Study of Dimming Control Methods For HID Automotive Lamps

B.P. Divakar and K.W.E. Cheng[*]

Power Electronics Research Centre, Department of Electrical Engineering, The Hong Kong Polytechnic University

Hung Hom, Kowloon

[*]email:eeecheng@inet.polyue.du.hk

Abstract— **HID lamps offer better efficacy than halogen lamps and hence many cars are being fitted with metal halide HID lamps. The lamps are operated at 35 W in automobiles in all driving conditions. The present paper proposes for the first time the techniques to achieve dimming control by operating the lamp at reduced power to save energy in low-beam driving. The paper investigates the merits of each method and discusses the practical issues for implementing such a control.**

Keywords-*HID lamps; Dimming control*

I. INTRODUCTION

HID lamps deliver high output compared to halogen lamps but with relatively low consumption of power. HID lamps are operated at 70 W during start up to meet the SAE J2009 standard and 35 W at steady state. HID lamps are being fitted in high beam, low beam and both, and operated at the same rated power of 35 W for both high and low-beam fittings. In low-beam position al the rays from the lamp will be projected onto the road close to the automobile while in high-beam position the beam is projected far away from the vehicle. As a result the surface of the road close to the automobile is illuminated more when driven in low-beam position than in high-beam position. As the light in high-beam position is to be projected far away from the car, the lamp has to be driven at its rated power to develop maximum light output. While the purpose of operating the lamp in high-beam position can be justified because of the visibility requirement in high-beam driving condition, one can question the requirement to drive the lamp at the rated power for driving in low-beam position. The other motivating factor for this work is to include some flexibility in the control of the HID lamp to suit the driving environments in the modern cities around the world which are very well lit at night.

In [1], a new HID lamp controller is introduced which has all the function to operate the lamp. In [2], a two winding transformer is used in which the second winding is used to drive the ignition transformer. This enables the use of low rated devices in the circuit. Paper [3] describes method by which the voltage doubler is shifted on the inverter side resulting in the removal of the second winding in the transformer. All the papers so far have discussed the means to operate the lamp at its rated power and no report has been made on dimming control. The scope of the present work is to look into the possibilities of achieving dimming control of HID lamps fitted in automobiles and studying the impact of dimming method on the light output with a view to saving the energy.

This paper discusses the methods to implement the dimming control in automotive HID lamps as well as the practical issues to be taken care of in the actual implementation of the control. The theoretical analysis of the power control is discussed in section II, various dimming methods are introduced in section III, experimental results are presented in section IV followed by concluding remarks.

II. THEORETICAL ANALYSIS OF POWER CONTROL

As the HID lamps exhibit negative resistance characteristics, the lamps are driven in constant power mode in steady state. One of the methods to control the power is to control the lamp voltage and this can be achieved from the inverter side by reducing the pulse width of the inverter switches. This method was considered but later abandoned as the method introduces blank time during which all the switches are open in each half cycle. This essentially creates a short of the lamp with the secondary winding of the high voltage igniter. As the energy stored in the secondary of the igniter transformer is not enough to sustain the current through the lamp, the lamp can extinguish during the blank time. Therefore, other methods of operating the lamp were considered based on the constant power algorithm. The following section gives the principle behind the constant power control operation of the lamp and the steps that lead to the identification of methods to achieve dimming control.

The principle of the constant power algorithm can be best understood from figure 1, where $K_v V_o$, $K_i I_o$ and ref are the sensed voltage, load current and the reference signals [1]. The sensed voltage and current signals are summed and compared with the reference signal in an opamp as in figure 1. As the sum of the sensed signals is equal to the reference, any change in one will cause a corresponding change in the other so as to maintain the sum at the reference value resulting in constant power of the lamp.
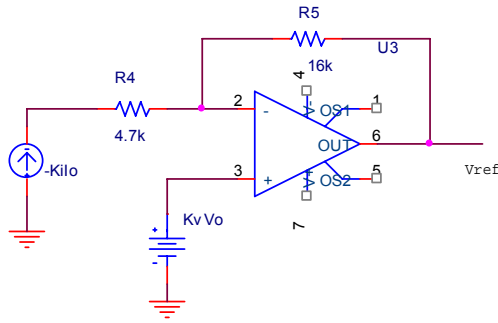
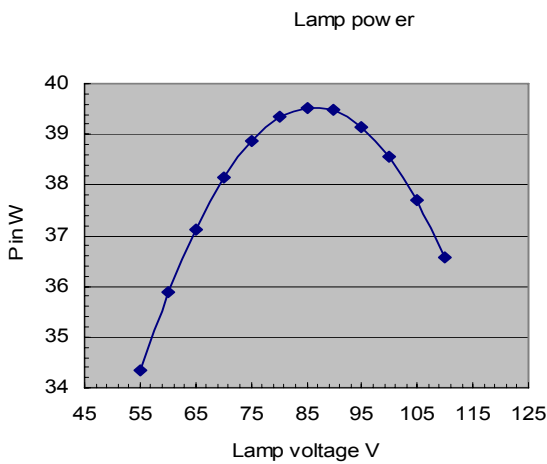Figure 1. Op-amp implementation of constant power algorithm

