The Development of the Buck Type Electronic Dimming Ballast for 250W MHL

Dong-Youl Jung* and Chong-Yeon Park†

Abstract - In this paper, we studied the development of the electronic ballast for 250W MH (Metal-Halide) lamps. We were able to improve the input power factor by using a PFC IC. To provide the lamp with the rated voltage required, we used the buck-type dc-dc converter. The stress of the switching devices in the inverter could be reduced by this method. To eliminate the acoustic resonance phenomena of MH lamps, the voltage of the lamp added the high frequency sine-wave to the low frequency square-wave by using the full bridge typed inverter. We have developed a simple igniter using the L and C elements. We could control the dimness of the lamp by varying the output voltage of the buck converter. The buck converter output voltage could be controlled by using a microprocessor.

Keywords: Acoustic resonance, Buck converter, Electronic ballast, Metal halide lamp, Switching stress

1. Introduction

Recently, the studies of the ballast for MH lamps have been being performed actively because these lamps have good intensity efficiency and color characteristics and are used in various places [1].

MH lamps have a particular ignition characteristic and a negative resistance characteristic so they need the ballast that can control these two characteristics. Most of the conventional ballasts were composed of the inductor and the capacitor which were passive devices. There are many problems in reference to their size and weight and they have poor efficiency but their weak points could be improved by using the electronic ballast [2].

Under development of the electronic ballast, the driving frequency of the inverter is so high that the switching loss is increased and the output voltage of the PFC (Power Factor Correction) circuit that is connected directly to the inverter circuit is higher than lamp voltage so it causes stress to the switching devices [3]. In this paper, we could reduce the stress and loss of the switching devices by supplying the lamp with the rated voltage. Following ignition, the magnitude of the lamp current is decreased to the steady state. On the other hand, the magnitude of the lamp voltage is gradually increased to the steady state. At this time, the transient current to the steady state causes the high stress of inverter switching devices. The starting and transient currents are fixed to the value of the steady state current in order to reduce the stress of switching devices. This method is achieved through the PWM control technique of the buck converter.

MH lamps also have the acoustic resonance phenomenon. The phenomenon has been observed especially when MH lamps are operated at high frequency. This phenomenon causes various problems such as arc instability, light output fluctuation, color temperature variation, and in the worst case, it can crack arc tubes [4-6]. Currently, there are many ways to eliminate the acoustic resonance phenomenon. In this paper, we eliminated the acoustic resonance phenomenon by providing the lamp with the low frequency square-wave adding the high frequency sine-wave.

Various dimming control ballasts for MH lamps have been developed. Most of the methods for the dimming control are to change the driving frequency of the inverter. These methods can be adapted to ballasts whose output circuit for lamps is a kind of LCC-type, but the output circuit of the ballast developed in this paper is not a kind of LCC-type. In case of the developed ballast, the dimming control is implemented by changing the DC-link voltage of the inverter.

2. Structure of the ballast and the dimming control system

The developed ballast consists of the power factor correction using PFC IC, the buck converter for dimming the lamp through the change of the dc-link voltage, the inverter for lightening lamps, and the PWM controller. The structure of the developed ballast appears in Figure 1.

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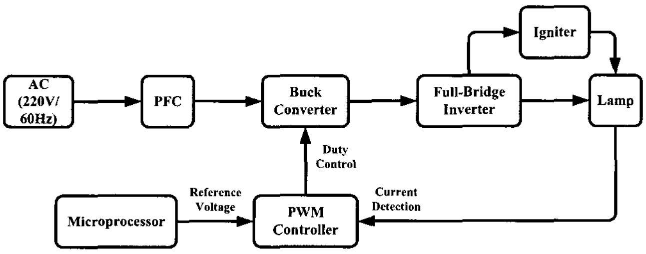

Fig. 1. The structure of the developed ballast

Full wave rectified voltage is boosted up to 400V by PFC IC. We used MC34262 (Motorola) as the PFC IC. Figure 2 shows the PFC circuit.

