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Electronic Ballast with Constant Power Output Controller for 250W MH Lamp

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Abstract - In this paper, an electronic ballast was developed to control a 250W metal halide lamp. To avoid acoustic resonance phenomenon, we calculated the acoustic resonance band and determined the driving frequency from 70kHz to 100kHz. Due to the switching loss of MOSFET, many problems are caused in the inverter circuit during lamp lighting, so we reduced the loss by connecting the capacitor that minimizes the magnitude of the impulsive voltage. In this paper, the main point of research is to find the methods to operate the lamp on the rated output power. After detecting the current and the voltage of the lamp, we changed the driving frequency by adjusting the DC voltage level of the VCO input.

Keywords: Acoustic resonance, Constant power, Electronic ballast, MH lamp, Switching loss

1. Introduction

Much attention is currently being given to the improvements of characteristics in high-pressure sodium lamps and high-pressure metal-halide lamps, because the technical development of ballasts for high-pressure mercury lamps had been saturated. Especially, metal halogen chemical compounds are being added in the arc tube of metal-halide lamps to improve the intensity of high-pressure metal-halide lamps. Therefore, metal-halide lamps have good intensity efficiency and color [1].

In this paper, we have researched the electronic ballast for the 250W metal-halide lamp. The current and the voltage of the lamp change when the lamp dies, or when a change in the ambient temperature of the lamp is generated. If the current changes, the power also changes. This causes a decrease in the life and illumination of the lamp. We have developed a controller to increase the life of the lamp and to maintain its rated power. The current and the voltage of the lamp are detected by the controller. When they are abnormal, the controller regulates the output power of the lamp by changing the driving frequency of the inverter [2, 3].

2. The Acoustic Resonance

Acoustic resonances are composed of a longitudinal resonance, a radial resonance, and an azimuthal resonance.

The longitudinal resonant frequency is

$$f_L = \frac{C}{2L} \tag{1}$$

Where C is the sound velocity and L is the tube length.

The radial resonant frequency is

$$f_R = \frac{3.83C}{2\pi L} \tag{2}$$

Where R is the radius of tube

The azimuthal resonant frequency is

$$f_A = \frac{1.84\,C}{2\pi L} \tag{3}$$

The lowest frequency f_L and the highest frequency f_H of the acoustic resonance are shown [4-6]

$$f_L = \frac{C}{2L} \times \frac{1}{6} \tag{4}$$

$$f_H = 4 \times \frac{C}{2L} \tag{5}$$

The length of the metal halide lamp for our experiment is $0.045m$, and the sound velocity in the arc tube is assumed to be $500m/s$. Therefore, the lowest frequency of the acoustic resonance is $f_L = 926Hz$, and the highest frequency of the acoustic resonance is $f_H = 22kHz$. The free ranges of the acoustic resonance are below $926Hz$ and above $22\ kHz$. Above $22kHz$, we chose the driving frequency as $80kHz$. In this experiment, the stable maximum frequency of the driver IC was $140kHz$. As such, we determined the driving frequency as the center

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frequency between 22*kHz* and 140*kHz*.

3. The Loss of the Switching Device

In the experiments, the most serious problem is the switching loss of the MOSFET. The MOSFET is heated by this loss and this heat is enough to destroy the MOSFET. Therefore, the heat of the MOSFET must be reduced to maintain stable ballast. The switching loss is caused by the impulsive voltage during the on-off switching of the MOSFET, causing it to heat up. When the drain-source voltage of the switching devices is not '0', it is turned on. When the drain current of the MOSFET is not '0', it is turned off. At this time, the impulsive voltage is generated in the MOSFET's D-S.