Figure 2. Theoretical plot of lamp power v/s lamp voltage

Following equations can be written in terms of Io from figure 1b:

$$I_o = \frac{ref}{G * K_i} - \frac{K_v V_o}{G * K_i}(1+G) \qquad (1)$$

$$P_o = \left[\frac{ref}{G * K_i} - \frac{K_v V_o}{G * K_i}(1+G)\right] V_o \qquad (2)$$

Where ref = 2.5V; G = R_5/R_4 = 3.4 and P_o is the lamp power.

The theoretical plot of the lamp power against the voltage in the range from 55 to 110 V for the values is shown in figure 2, which depicts the constant power operation based on the equation (2).

One can choose proper values for gains G (op-amp gain), k_v (voltage gain) and k_i (current gain) to achieve constant power control at any desired value. The factors in the above equations form the basis of the control techniques to achieve dimming control which is explained in the next section.

III.   METHODS OF CONTROL FOR DIMMING

A set of curves can be obtained by plotting the power P from (2) against the output voltage by varying other parameters in the equation and by doing so, the following three methods, which can control the power, can be identified.

- Current gain control (k_i)

- Voltage gain control (k_v)

- Op-amp gain control (G)

A.   Current gain control (k_i)

It is observed from (2) that the current gain "k_i" appears in the denominator of both the first and the second term of the expression and as a result it can be predicted that the current gain acts like a scaling factor to adjust the lamp power. A set of plots are obtained for power versus lamp voltage for various values of current gain and the plots are shown in figure 3.

The plots [using (2)] as in figure in 3 illustrate the variation of the power output against the lamp voltage and the gain k_i. It can also be seen from the plots that the power does not change appreciably with the lamp voltage for a given value of ki and this observation is useful in regulating the power as the lamp ages. Suppose the brightness of the lamp is low on account of ageing, it is possible to drive the lamp at lower current gain setting in order to increase the power and thereby compensating the loss of intensity due to ageing.
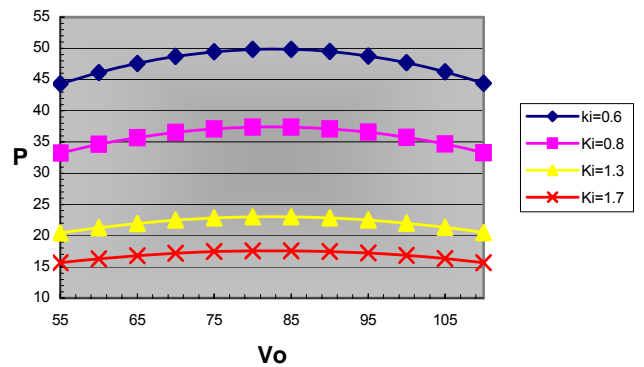

Figure. 3 2D plot for current gain control with G =3.45; k_v=0.0034

Figure 3 shows the power regulation capability of the current gain control which helps in achieving +/-5% regulation for a wide change in the steady state voltage.

B. *Voltage gain (k_v) control*

A set of theoretical plots are obtained from (2) by keeping k_i and G constant and varying k_v as shown in figure 4.

