Intelligent Control Strategy for Ceramic Metal Halide Lamps

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ABSTRACT: An intelligent control strategy for driving a 35w Ceramic Metal Halide (CMH) lamp is built. By integrating the microcontroller STM32F103 with the digital potentiometer X9313 in the circuit, we are able turn the lamp on and off flexibly. The lamp power can be altered automatically according to the environment, since it is designed to be linearly dependent on the resistance of X9313. The energy conversion efficiency of the driving circuit can be larger than 88%. A remote desktop client on the Android is developed for the purpose of wireless and convenient control. The proposed model will useful for designing high performance small-wattage CMH lamps.

1. INTRODUCTION

Ceramic Metal Halide (CMH) lamps with merits of high efficiency and high color rendering are becoming increasingly popular in publish lightings [1, 2]. In previous studies, CMH lamps using inductive ballasts exhibit disadvantages of low power factors and high energy consumption [1]. More and more research groups are making efforts to design digital electronic ballasts to realize complex control strategies [3].

Traditionally, analog circuits are used to control the driving circuit for CMH lamps. The analog control method needs to detect the lamp voltage and lamp current and, subsequently, an analog signal process is conducted with a large number of processing elements. Comparing with the analog control method, the digital control circuit is convenient and flexible for realizing various control strategies using microprocessor-based controllers. However, most intelligent control strategies for CMH lamps are only implemented for constant power output [4]. Here, we will combine a small-wattage CMH lamp with intelligent control techniques for developing high reliable lighting systems.

The concrete contents of the paper are organized as follows: First, the circuit structure is described in detail. Next, the strategy for implementing power control will be presented. At last, the performance of the lighting system will be determined by experiments.

2. CIRCUIT STRUCTURE

The circuit configuration of the small-wattage CMH lamp is shown in Fig.1. The driving circuit consists of an EMI filter circuit, an active power factor correction (APFC) circuit, a buck converter, a microcontroller circuit, a full-bridge converter, an igniter, and an auxiliary power supply module. The APFC circuit utilizes a boost converter to increase the bus voltage and realize the power factor correction [5]. The buck converter operating at a high switching frequency is capable of reducing the DC voltage to the lamp voltage. By implementing the digital control in the buck converter, the lamp power can be flexibly determined. The full-bridge converter will convert the DC current into a square-wave current at low frequencies within 100–200 Hz such that the effects of acoustic resonances in the lamp can be avoided. Especially, a bluetooth client server application (Bluetooth App) is developed, allowing man-machine interactive control.
3. THE DC/DC BUCK CONVERTER AND THE DC/AC FULL BRIDGE CIRCUIT

Since the working voltage for CMH lamps is much lower than 400V, a power width modulation (PWM) DC/DC buck converter is needed to reduce the output voltage of the APFC circuit. As presented in Fig. 2(a), the high performance current mode controller UC3845B, high frequency diode D3, MOS switch Q6, and inductor L1 are the main components of the buck converter. The pulse width of UC3845B, which can be adjusted by the operational amplifier LM2904, determines the output voltage of the converter [6, 7].

![Diagram of a buck converter and PWM control circuit](image)

Figure 2. (a) The circuit diagram of a buck converter. (b) The diagram of a PWM control circuit in the buck converter.

In the buck converter, the PWM control circuit consists of an in-phase proportion operational amplifier and a current sense resistor R15, as depicted in Fig. 2(b). The non-inverting input $u_i$ of LM2904 is determined by resistors R15 and R9, while the inverting input is governed by the rheostat R8 and the resistor R10. It should be noted that R8 is connected to a digital potentiometer Rx (X9313) for the convenience to control the power output of the lamp [8]. The output voltage $u_o$ of LM2904 and the duty cycle of UC3845B can be digitally controlled by varying the resistance of X9313. It can be derived from Fig. 2(b) that $u_o = (1 + R_7 / R) u_i$, where $R = R_{R7} + R_{Rx}$, $u_i = R_{R15} I_{LAMP}$, and $R_7$, $R_8$, $R_{R7}$, $R_{Rx}$, and $R_{R15}$ are, respectively, the resistances of R7, R8, R10, R15, and Rx. The output voltage $u_o = V_{REF}$, because the error amplifier (Error AMP) of UC3845 produces a virtual short circuit between its input terminals. It can be found that the lamp current $I_{LAMP} = V_{REF} R / (R + R_{R7}) R_{R15}$. Thus, the power output of the lamp can be computed by

$$P_{LAMP} = V_{LAMP} I_{LAMP} = \frac{V_{LAMP} V_{REF} R}{(R + R_{R7}) R_{R15}}$$

(1)

Which shows that $P_{LAMP}$ is closely related to the resistance $R$ and can be readily controlled by the digital circuit.

The inductance of the buck converter is [6]

$$L = \frac{1}{2 f_{UC3845}} I_{LAMP} \left( 1 - \frac{V_{LAMP}}{V_i} \right) V_{LAMP}.$$  

(2)

When a 35W CMH lamp (PHILIPS CDM-T 35W/942) is operating normally, the lamp voltage $V_{LAMP} = 85.0V$ and the lamp current $I_{LAMP} = 0.42A$. The frequency of UC3845 $f_{UC3845} = 39kHz$ [6] and can be adjusted by the RC oscillator (R13 and C18).