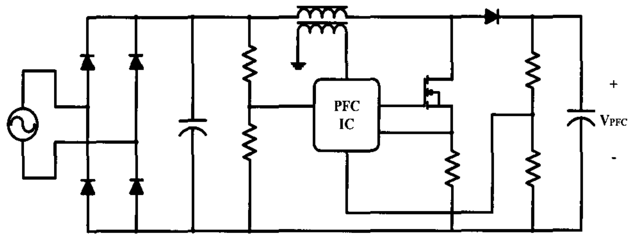

Fig. 2. The circuit for a power factor correction

In the conventional electronic ballast the output voltage (about 400V) of the PFC circuit is connected directly to the inverter circuit generally. This means that the switching devices of the inverter receive about 400V of stress when they turn on/off. However, the rated voltage of 250W MH lamps is about 130V and if the dc-link voltage to the inverter is 130V, the stress of switching devices is dramatically decreased. Therefore, the dc-link voltage, which is boosted by PFC needs to be reduced by the Buck converter. Figure 3 shows the Buck converter and the inverter. V_{PFC}, which is the output voltage of the PFC, is 400V and the type of the inverter is full bridge.

The PWM frequency of the buck converter is 20kHz and the magnitude of the output voltage can be changed by the variation of the duty ratio. The driving frequency of the inverter is 127Hz. The lamp voltage becomes the square-wave because the lamp is connected directly to the output of the inverter. The lamp current also becomes the square-wave because the lamp has the characteristic of resistance.

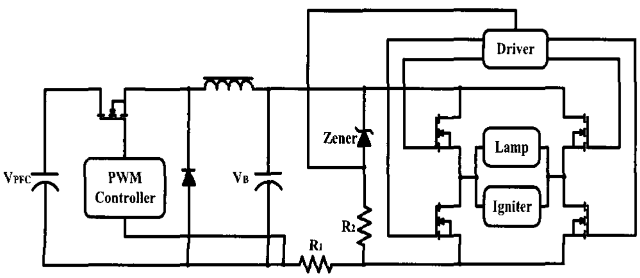

Fig. 3. The Buck type dc-dc converter and the inverter

3. The Function of the Ballast

3.1 The Igniter

Figure 4 shows the structure of the igniter.

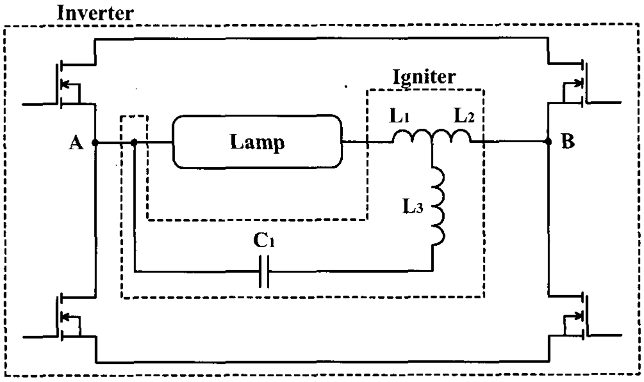

Fig. 4. The structure of the igniter

Before the ignition, the lamp has infinite resistance value and after the ignition, the resistance value of the lamp is about 60Ω.

The voltage between points A and B is the square-wave and the resonance of L_1, L_3 and C_1 gives the high voltage to a lamp.

The square-wave consists of the fundamental frequency and its odd harmonics. If we set up that the resonance frequency with L_1, L_3 and C_1 equals one of the odd harmonics, the voltage of the odd harmonic will rise up and ignite the lamp. After the ignition, the currents flow through L_1, L_2 to the lamp and the impedance of L_1, L_2 is even smaller than that of the lamp, so the square-wave is only given to the lamp. L_2 prevents the in-rush current from flowing to the circuit during the ignition, so it should be bigger than L_1, L_3.