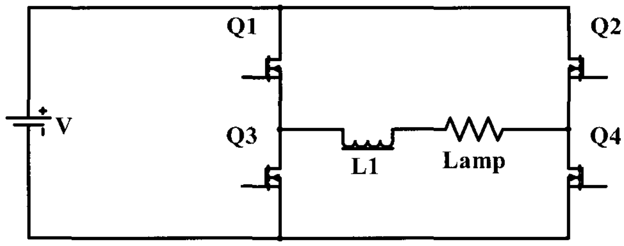

Fig. 1. The circuit of the inverter

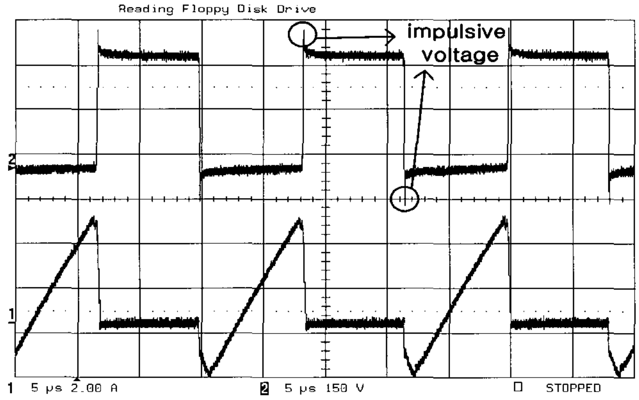

Fig. 2. The experimental results of the impulsive voltage and the current in the MOSFET's D-S (150V/div, 2A/div)

The first proposed circuit of the inverter (Fig. 1) had only the L1 (inductor) for limiting the current of the lamp. In this case, the impulsive voltage is generated during the switching device's on-off movement. Fig. 2 presents an experimental result in which the impulsive voltage and the current have been generated in the MOSFET's D-S. The impulsive voltage is over 100V in the result.

It could be solved by connecting the capacitor to the D-S of the MOSFET to eliminate the impulsive voltage during the MOSFET's turn on-off action since the impedance of the capacitor is much smaller than the impedance of the MOSFET's D-S. Fig. 3 shows the circuit diagram in which the capacitor is connected to the MOSFET in parallel and Fig. 4 indicates that the voltage and the current have been appeared in the MOSFET's D-S.

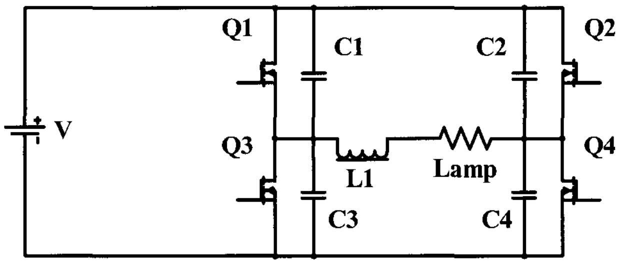

Fig. 3. The circuit diagram that presents the parallel connection between the MOSFETs and the capacitors

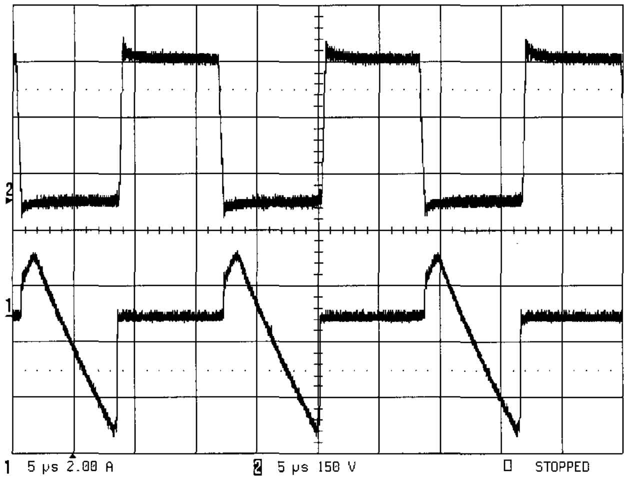

Fig. 4. The voltage and the current by the experimental results (150V/div, 2A/div)

As per the experimental results (Fig. 4), we could know that the impulsive voltage is reduced during the MOSFET's turning on-off. In the commercial development stage, connecting the capacitor to the switching element is not beneficial in terms of cost and efficiency, so we have experimented in an effort to reduce the number of capacitors. When two MOSFETs are turned on, Fig. 3's circuit could appear as being equivalent with the circuit in Fig. 5.

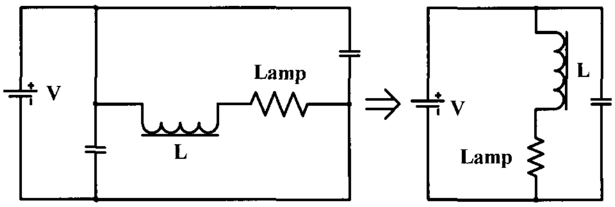

Fig. 5. The equivalent circuit of Fig. 3 when two MOSFETs are turned on

This is likely to connect the capacitor to both ends of the L and the lamp in parallel direction, so this circuit could be modified to the circuit shown in Fig. 6.

