Sensitivity and Removed THD of a Phase-Cutting Dimmer

H. Fathabadi

***Abstract*—**In this paper, we consider a designed and implemented phase-cutting dimmer. In fact, the dimmer is closed loop and a microcontroller calculates and then regulates the firing delay angles of each channel. Depending on the firing angle, the harmonic distortion in the input current will not comply with international standards, such as IEC 61000-3-2 (class C equipments). For solving this problem, eight harmonic compensators have been added to the dimmer. So, the proposed dimmer has a little harmonic distortion in the input current whereas conventional phase-cutting dimmers are not so. Sensitivity and removed THD of the proposed dimmer will be presented.

***Keywords*—**Dimmer, compensator, harmonic, dimming.

I. INTRODUCTION

As we know electrical energy is expensive. So, when the luminosity of environment is higher than enough, the electrical power is become useless. In order to economize of electrical energy, we must turn off or decrease the luminosity of lamps. In this way, a lot of electrical power will be economized. As we know, a dimmer can do this. Recently, dimmers have attracted considerable attention [1]-[10]. Most results addressing this subject, available in power electronic literature. As we know, phase-cutting dimmers are two types, open loop and closed loop. In open loop dimmers, the luminosity of environment is regulated manually. Conversely, in closed loop dimmers, luminosity is regulated automatically. So the economy of energy is higher. The dimmer which is presented in this paper, is closed loop. This dimmer regulates the luminosity of eight locations synchronously. Also eight harmonic compensators have been added to system. In order to economize the electrical energy, the outputs of compensators have been connected to resistances (elements) of the water heaters or boilers in houses or industrial centers.

II. BLOCK DIAGRAM AND HARDWARE OF THE DIMMER

The block diagram of the dimmer has been shown in Fig. 1. As we see, the system consists of the following units:

1) Eight sensors in eight locations. These sensors generate eight feedback signals which are changed by varying in the luminosities of the eight locations.
2) Analog to digital converter. The output signal of each sensor must be converted to digital signal. These digital signals can be used by C.P.U. or microcontroller.
3) A multiplexer. Eight digital signals must be multiplexed in order to transmit on one data bus.
4) A cross-over zero detector. This unit generates a negative edge pulse, when AC power line passes from negative alternation to positive alternation. In fact, this unit generates the origin of time.
5) A CPU or microcontroller. This unit is necessary, because it calculates and regulates the firing delay angles of eight triacs base on the eight feedback signals.
6) Eight isolators and couplers. Power section of circuit is isolated from the control section of circuit by these elements.
7) Eight controlled power drivers. Controlled power drivers are electronic elements such as triac or thyristor that operate as controlled switches.
8) Eight harmonic compensators.
9) Twenty four lamps (three lamps for each location or channel). In fact, they are the output of the system.

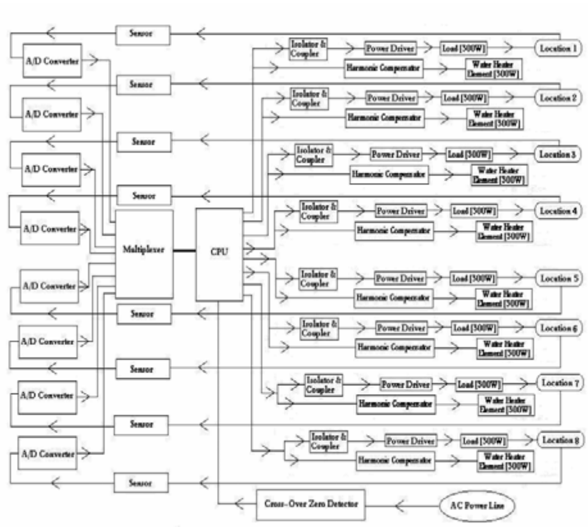

Fig. 1 Block diagram of the dimmer

Also implemented dimmer has been shown in Fig. 2.

Manuscript received March 30, 2008.

Hassan Fathabadi is with the Electrical Engineering of I. K. I. University, Daneshgah Blv. Qazvin, Iran, P.O.Box: 34149 (phone: 0098-0281-3780038; fax: 0098-281-3780073; e-mail: h4477@hotmail.com).

III. Flow Chart and Software

A flow chart for software of the dimmer has been shown in Fig. 3. Base on this flow chart, the software for the dimmer has been written. In fact, this software is a program in C++ language for programming microcontroller 89C51. This program has been presented in appendix.