Figure 3 shows the configuration of a DC/AC full-bridge converter controlled by the full bridge driver IRS2453DS and an igniter circuit. As a first step, the MOS switch Q5 is located in a cut-off state. The frequency of IRS2453DS can be determined by the resistor R6 and the capacitor C8. At this moment, the driving circuit is operated at a high-frequency condition with $f_h = 64kHz$, which is available to generate a high-voltage starting pulse for the CMH lamp ignition. Until the ignition process is completed, Q5 will be turned on by the microcontroller. Consequently, the frequency of IRS2453DS will depend on R6, C8, and C5. The lamp will be driven by a low-frequency square-wave ($f_L = 160Hz$) such that the acoustic resonances in the CMH lamp can be avoided.

![Configuration of a DC/AC full-bridge converter and an igniter](image)

Figure 3. The configuration of a DC/AC full-bridge converter and an igniter.
4. THE CIRCUIT OF A MICROCONTROLLER AND THE STRATEGY FOR CONSTANT POWER CONTROL

Figure 4 shows the circuit diagram of a microcontroller. The CMH lamp incorporates STM32F103 as the main control system [9]. STM32F103 device utilizes the high performance ARM Cortex-M3 core with a maximum CPU speed of 72 MHz. The optimum operations of a CMH lamp will be digitally manipulated via the mutual exchange of information between the control system and the control terminal.

The power output of the lamp can be easily modified by altering the parameters of X9313 [8]. As shown in Fig. 4 (a), the \( U / D \), \( CS \), and \( INC \) inputs of X9313 are connected to the relevant outputs of the STM32F103 device. The resistance \( R_x \) can be detected from the low terminal \( V_L \) and the wiper terminal \( V_W \). It should be noted that HC-06 Bluetooth module is adopted for information transmission in the present study. HC-06 and STM32F103 devices are coupled with each other via a universal asynchronous receiver transmitter (UART).

Figure 4(b) shows the feedback loop control strategy for achieving a constant lamp power. The microcontroller primarily detects the voltage and current. An analog-to-digital (AD) converter is used to convert the detected signals to a digital number that represents the lamp power. Comparing the present lamp power \( P_{\text{LAMP}} \) with the required value \( P_{\text{set}} \), the digital comparator will generate a digital error signal. Subsequently, a Proportional-Integral (PI) algorithm in the microcontroller embedded system will be executed [10]. The PI algorithm combining with the integration and separation methods will determine the voltage increment \( \Delta u \) based on the previous digital error signal, to control the duty cycle of the PWM control circuit and maintain the target lamp power. For improving the control performance, the computing process is segmented into two consecutive intervals. Different integral times are adopted in these two intervals, because a high integral gain can cause the system to become unstable.

5. EXPERIMENTAL RESULT AND DISCUSSION

In the experiment, a Philips 35-W ceramic metal halide lamp (model CDM-T 35 W/830) is used. The standard input AC voltage is 220 V. The voltage and current are measured by DM3058E 5 ½ Digit Digital Multimeter. All waveforms are recorded by the digital phosphor oscilloscope (Tektronix DPO2014B with 100–200 MHz bandwidth). The power output of the lamp is obtained by using Yokogawa WT210 Digital Power Meter with 100 kHz bandwidth.

Figure 5 shows the driving signals for MOS switches (Q1, Q2, Q3, and Q4) in the full-bridge converter when the driving circuit is operated in the steady state. The driving frequencies of the full-bridge converter and the buck converter are 164 Hz and 39 kHz, respectively. Two pairs of switches Q1/Q4 and Q2/Q3 are turned on and off complementary to each other, which will enable the proper operation of the lamp.

The curve of the lamp power \( P_{\text{LAMP}} \) varying with the resistance of the digital potentiometer X9313 (Rx) is illustrated in Fig. 6 (a). When Rx increases from 9.79 kΩ to 18.03 kΩ, \( P_{\text{LAMP}} \) will be enhanced from 19.15 W to 35.03 W. There exists a significant linear relationship between \( P_{\text{LAMP}} \) and Rx. It means that the lamp power can be automatically controlled.
by the digital driving method. Figure 6 (b) indicates the curves of the power output of the lamp $P_{\text{LAMP}}$ and the electrical efficiency $\eta$ varying with the input AC voltage $V_{ac}$. The power $P_{\text{LAMP}}$ is stable around 35W when $V_{ac}$ increases from 175 to 265 V, indicating that the lamp is operated in the steady state. The electrical efficiency $\eta$ stays between 87% and 88%.

![Figure 6](image)

Figure 6. (a) The curve of the power output $P_{\text{LAMP}}$ of the lamp varying with $R_x$. (b) The curves of the power output of the lamp $P_{\text{LAMP}}$ and the electrical efficiency $\eta$ varying with the input AC voltage $V_{ac}$.

At last, we provide a remote control method for implementing wireless and convenient control of the device. Android's open nature has encouraged a large and growing community of developers to add new features for users due to its open nature. Android can also be used for developing a ready-made, low-cost and customizable operating system for CMH lighting devices. Figure 7 shows the remote desktop client of the low frequency small-wattage CMH lamp on the Android device. The smartphone is connected to the microcontroller (STM32F103) via a HC-06 bluetooth module. The Android client can control the lamp to accomplish missions of accurate timing, gradient dimming, and automatically turn on and off.

6. CONCLUSIONS

A digital control method has been developed for improving the performance of small-wattage CMH lamps. A digital potentiometer X9313 has been introduced to control the lamp power. The lamp power can be altered flexibly according to the needed luminance for saving electric energy. Particularly, a remote desktop client on the Android device is developed for realizing the remote control of devices.

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