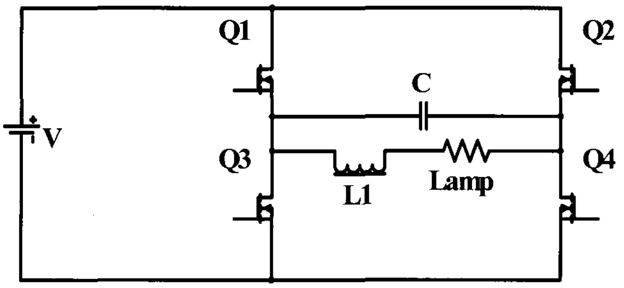

Fig. 6. The proposed inverter circuit in this paper

Fig. 7 shows the waveform of the current and the voltage of the MOSFET's D-S using the circuit of Fig. 6, so we could find that the experimental result of Fig. 4 and Fig. 7 are identical.

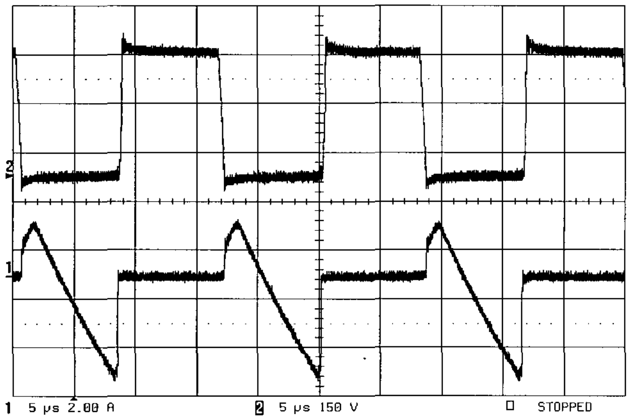

Fig. 7. The experimental result of the current and the voltage of the MOSFET D-S with connecting the capacitor to both ends of the L and the lamp in parallel direction (150V/div, 2A/div)

As a result, we could reduce the magnitude of the impulse voltage that is generated during four switching device's on-off action and thereby decrease the power loss and the heat up of the MOSFET.

4. The Method for Controlling the Rated Power of a Lamp

When the current and the voltage of the lamp are abnormal, the power of the lamp is out of the rated power. Then, the change of the inverter driving frequency makes the rated power of the lamp power. The power was calculated by adding the current and the voltage of the lamp. This is $aI + bV$, in which a and b are the factors that are composed by resistant distribution and were decided with the ratio of resistors. If the voltage of both ends of the inductor (L) and the lamp (R) is V (dc-link voltage), the current that is flowed through the lamp is as follows;

$$I = \frac{V}{|Z|} = \frac{V}{|jwL + R|} = \frac{V}{\sqrt{(2\pi fL)^2 + R^2}} \tag{6}$$

If the frequency 'f' is increased, I is decreased, and if f is decreased, I is increased. If the current and the voltage of the lamp are increased, the controller increases frequency f to reduce the current I, and if the current and the voltage of the lamp are decreased, the controller increases frequency f to increase the current I.

The equivalent resistance R of the lamp is the ratio of the voltage and the current of the lamp ($R = V_L / I_L$), so then Equation (6) could be changed into Equation (7).

$$I_L = \frac{V}{\sqrt{(2\pi fL)^2 + (V_L / I_L)^2}} \tag{7}$$

Where, I_L is the lamp current and V_L is the lamp voltage. If Equation (7) is adjusted to the lamp current I_L, I_L is

$$I_L = \frac{\sqrt{V^2 - V_L^2}}{2\pi fL} \tag{8}$$

The power related with the change of the driving frequency at the constant lamp voltage is

$$P_l = V_L \times \frac{\sqrt{V^2 - V_L^2}}{2\pi fL} \tag{9}$$

Fig. 8 is the result of the simulation concerning Equation (9), V=400V, V_L =130V, L=375 μH.

In Fig. 9, if the current of the lamp increases at the determined driving frequency that is generated as the rated output, the curve of the power is moved to the upper portion. At this time, the output power is to be decreased by increasing the driving frequency.

