made up of L_a , and the parasitic capacitance of the transformer, so the dual frequency trigger voltage pulse to ignite the lamp is obtained from the secondary side of the transformer. When the lamp is ignited successfully, S_3 is always in the turned-off state, the voltage of Ci is always equal to the bus voltage, but there is no discharging loop for Ci , so the igniting circuit does not affect the operation of the ZVS-QSW converter in, and the working modes are shown in Fig.8.

The traditional switching component for S_3 is the spark gap or SCR. But the life time of the spark gap is very short, which limits the spark gap used for the igniting circuit. The working frequency of SCR is not very high, so it's not suitable to use it here. The reliability of MOSFET component is high with simple drive circuit, so here MOSFET is chosen to be the switch for S_3[10].

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III. EXPERIMENTAL RESULTS

This paper uses the 70-W metal halide lamp, and its type is OSRAM HQI 70 W. S_3 is chosen to be FGA25N120, and the driving IC isTLP250. Here the energy storage capacitor is chosen to be 15nF/630 V, and it is film capacitor with low ESR. The auxiliary inductor is 30μH, the word inductance with the size 10 mm×12 mm is adopted, and the wingding is enameled wire with 0.5-mm diameter.

For the design of the turn ratio of the transformer, first, the amplitude of the voltage pulse must be higher than 3 kV. Second, the loop current must be lower than 10 A. Third, the high voltage pulse lasting time must be larger than 1μs. As can be seen in Figs. 10, 11, and 14, when the turn ratio is chosen to be 8 and the auxiliary inductor is chosen to be 30μH, the amplifier of the pulse voltage is higher than 3 kV, the peak loop current is lower than 10 A, the width of the pulse voltage is larger than 1μs, which is satisfied with the standard, so the turn ratio is chosen to be 8. The core of the transformer is EE18 mm×20 mm, the sandwich winding method is adopted here, the enameled wire with 0.4 mm diameter is used, and L_p is 17.8μH. Also, in practical use, the manufacturing tolerances or the temperature does not affect the igniter capacitances/inductors and the igniting voltage significantly. As can be seen in Figs. 8 and 9, since the value of *Ci* is selected to be 15nF, even with 5% of the deviation, the amplitude of the pulse voltage is still higher than 3 kV, and the loop current is still lower than 10 A.

In Fig.9(a), V_{GSS3} is the drive signal of S_3 and V_{tlp250} IN is the low-frequency square wave obtained by tlp250 pin, and S_3 is turned ON with 400μs time delay after the low-frequency commutation moment to guarantee that the lamp voltage is stable. Fig.9(b) shows the lamp voltage in the open circuit state with high igniting pulse voltage.

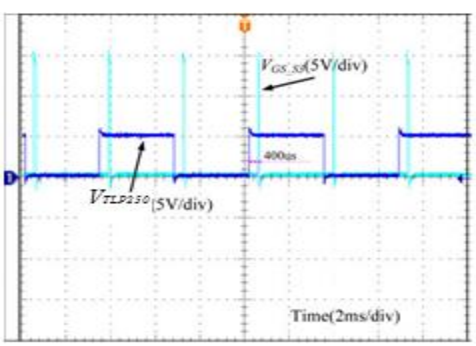

Fig 9 (a) Driving voltage of *S*3

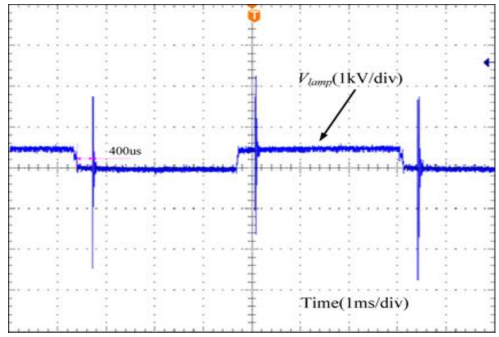

Fig 9 (b) Lamp voltage in the open-circuit stage with high igniting pulse voltage.

Fig 10. Hardware prototype of electronic ballast for 70watt OSRAM lamp

The above shown hardware prototype for HID lamp produces or meets the following specifications of electronic ballast. For AC mains voltage: Vin = 230V, 50Hz;

- output power: Po = 70W;
- DC-DC switching frequency: fs = 50kHz;
- inverter switching frequency: fs = 150Hz;
- ignition lamp voltage: Vig = 4kV.
- the duration of high voltage pulse is>1µs

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IV. CONCLUSION

In this work, a metal halide pulse igniting circuit based on the dual frequency trigger pulse method is proposed, and it's very suitable to be used for the metal halide lamp electronic ballast with the ZVS-QSW converter. It adds an auxiliary inductor in the traditional pulse igniting circuit and uses the parasitic capacitance of the transformer to generate two groups of ignition pulse sequences with different frequencies applied to the lamp.