The plots in figure 4 show the results obtained with the voltage gain control when the current gain k_i was set to 0.9 It can be seen from the plots that satisfactory power regulation is achieved only within a narrow band of change in k_v and therefore this method does not offer any better advantage than the current-gain control method. Also, the power regulation as the lamp ages is also poor compared to the previous method.
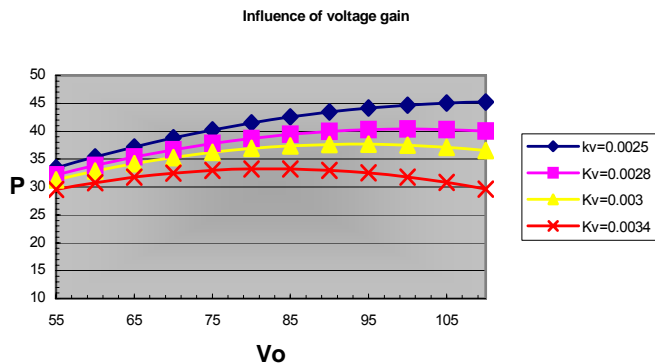
Influence of voltage gain

Figure. 4 2D plots for voltage gain control with G =3.45; ki_v=0.9

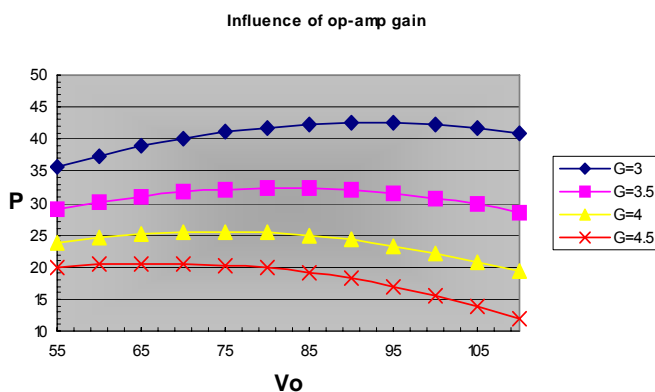## C. *Amplifier gain (G) control*

Influence of op-amp gain

Figure 5. 2d Plots for op-amp gain control with Ki = 0.9; k_v=0.0032

The last method is the op-amp gain control method in which the gain of the op-amp is adjusted to to control the lamp power. A set of theoretical plots could be generated using (2) to demonstrate that controlling the amplifier gain "G" the lamp power can be controlled. The selection of the op-amp gain (G) is critical to achieve good power regulation as seen from the plots, wherein for low and large values of

G, the power regulation exceeds 5% as seen in figure 5. The method like the voltage gain control suffers from poor power regulation and hence is not suitable for dimming control.
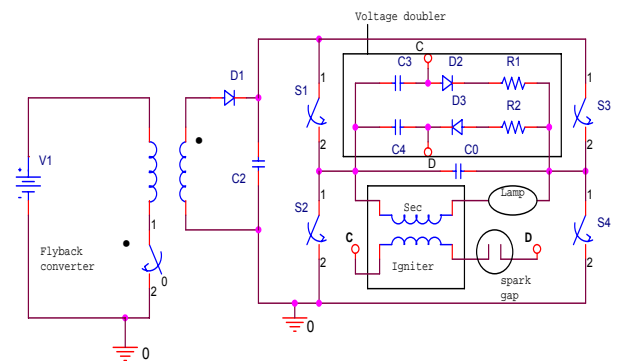
IV. EXPERIMENTAL RESULTS

Figure 6. Schematic of the HID ballast

An experiment was conducted on a 35W HID ballast driving a D2S type lamp using the current gain control method. The circuit diagram is shown in figure 6. The circuit consists of a flyback converter, a full-bridge inverter, a voltage doubler and an ignition transformer. The function of the flyback converter is to step up the battery voltage to about 300 V at start up and then control the lamp at 70W immediately upon ignition and then control the lamp at constant power of 35 W at steady state. The function of the igniter is to generate the necessary striking voltage of 10 – 22 kV for the lamp at start up. This necessary high voltage is generated using the combination of a voltage doubler, a spark-gap, a capacitor and a high voltage transformer. The output from the voltage doubler is fed to a capacitor (not shown in the figure and is connected across the terminals C and D). When the voltage across the capacitor exceeds 600 v, the spark gap breaks down and the energy stored in the capacitor is discharged into the primary of the ignition transformer. Due to this a high voltage pulse is generated across the secondary resulting in the ignition of the lamp. The resistance of the lamp falls to few tens of ohms and the controller will limit the maximum current drawn by the lamp. The voltage of the lamp will gradually increase to a steady state value between 75 – 80V and during this time the lamp is driven in a constant power mode. The ballast in the experiment was first operated at the rated power till the steady state was reached and then the current gain was adjusted manually to reduce the lamp power to about 22 W. An integrated sphere was used to measure the effectiveness of the dimming control. lux meter was used to measure the light output of the lamp and a drop in the reading was observed. The flux in normal operation was 1567 lumen while in dimming operation was 604 lumen as shown in figures 7a and 7b. (the low value of flux in the normal operation is due to large size of the pcb board used in the experiment which introduces error due to blocking of light