The L and C values of the igniter in this paper is L_1=40 μH, L_2=600 μH, L_3=80 μH, and C_1=15nF

3.2 The steady state of the lamp

Following the ignition, tremendous current flows into the lamp for a very short time. This current can destroy the switching devices of the inverter in the event of flowing for hundreds of μ sec. Therefore, this current needs to be limited to the rated current of the lamp. This can be controlled by the PWM Controller. In Figure 3, the current flowing in the lamp flows through the resistor R_1 and then the PWM controller detects the voltage of R_1. If the lamp current overflows, the voltage of R_1 will rise up. When this voltage exceeds the reference voltage, the PWM controller reduces the output voltage of the buck converter. For a while, this kind of procedure is repeated again and again.

In the conventional ballasts, the lamp voltage is gradually increased until the steady state and the current is gradually deceased. However, in case of the ballast developed in this paper, because the lamp current is limited to 1.8A, the voltage increases up to the steady state and the current is maintained uniformly until steady state all the time.

The time chart of the lamp voltage and the current is presented in Figure 5. Figure 6 shows the equivalent circuit of the buck converter output (V_L) and the lamp (R_L).

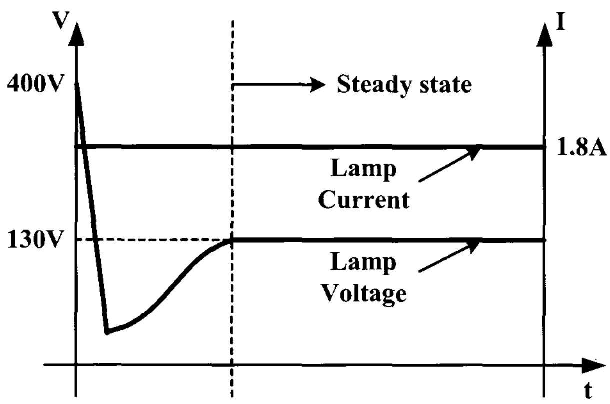

Fig. 5. The time chart of the lamp voltage and current

I_L is the current of the lamp, V_L is the voltage of the lamp, D is the duty ratio of the PWM, and V_{PFC} is the output voltage of the PFC.

$$I_L = \frac{V_L}{R_L} = \frac{V_B}{R_L} = \frac{DV_{PFC}}{R_L} \tag{1}$$

After the ignition, R_L increases from the very small value to the resistance values (60Ω) at the normal state of the 250W MH lamp.

When the resistance (R_L) characteristic of the lamp gradually changes over time, V_L and D are changed continuously in order that I_L is maintained uniformly.

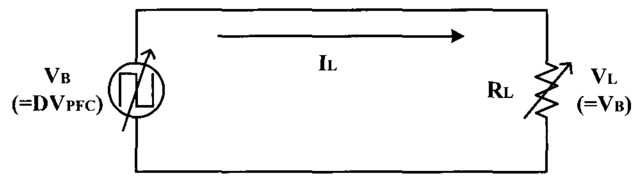

Fig. 6. The equivalent circuits of the buck converter, the inverter and the lamp

3.3 Acoustic resonance phenomenon

The acoustic resonance phenomenon generated during the gas discharge changes the pressure in the arc tube. This change of the pressure makes the arc discharge and the lamp luminous flux unstable. In the worst case, the arc is extinct and the arc tube is destroyed. Therefore, the acoustic resonance phenomenon must be eliminated absolutely.

To eradicate the acoustic resonance phenomenon, we add the high frequency sine-wave to the low frequency square-wave.

When the lamp is lighted by the low frequency square-wave, the power of the lamp is maintained uniformly [7]. However, if the pure square-wave of the low frequency is impressed to the lamp, the lamp life is reduced, because the temperature distributions of the cathode electrode of the lamp are not uniform. Therefore, the high frequency sine-wave whose magnitude is less than 10 percent that of the square-wave needs to be added to the pure square-wave of the low frequency and then this wave is impressed to the lamp. In this way, the temperature distribution of the electrode can be uniform and the reduction of the lamp life can be prevented [8].