If Equation (7) is adjusted to the lamp voltage V_L, V_L is

$$V_L = \sqrt{V^2 - (2\pi fL)^2 I_L^2} \tag{10}$$

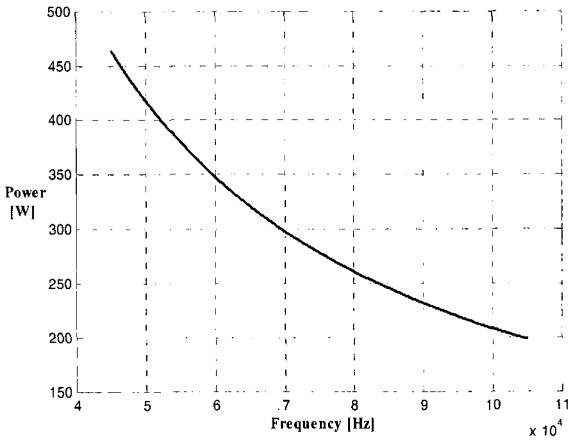

Fig. 8. The simulation result of the power curve related with the change of the driving frequency

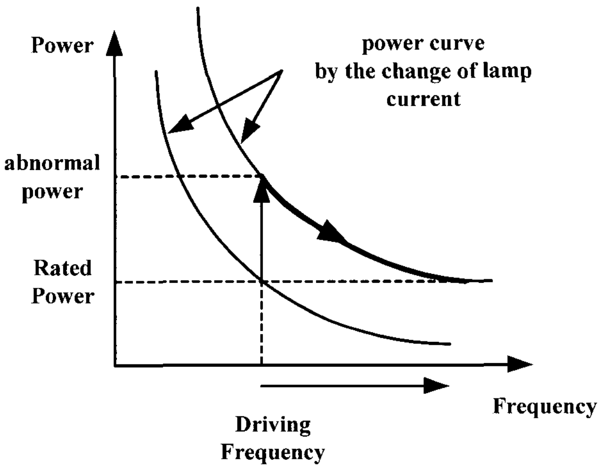

Fig. 9. The relation of the rated power and over rated power (the constant voltage, the changed current)

The power related with the change of the driving frequency at the constant lamp current is

$$P_L = I_L \times \sqrt{V^2 - (2\pi f L)^2 I_L^2} \tag{11}$$

Fig. 10 is the result of the simulation about the equation (11), V=400V, I_L=2.1A, L=375μH.

In Fig. 11, if the voltage increases at the determined driving frequency which is generated at the rated power, the curve of the power is moved to the upper. Also, in the case in which the current I_L is constant and the voltage V_L is changed, the current I_L is changed by controlling the driving frequency and the power is maintained as the rated value.

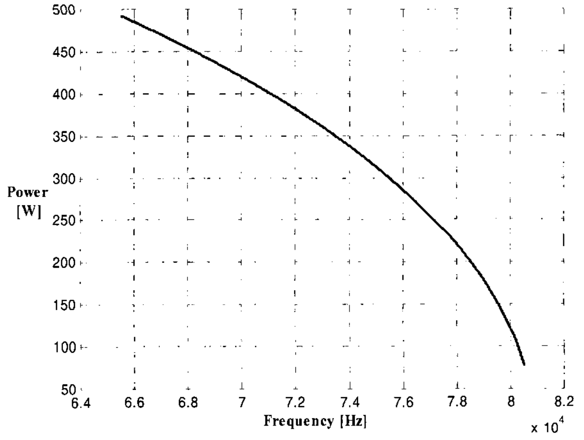

Fig. 10. The simulation result of the power curve related with the change of the driving frequency

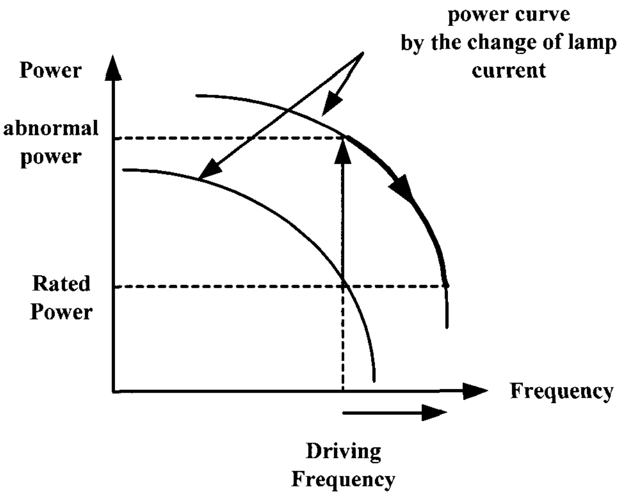

Fig. 11. The relation of the rated power and over power (the constant current, the changed voltage)