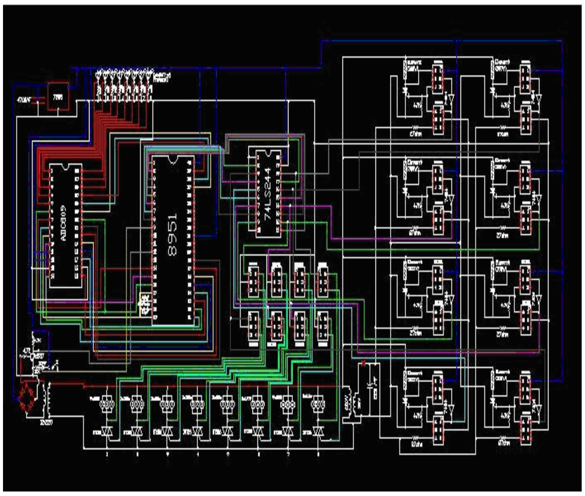

Fig. 2 Hardware of the dimmer

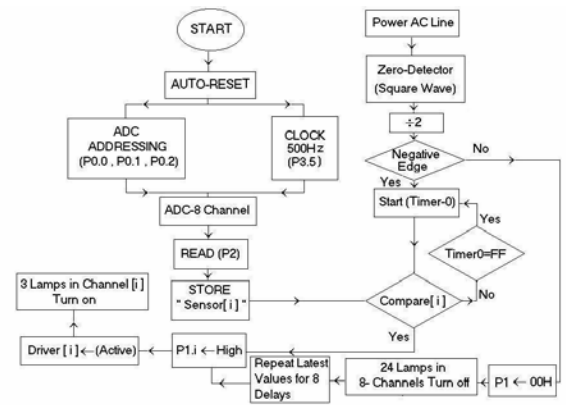

Fig. 3 Flow chart for software of the dimmer

IV. Sensitivity of the Dimmer

In this section sensitivity of the dimmer which realized and constructed in above, will be calculated. Eight photocells with number Cds 8107 have been used as the feedback sensors of the dimmer.

As we know, Cds cells are a type of photoconductive devices. They are semiconductor sensors that utilize the photoconductive surface that reduce resistance. The spectral response of Cds 8107 is close to that of the human eye, so it can be widely and easily used in applications as sensors substituting for the human eye. Thus, it can be used for detecting the luminosity of daylight. The Cds 8107 resistance vs. illuminance characteristic has been shown in Fig. 4. Form this characteristic curve we have,

$$\log\left(\frac{R_O[k\Omega]}{800}\right) = \log\left(\frac{1}{4}\right)\log(E[Lux]) \tag{1}$$

where R_O is output resistance of Cds 8107 and E is the luminosity of environment. So,

$$R_O[k\Omega] = 800E^{-0.602}[Lux]\,. \tag{2}$$

In the other hand, the input voltage to ADC809 is

$$V_O[v] = \frac{R}{R+R_O}(+5) \tag{3}$$

where R is the resistance of 50 $[k\Omega]$ potentiometer which has been cascaded with photocell. From (3), we obtain that

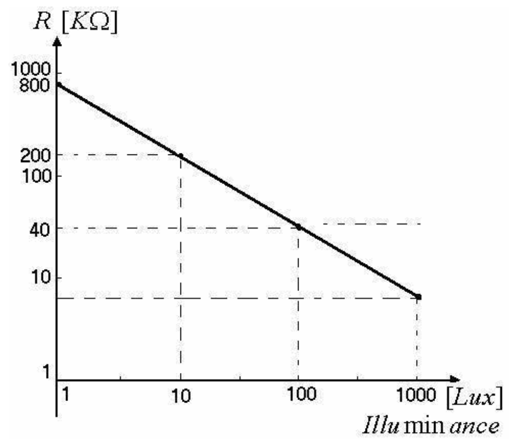

Fig. 4 Cds 8107 resistance vs. illuminance characteristic

$$\frac{\partial V_O}{\partial E} = \frac{2408R.E^{-1.602}}{(R+800E^{-0.602})^2} \tag{4}$$

and so,

$$\Delta V_O \approx \frac{2408R.E^{-1.602}}{(R+800E^{-0.602})^2}\Delta E\,. \tag{5}$$

As we know, ADC809 is an 8-bit analog to digital converter. So, the input voltage to this converter is quantized to 256 levels. With considering this fact, we conclude that

$$\Delta V_{O\,MIN} = \frac{+5\ [v]}{256}\,. \tag{6}$$

From (5) and (6), we obtain that

$$\frac{+5}{256} \approx \frac{2408R.E^{-1.602}}{(R+800E^{-0.602})^2}\Delta E_{MIN} \tag{7}$$

and so,

$$\Delta E_{MIN} \approx \frac{5\times(R+800E^{-0.602})^2}{256\times 2408R.E^{-1.602}}\ [Lux]\,. \tag{8}$$

For example, for adjusted resistance of potentiometer at $R = 50\ [k\Omega]$ and the luminosity of the environment at $E = 300\ [Lux]$, from (8), we have

$$\Delta E_{MIN} = 8.6687\ [Lux]\,. \tag{9}$$

This means that, the dimmer can regulate the luminosity of the environment at $E = 300\ [Lux]$ with accuracy of $8.6687\ [Lux]$.

V. Dimming Range and Removed THD

Microcontroller generates the delay time for each channel. So, we have

$$\Delta t \in (0ms \ , \ 20ms) \tag{10}$$

where Δt is generated delay time for a channel. By considering

$$\alpha = \frac{2\pi \ .\Delta t}{20ms} \tag{11}$$

we have

$$\alpha \ \in (0 \ , \ 2\pi) \tag{12}$$

where α is the firing delay angle of one channel. So, dimming range of proposed dimmer is $(0 \ , \ 2\pi)$.