onto the sensor in the integrated sphere). It was very interesting to observe that despite the drop in the operating power, the magnitude of reduction in the light intensity was not significant to the naked eye and therefore, it is believed that the proposed method is suitable for driving the same lamp in high-beam at the rated power and in low-beam at reduced power. The experiment revealed that the lamp can be operated at lower power to achieve dimming control. However, the light output in low power mode should satisfy the requirements of the standards so, the future work will look into referring to the standards in order to select the current gain that can result in dimming of the lamp so as to meet the complying standards.
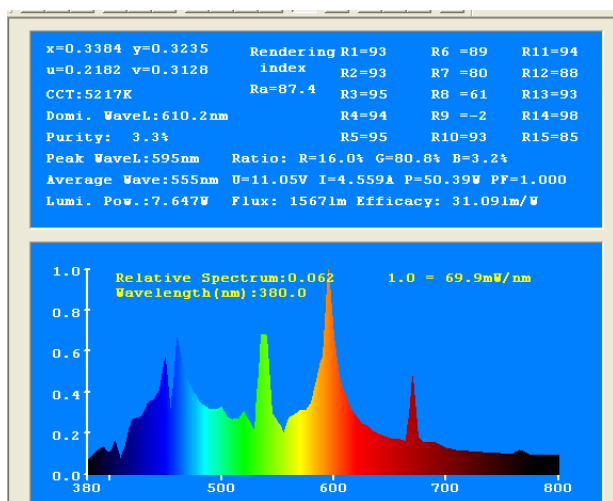

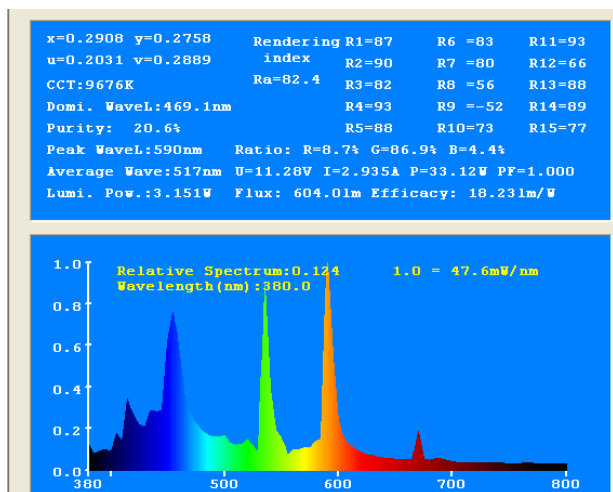Figure 7a. Measurement of flux under normal operation

Figure 7b. Measurement of flux under dimming operation

V. CONCLUDING REMARKS

In the present paper a study has been conducted to operate the HID lamp at less than its rated power to achieve dimming control. Three methods of controls and their merits are discussed in the paper. The current gain control because of its superior power regulation capability stands out among the three methods and hence the dimming operation is implemented using current gain method in this work. The preliminary work reveals the feasibility of the control technique to operate the lamp at lower power. The lumen output was brought down from 1567 lumen at 36 W to 609 lumens at 22.2 W by the adjustment of the current gain. It is envisaged that the lamps in low-beam position could be operated at low power for the reasons mentioned earlier by selecting the proper current gain that results in the light output which can satisfy the regulations. In the present work, the current gain was adjusted by adjusting the tapping of the current gain resistor in the opamp of the controller and this method of control cannot be practical for the obvious reason. The problem with the present control could be surmounted by digital implementation of current gain control incorporating an intelligent gain control algorithm that can respond to different steady state lamp voltage and manipulate the current gain to achieve good regulation throughout the life of the lamp. A prototype of the ballast for low beam with the complete headlamp set will be put to test in future to check for its compliance of standards.

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[3] Qun Zhao, Y Hu, F.C. Lee, Juan A. Sabate and Faye Li "Examination of the Power conditioning driving circuit for automotive HID lamp", APSCOM 2006 proceedings, presented.