As inserting the buck converter into the developed ballast, ripple components, which are high frequency sine-waves, can be easily attained. If the ripple component of the buck converter's output voltage is ΔV_O, ΔV_O is appeared by Equation (2).

$$\Delta V_O = \frac{1}{LC} = \frac{V_{DC}(1-D)D}{8f^2} \tag{2}$$

In Equation (2), V_{DC}, D, L and f are decided, therefore the amplitude of ΔV_O can be adjusted by only the C value. In case of the developed ballast, V_{DC}=400V, D=0.375, f=120kHz, L=200μH, and the lamp voltage (V_L) is 130V. Because of 10% of lamp voltage, the value of the wanted ripple is

$$\Delta V_O = 0.1 \times 130 = 13[V] \tag{3}$$

The C value for obtaining the high frequency ripple is decided as Equation (4).

$$C = \frac{V_{DC}(1-D)D}{8\Delta V_O L f^2} = \frac{400 \times (1-0.375) \times 0.375}{13 \times 200 \times 10^{-6} \times 8 \times (20 \times 10^3)^2} = 11\mu F \tag{4}$$

3.4. The no-load and the over-current protection

In the case of no-load, the output voltage of the buck converter is over 200V. In Figure 3, the voltage over 200V is detected by a 200V zener diode, and when this voltage is continuously detected for about 5 minutes, the driver of the inverter is stopped.

Figure 7 reveals the protection circuit for no-load. If the detected voltage is over 200V, an input of the gate is low by the output of the timer and the input of the driver IC is low. Then, the driver of the inverter is stopped.

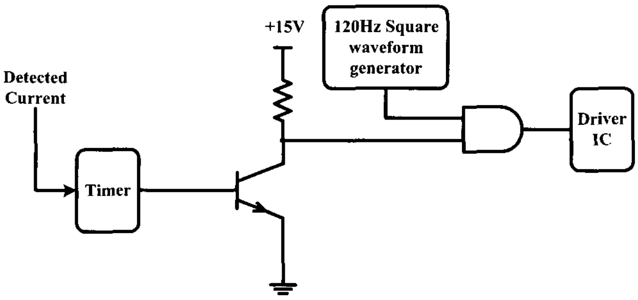

Fig. 7. The protection circuit for no-load

The lamp current is detected by R_l in Figure 3. If the current which flows through the R_l exceeds 1.8A, the duty ratio of the PWM controller's output signal is reduced, and when the duty ratio is reduced, the output voltage of the buck converter is reduced and the lamp current is kept to 1.8A.

4. The dimming control system

The dimming control system is realized using a microprocessor. The microprocessor is a kind of PIC (microchip), and the dimming control is divided into three steps; maximum luminance (100% dimming level), 75% of maximum luminance (75% dimming level) and 50% of maximum luminance (50% dimming level).

4.1 The dimming control method

The dimming control has to be performed during the steady state of the lamp. One of the dimming control methods is to control the output power of the lamp.

Although the output power of the lamp multiplies the lamp voltage by the current, the output power of the lamp is proportional to the square of the lamp voltage, because the lamp at the steady state has the characteristic of the resistance. The power control of the lamp is equal to the voltage control of the lamp, and the voltage of the lamp is the output voltage of the buck converter. Therefore, controlling the output voltage of the buck converter is dimming the lamp.

4.2 The structure of dimming controller

The output voltage of the buck converter is controlled by the PWM controller, and Figure 8 shows the structure of the controller.

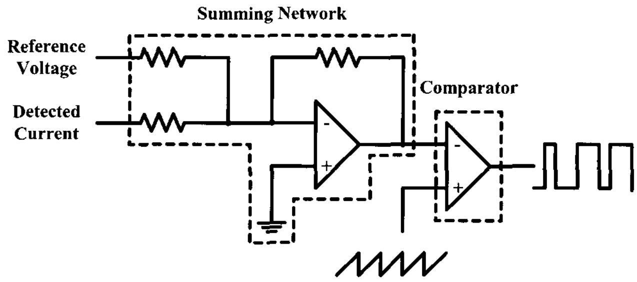

Fig. 8. The structure of the PWM controller

The current detection means the voltage of R_l in Figure 3, and this voltage is added to the reference voltage through the summing network. Figure 9 shows the circuits for generating the reference voltage. The microprocessor produces the rectangle wave. This rectangle wave passes the buffer and becomes the input of the RC filter. It is converted to the dc level, which becomes the reference voltage through the RC filter. The magnitude of the reference voltage is changed by controlling the duty ratio of the rectangle wave. The comparator generates square-signal after comparing the added voltage with the saw-signal. If the detected current and reference voltage are changed, the duty ratio of the generated square-signal is changed. Figure 10 indicates the relation between the output of the summing network and the duty ratio of the square-signal. The dimming control is performed by changing the reference voltage because this voltage alters the duty ratio of the square-signal, which is the output of PWM controller.