Suppose that, the compensators of proposed dimmer have been removed. For THD of dimmer (without compensators), we have

$$THD = \sqrt{\frac{\sum_{n=2}^{+\infty} |A_n|^2}{|A_1|^2}} \tag{13}$$

where

$$|A_n|^2 = [\frac{1}{\pi}\int_{\alpha}^{2\pi} \sin(x)\cos(nx)dx]^2 + [\frac{1}{\pi}\int_{\alpha}^{2\pi} \sin(x)\sin(nx)dx]^2 \tag{14}$$

So, we have

$$|A_n|^2 = \frac{1}{4\pi^2}[(\frac{1}{n+1})^2 + (\frac{1}{n-1})^2 + (\frac{2}{n^2-1})^2 - \frac{2}{n^2-1}\cos(2\alpha) + \frac{4}{(n^2-1)(n+1)}\cos(n+1)\alpha - \frac{4}{(n^2-1)(n-1)}\cos(n-1)\alpha]$$

$$\text{for } n \geq 2 \tag{15}$$

and

$$|A_1|^2 = \frac{1}{8\pi^2}(1-\cos 2\alpha) + (1-\frac{\alpha}{2\pi})^2 + \frac{1}{2\pi}(1-\frac{\alpha}{2\pi})\sin 2\alpha \ . \tag{16}$$

It follows that,

$$THD = \frac{1}{2\pi} \ . \tag{17}$$

$$\sqrt{\frac{\sum_{n=2}^{+\infty}[(\frac{1}{n+1})^2 + (\frac{1}{n-1})^2 + (\frac{2}{n^2-1})^2 - \frac{2}{n^2-1}\cos(2\alpha) + \frac{4}{(n^2-1)(n+1)}\cos(n+1)\alpha + ..}{\frac{1}{8\pi^2}(1-\cos 2\alpha) + (1-\frac{\alpha}{2\pi})^2 + \frac{1}{2\pi}(1-\frac{\alpha}{2\pi})\sin 2\alpha}}$$

So, equation (17) presents the removed THD of a channel with using the harmonic compensator of the same channel. In practice, there are mismatching between the loads of one compensator and its related channel. So, a little harmonic distortion can remain in system. In this case, the value of THD can be reduced and limited to zero by matching the loads of each compensator and its related channel.

VI. Conclusion

In this paper, we considered a designed and implemented phase-cutting dimmer. The dimmer had been contained eight harmonic compensators. Sensitivity and removed THD of the dimmer were presented.

References

[1] H. J. Chiu, L. W. Lin and C. M. Wang, "Single-stage dimmable electronic ballast with high power factor and low EMI," IEE Trans. Electric Power Applications, vol. 152, pp. 89-95, 2005.

[2] A. R. Seide, F. E. Bisogno, H. Pinheiro and R. N. do Prado, "Self-oscillating dimmable electronic ballast," IEEE Trans. Industrial Electronics, vol. 50, pp. 1267-1274, 2003.

[3] J. M. Alonso, M. A. Dalla-Costa, J. Cardesin and J. Garcia, "Magnetic dimming of electronic ballasts," IEE Trans. Electronics Letters, vol. 41, pp. 718 - 719, 2005.

[4] S. Y. R Hui, L. Leung Ming, H. S. H. Chung and Y. K. Ho, "An electronic ballast with wide dimming range, high PF, and low EMI," IEEE Trans. Power Electronics, vol. 16, pp. 465 - 472, 2001.

[5] W. Tsai-Fu, W. Yung-Chun and S. Zing-Ying, "Design considerations for single-stage electronic ballast with dimming feature," IEEE Trans. Industrial Electronics, vol. 37, pp. 1537 - 1543, 2001.

[6] L. Li-Wei, H. Hsiu-Ming, C. Huang-Jen and M. Shann-Chyi, "A single-stage dimmable electronic ballast with high power factor," in Proc. IEEE Conf. and Exp. Applied Power Electronics, 2005, pp. 1758 - 1763.

[7] S. S. T. Lee, H. S. H. Chung and S. Y. R. Hui, "TRIAC dimmable electronic ballast with lamp power equalization," in Proc. 35th IEEE Conf. Power Electronics Specialist, 2004, pp. 1754 - 1760.

[8] L. Chang-Hua, L. Ying and P. Kai-Jun, "Digital-dimming controller with current spikes elimination technique for LCD backlight electronic ballast," in Proc. IEEE Conf. and Exp. Applied Power Electronics, 2004, pp. 153 - 158.

[9] D. Klien, "A sensing and regulation concept for high end dimming ballasts," in Proc. 38th IEEE Conf. Industry Applications, 2003, pp. 785 - 790.

[10] S. S. T. Lee, Samuel Chan, H. S. H. Chung and S. Y. R. Hui, "Use of saturable inductor to improve the dimming characteristics of frequency-controlled dimmable electronic ballasts," in Proc. 34th IEEE Conf. Power Electronics Specialist, 2003, pp. 988 - 993.