5. The Structure of the Controller

Fig. 12 is the block diagram of the proposed electronic ballast. The power factor is improved by using the PFC IC and the type of inverter is a full-bridge. Fig. 13 is the circuit of the inverter and controller. A1 and A2 is the terminal for detecting the lamp current and B1 and B2 is the terminal for detecting the lamp voltage. $aI + bV$ is realized by two rectifiers (DF04M) and OP-Amps (TL072) The summing network consists of OP-Amps and the detected current and voltage are added to each other. The output of U2 (OP-AMP) is connected with the VCO as DC voltage and the output of the VCO (LM566) is the squared-wave, which has the frequency. This squared-wave drives the driver IC.

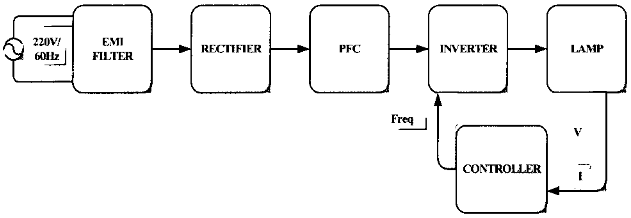

Fig. 12. The block diagram of the ballast

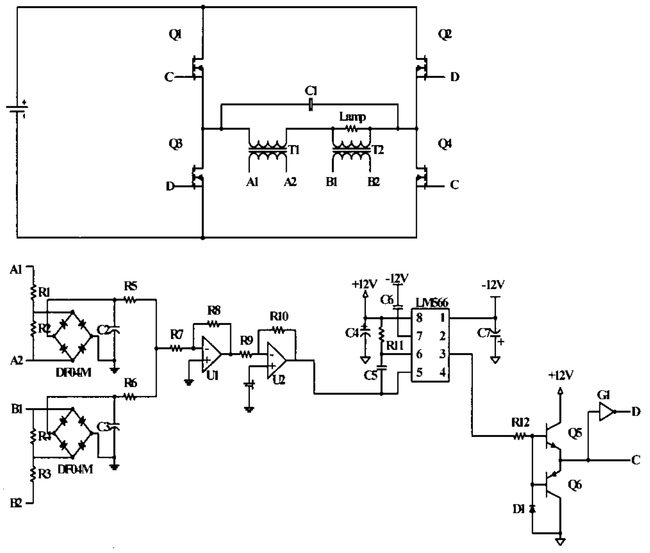

Fig. 13. The proposed circuits of the inverter and the controller

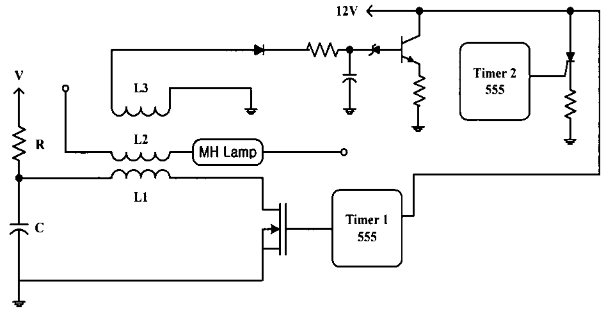

Fig. 14. The simple diagram for the igniter

6. The Igniter

Fig. 14 shows the scheme of the igniter. The voltage is charged to capacitor (C) during the RC time constant and the timer 1 operates the FET and induces the high voltage in the L1. The high voltage that is induced in the L1 is transferred to the L2 by the turn ratio and the lamp (MHL) is discharged initially by this voltage[7]. If the lamp is turned on, the current of the lamp is flowed to the L2 and the voltage is induced in the L3 by the current of the L2. Then the igniter is stopped. Timer 2 stops operating the igniter at no load or wrong lamp.