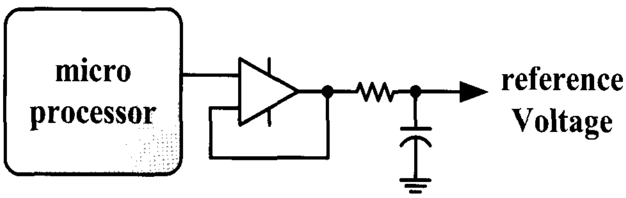

Fig. 9. The circuit for generating the reference voltage

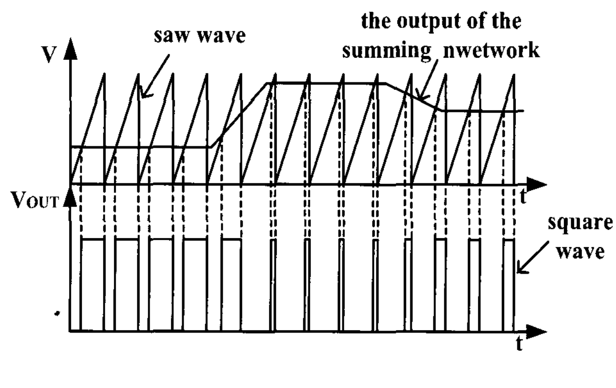

Fig. 10. The relation between the output of the summing network and the duty ratio

5. Experimental results

To understand characteristics of the developed ballast in this paper, the major waveform of the MH lamp and the ballast is measured by using the oscilloscope and the power analyzer.

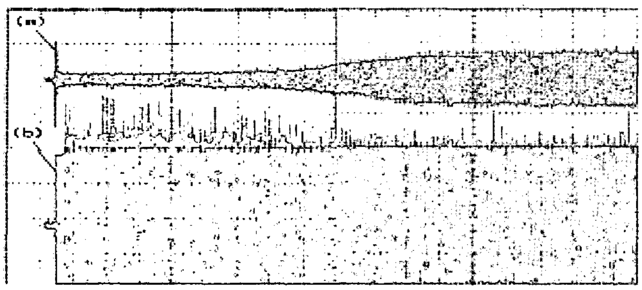

Fig. 11. The lamp voltage (a) and the current (b) at the transient state [200V/div, 1A/div]

Figure 11 presents the transient state of the lamp voltage and the current. Figure 11 (a) is the waveform of the lamp voltage, Figure 11 (b) is the waveform of the lamp current. The lamp current is almost constant. On the other hand, the lamp voltage is decreased to 20V after the ignition, and then it is gradually increased. Figure 12 shows the lamp voltage and the current at 100% dimming level. Figure 12 (a) is the waveform of the lamp voltage, Figure 12 (b) is the waveform of the lamp current. The lamp voltage is 130V and the lamp current is 1.8A. The oscillation is generated at the rising edge of the lamp voltage and the current in Figure 12. In spite of the steady state of the lamp, it is affected by L and C of the igniter. Figure 13 reveals the lamp current. The current consists of the square-wave and a 22kHz sine-wave. Consequently, the resonance phenomenon could be eliminated.