Pic controller is used to provide PWM signals to the MOSFET switches by using TLP250ic and the appropriate lamp ignition voltage is generated to ignite a 70watt HID lamp. the peak pulse voltage is high enough and pulse voltage width is also enough, and it improves the reliability of the igniting circuit. The auxiliary inductance effectively limits the peak loop current and overcomes the peak pulse voltage fluctuations caused by the discreteness of the parasitic capacitance. The experimental results prove the reliability and feasibility of the design. The loop current is limited to 10 A, and the lamp can be ignited reliably.

REFERENCES

1) Tsorng-Juu Liang, *Member, IEEE*, Chien-Ming Huang, and Jiann-Fuh Chen, *Member, IEEE "*"**Two-Stage High-Power-Factor Electronic Ballast for Metal–Halide Lamps"** IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 24, NO. 12, DECEMBER 2009

2) Nan Chen, *Student Member*, *IEEE*, and Henry Shu-Hung Chung*, Senior Member, IEEE "*"**Energy-Recyclable Burn-In Technology for Electronic Ballasts"** IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 26, NO. 9, SEPTEMBER 2011

3) Ryan W. Schnell, Regan A. Zane, *Member*, *IEEE*, and Francisco J. Azcondo, *Senior Member*, *IEEE* "**Size Reduction in LFSW Ballasts for High-Intensity Discharge Lamps Using Soft-Saturation Magnetic Material and Digital Control Techniques**" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 28, NO. 2, FEBRUARY 2013

4) Hung-Liang Cheng, *Member*, *IEEE*, Chin-Sien Moo, *Member, IEEE*, Chung-Sheng Yang, and Chun-Kai Huang **"Analysis and Implementation of an HPF Electronic Ballast for HID Lamps With LFSW Voltage"** IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 27, NO. 11, NOVEMBER 2012.

5) Yijie Wangy, Xiangjun Zhang_, Wei Wang_, and Dianguo Xu_ "**Digital Control Methods of Two-Stage Electronic Ballast for Metal Halide Lamps with a ZVS-QSW Converter"** Journal of Power Electronics, Vol. 10, No. 5, September 2010

6) André Luís Kirsten,Marco A. Dalla Costa, Cassiano Rech, Ricardo Nederson do Prado,and Tiago Bandeira Marchesan, *Member, IEEE "*"**Digital Control Strategy for HID Lamp Electronic Ballasts "** IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 60, NO. 2, FEBRUARY 2013.

7) Hung-Liang Cheng, *Member*, *IEEE*, and Ping-Wen Wang "**A Novel Single-Stage High-Power-Factor Electronic Ballast for Metal-Halide Lamps Free of Acoustic Resonance**" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 26, NO. 5, MAY 2011

8) Yuequan Hu and Milan M. Jovanović "**High-Intensity-Discharge Lamp Ballast With Igniter Driven by Dual-Frequency Inverter**" IEEE TRANSACTIONS ON POWER ELECTRONICS 2007.

9) Yijie Wang, *Student Member*, *IEEE*, Dianguo Xu, *Member*, *IEEE*, Wei Wang, Xiangjun Zhang, and Bo Xu "**Electronic Ballast for Metal Halide Lamps Using a Quasi-Resonant Inverter With Digital Control"** IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 59, NO. 4, APRIL 2012

10) Yijie Wang, *Student Member*, *IEEE*, Huaiyuan Liu, Xiangjun Zhang, Dianguo Xu, *Senior Member*, *IEEE*, Wei Wang, and Xinyu Liang "**A Pulse Igniting Circuit for Electronic Ballast With the ZVS-QSW Converter"** IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 29, NO. 6, JUNE 2014

ISSN: 2278 – 7798

11) "**Shedding Light on HID Ballast Control"** By Tom Ribarich, Director, Lighting IC Design Center, International Rectifi er, El Segundo, Calif. power electronics journal and magazines 2006

12) "**Microcontroller simplify lamp ballast design**" By Vivien Delport, Engineering Manager, Microcontroller and Technology Development Division, Microchip Technology. power electronics journal and magazines Feb 2007

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