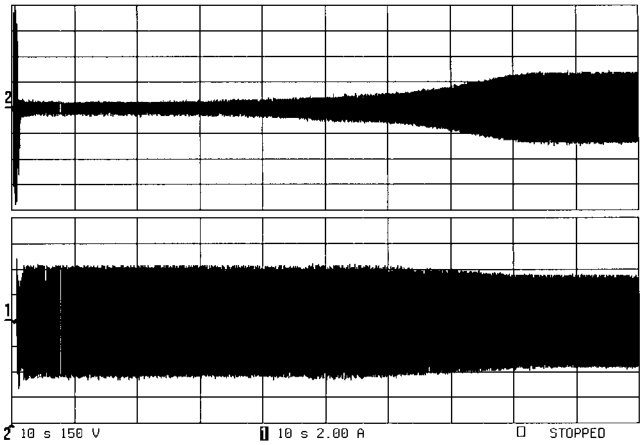

Fig. 15. The current waveform and the voltage waveform at a transient state (100V/div, 2A/div, 10s/div)

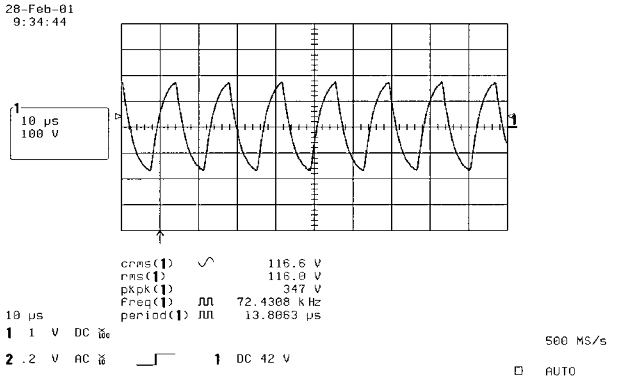

Fig. 16. The voltage waveform of the lamp (100V/div, 10s/div)

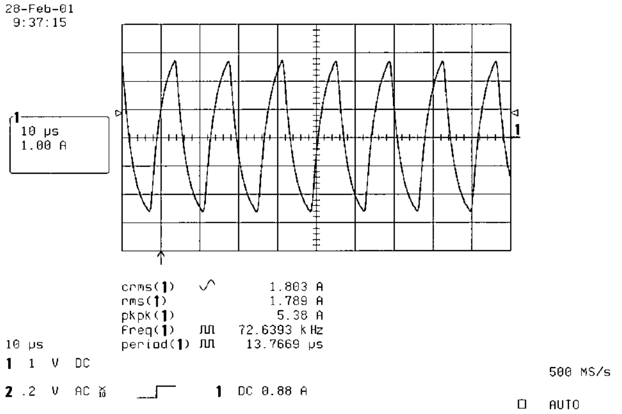

Fig. 17. The current waveform of the lamp (1A/div, 10us/div)

7. Experiments

We used the MC34262 PFC IC (Motorola) for the power factor correction and the power factor is above 0.96. The type of the inverter is the full bridge, which consists of MOSFET IRF840s as the switching device and L6569 (SGS Thomson corp.) as the driver IC.

Fig. 15 shows the current and the voltage of the lamp at a transient state.

Fig. 16 shows that the peak voltage of the lamp is 180V and the rms voltage is 127V at the normal steady state of the lamp.

Fig. 17 shows that the peak current of the lamp is 2.8A and the rms current is 1.97A at the normal steady state of the lamp.

8. Conclusion

When the voltage or the current of the metal halide lamp (250watt) is abnormal, unexpected various phenomena have occurred. This means that the lamp is not operated at the normal state. To change such an abnormal state into normal state, we proposed circuits that regulated the lamp power to a constant value by adjusting the driving frequency through the controller after combining the lamp current and the lamp voltage.

To reduce the switching loss on the MOSFET, we realized the technique of rejecting the impulsive voltage. The impulsive voltage is generated when the switching device (MOSFET) is turned on-off. It caused the power loss and the heat up of the MOSFET. We resolved this by connecting the capacitor to the circuit of the inverter. Because the impedance of the capacitor is much smaller than the impedance of the MOSFET's D-S, the impulsive voltage could be rejected by the capacitor. Therefore, the switching loss and the heat up of the MOSFET are reduced.

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