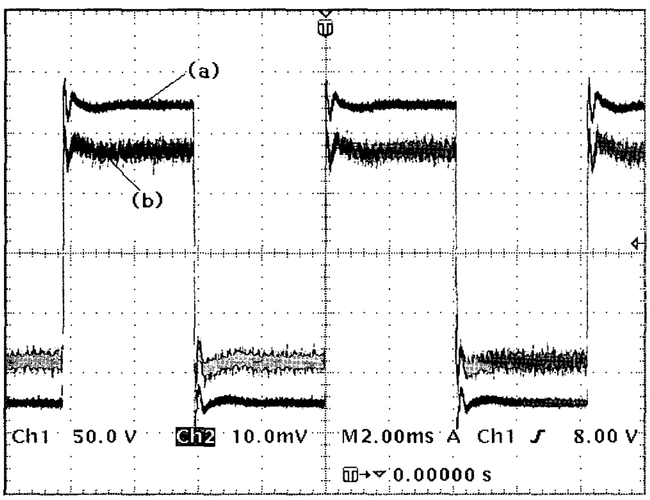

Fig. 12. The lamp voltage (a) and the current (b) at 100% dimming [50V/div, 1A/div]

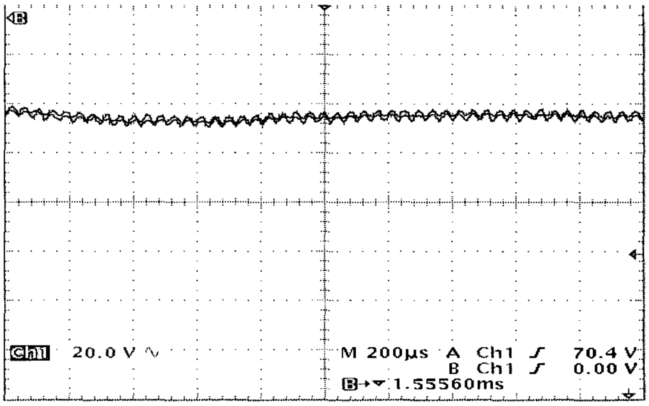

Fig. 13. The magnification of the lamp current [1A/div]

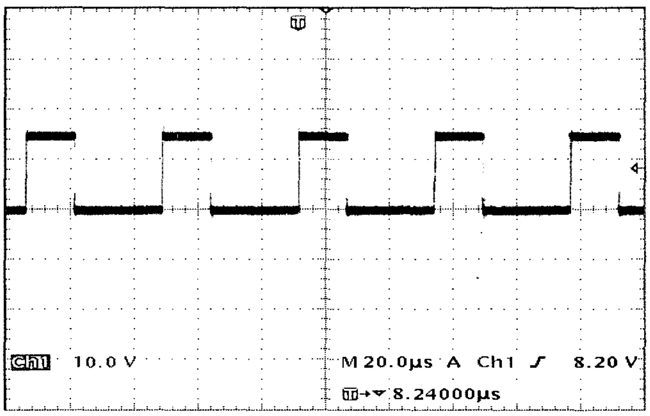

Fig. 14. The output of PWM controller at 100% dimming [1A/div]

Figure 14 shows the output of the PWM controller at 100% dimming level. The duty ratio is 0.325, the frequency is 22kHz, and the high level time is 14.77us

Figure 15 shows the lamp voltage and the current at 75% dimming level. Figure 15 (a) is the waveform of the lamp voltage, and Figure 15 (b) is the waveform of the lamp current. The lamp voltage is 125V and the lamp current is 1.52A. Figure 16 indicates the output of the PWM controller at 75% dimming level. The duty ratio is 0.3, the frequency is 22kHz, and the high level time is 13.63us.

Figure 17 presents the lamp voltage and the current at 50% dimming level. Figure 17 (a) is the waveform of the lamp voltage, and Figure 17 (b) is the waveform of the lamp current. The lamp voltage is 115V and the lamp current is 1.24A. Figure 18 shows the output of the PWM controller at 50% dimming level. The duty ratio is 0.2875, the frequency is 22kHz, and the high level time is 13.06us.

Figure 19 illustrates the input voltage and the current of the ballast at 100% dimming level. Figure 19 (a) is the waveform of the input voltage, and Figure 19 (b) is the waveform of the input current. The input voltage is 220Vrms, and the input current is 1.76Arms.

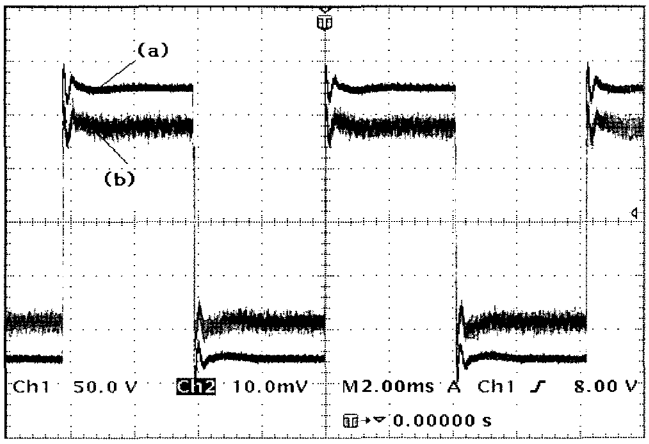

Fig. 15. The lamp voltage (a) and the current (b) at 75% dimming [50V/div, 1A/div]

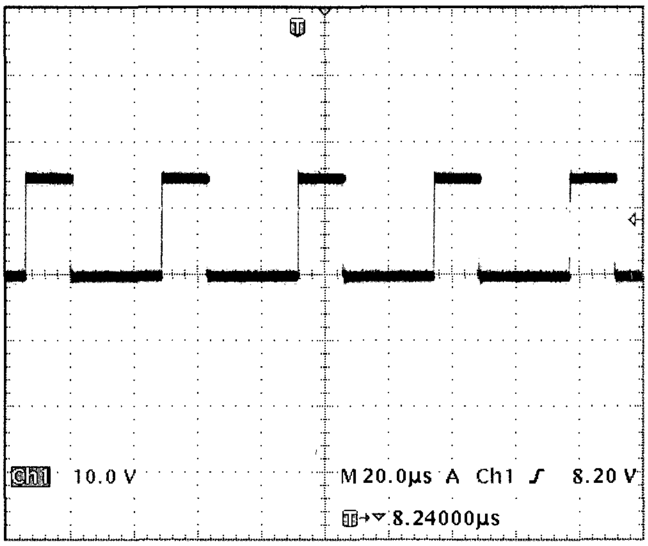

Fig. 16. The output of PWM controller at 75% dimming [1A/div]

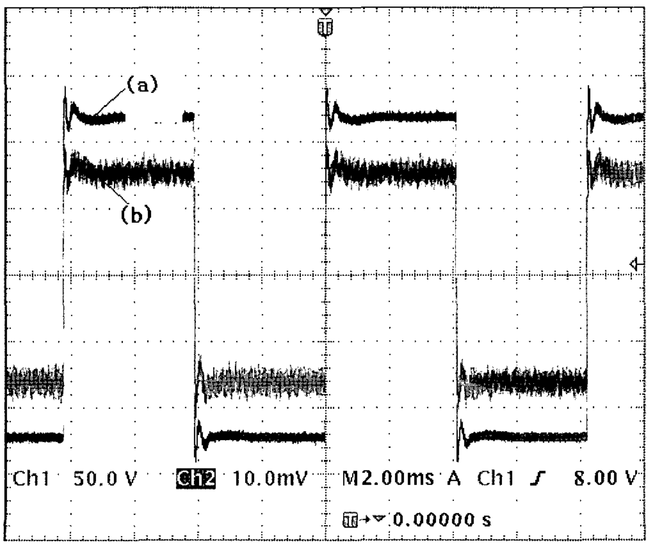

Fig. 17. The lamp voltage (a) and the current (b) at 50% dimming [50V/div, 1A/div]

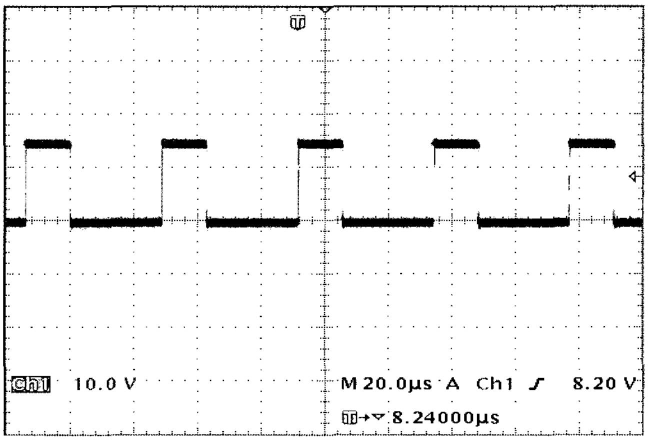

Fig. 18. The output of PWM controller at 50% dimming [1A/div]

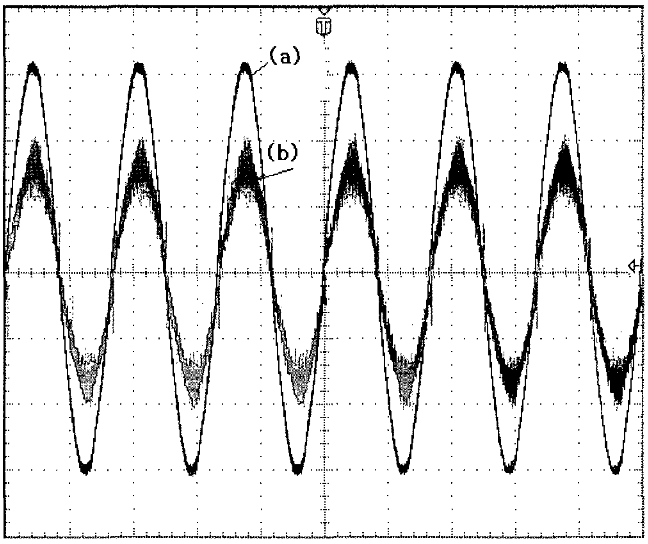

Fig. 19. The input voltage (a) and the current (b) waveform [100V/div, 2A/div]

The characteristic of the developed ballast is presented in Tables 1, 2 and 3.

Table 1. The characteristic of the developed ballast (100% dimming level)

Characteristic	Input Power (W)	Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)
Value	258.7	220	1.1759	130	1.8128
Characteristic	Power Factor (%)	Input Current THD (%)	Input Current CF	Output Current CF	
Value	99.5	8.9	1.71	1.13	

Table 2. The characteristic of the developed ballast (75% dimming level)

Characteristic	Input Power (W)	Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)
Value	200	220	0.909	125	1.52
Characteristic	Power Factor (%)	Input Current THD (%)	Input Current CF	Output Current CF	
Value	99.5	7.5	1.69	1.12	

Table 3. The characteristic of the developed ballast (50% dimming level)

Characteristic	Input Power (W)	Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)
Value	153	220	0.695	115	1.24
Characteristic	Power Factor (%)	Input Current THD (%)	Input Current CF	Output Current CF	
Value	99.5	6.6	1.56	1.1	

6. Conclusion

We have developed the dimming ballast for MH lamps with good color rendering.

The voltage of the 250W MH lamp at the steady state is 130V, and its current is 1.8A. We used the full bridge inverter and the buck converter to supply the lamp with the rated voltage. The full bridge inverter supplied the lamp with 127Hz square-wave. The voltage of the PFC output is reduced as much as the rated lamp voltage by using the buck converter. Finally, the stress and loss of switching devices were reduced dramatically.

To remove the acoustic resonance phenomenon, the high frequency sine-wave was added to the low frequency square-wave. This wave was impressed to the lamp.

The output voltage of the buck converter has some ripple due to its characteristic. The output 'C' value of the converter was adjusted in order that the magnitude of the ripple is about 10% of its output voltage.

The output voltage of the buck converter is higher at no load than at the steady state. When detecting this voltage, the protection circuit halts the operation of the inverter.

When the over current flows, the PWM controller detects the over current and forces the current not to flow over 1.8A by lowering the duty ratio.

It is possible to control the dimming by changing the output voltage of the buck converter. The output voltage is changed by the duty ratio of the rectangle wave which is the output of the PWM controller.

At each dimming level, the power factor is more than 0.99, and the THD is less than 8.9%.

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