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Application of Fuzzy Decision in Lighting Control of Cities

Chenghui Zhang, Naxin Cui, Maiying Zhong, Zhaolin Cheng

Abstract—Based on microprocessor a new intelligent control scheme is developed for city illumination systems. It eliminates pulse interferences of environmental light, such as fulmination, by using time delay filer, and distinguishes persistent interferences, such as welding flare and car light, based on fuzzy decision theory. The control system can turn on or off the transformer automatically according to environmental light, solving the trembling problem of breaker. It is not only suitable for control of streetlights but also suitable for lighting of enterprises. The paper also presents the hardware of the controller, detection circuits and software diagram. Experimental results show that both the pulse and persistent interferences can be distinguished and reduced by the proposed techniques.

I. INTRODUCTION

The quality of lighting is important for city life. Streetlight control is often implemented by turning on and off the transformers thereby making them being off during the daytime and on at the night. The transformer cannot be disengaged from the high-voltage power grids which results in great energy loss when operating idly during the daytime. Some systems adopt high-voltage special line for power supply but they are constricted to manual timing control which needs manual work and has high randomicity and low precision. Such a method cannot guarantee reliable lighting and results in great trouble in the people's life. It also leads to earlier turning on in the evening or later turning off in the morning, which even causes 'always-on-lighting' producing severe power energy loss. According to a survey, there is 400 streetlight transformers of 50kVA producing over one million RMB Yuan idling loss each year and the power loss for the 'always-on-lighting' is also over one million RMB Yuan in a medium-scale city in China, which results undoubtedly in a great deal of energy waste[1][2]. The quality of existing products is not reliable and stable enough, especially the unresolved problem of breaker jittery caused by environmental interference, i.e. the pulse interference, such as fulmination, and persistent interference, such as lights of welding and cars.

As a method of intelligent control, fuzzy-logic-based control can provide a powerful solution to occasions in presence of uncertainties. Due to the simplicity in design and implementation, inherent capability of dealing with uncertainties in dynamic systems and ability to incorporate easily human experiences into the controller design, fuzzy control has been becoming one of the favorite choices for control engineers[3][4]. This paper develops a microprocessor-based intelligent control device for streetlight control, applying fuzzy decision theory to distinguish various interferences accurately and to make it operate reliably. The device can make the transformer be disengaged from the high-voltage power grids automatically during the daytime without idling loss, minimizing the power energy waste through intelligent control of high-voltage breaker. The operational results indicate that the device operates stably and reliably.

II. DISTINGUISHING LIGHTING INTERFERENCES BY FUZZY DECISION

To make the high-voltage breaker operate efficiently and reliably, it must distinguish dusk, dawn and the two kinds of environmental interferences: one is the pulse interference with lasting time shorter than a second, such as the fulmination in the night and the instantaneous veiling interference; the other is the persistent interference with lasting time longer than a second, such as the headlight in the night and the long veiling interference during daytime. The pulse interference can be eliminated through time delay filtering by the hardware. But the persistent interference cannot be distinguished by such a method accurately and it often causes wrong action because the lasting time is uncertain. The essential reason is that the difference between dusk, dawn and persistent interference is blur and cannot be distinguished by a precise threshold. In other words, their boundaries are imprecise and only fuzzy sets can describe them appropriately[5][6].

Fuzzy decision is adopted in the system to solve the problem. According to the operators' experience, the light signal L and the changing rate ΔL are considered comprehensively to distinguish different signals, i.e. dawn,

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dusk, lighting interference and veiling interference [7][8]. The single-chip microprocessor produces an appropriate output-switching signal to denote turning on or off of the streetlights, which is an input signal of the trigger circuit of the TRIAC after photoelectric insulation[9].

According to the experimental data, the lighting signal is about 4Lx at dawn. Considering the slow and symmetric change of dawn and dusk, define two fuzzy sets, daytime and night, in the universe of discourse X={x | 0Lx≤x≤10Lx} as follows.

Daytime:

$$\mu_{DY}(x) = \frac{1}{1+\exp(-1.5(x-5))} \quad (1)$$

Night:

$$\mu_{NT}(x) = \frac{1}{1+\exp(1.5(x-5))} \quad (2)$$

These membership functions are shown in Fig. 1.The light-changing rate of dawn and dusk is about 0.1Lx/s while the light changing rate of the interferences is much greater than 0.1Lx/s. Thus, the changing rate is the key factor to distinguish the interferences. Based on the experimental data, define fuzzy sets in the universe of discourse $Y=\{y|-20Lx\cdot s^{-1}\le y\le 20Lx\cdot s^{-1}\}$ as follows.

Zero:

$$\mu_{Z}(y) = \frac{1}{1+\left|\frac{y}{0.02}\right|^{4}} \quad (3)$$

PS (Positive Small):

$$\mu_{PS}(y) = \frac{1}{1+\left|\frac{y-0.33}{0.3}\right|^{16}} \quad (4)$$

MS (Minus Small):

$$\mu_{NS}(y) = \frac{1}{1+\left|\frac{y+0.33}{0.3}\right|^{16}} \quad (5)$$

PB (Positive Big):

$$\mu_{PB}(y) = \frac{1}{1+\exp(-20(y-0.65))} \quad (6)$$

MB (Minus Big):

$$\mu_{NB}(y) = \frac{1}{1+\exp(20(y+0.65))} \quad (7)$$

These membership functions of the changing rate are shown in Fig. 2.

According to the operators' experience, we can derive the following control rules as follows.

IF L is Daytime AND ΔL is MS THEN turn off;

IF L is Night AND ΔL is PS THEN turn on;

IF L is Night AND ΔL is PB THEN maintain the state;

IF L is Daytime AND ΔL is MB THEN maintain the state;

IF (L is Daytime OR Night) AND ΔL is Zero THEN maintain the state.

Where L is the light signal and ΔL is the changing rate.

Define fuzzy sets C_1, C_2, C_3, C_4 in the universe of discourse $Z=X\times Y=\{(x,y)\,|\,0Lx\le x\le 10Lx,\ -20Lx\cdot s^{-1}\le y\le 20Lx\cdot s^{-1}\}$ to denote dusk, dawn, light and veiling interference. Based on the rules, we obtain the following equations.

$$\mu_{C_1}(x,y) = \mu_{DY}(x)\mu_{NS}(y) \quad (8)$$

$$\mu_{C_2}(x,y) = \mu_{NT}(x)\mu_{PS}(y) \quad (9)$$

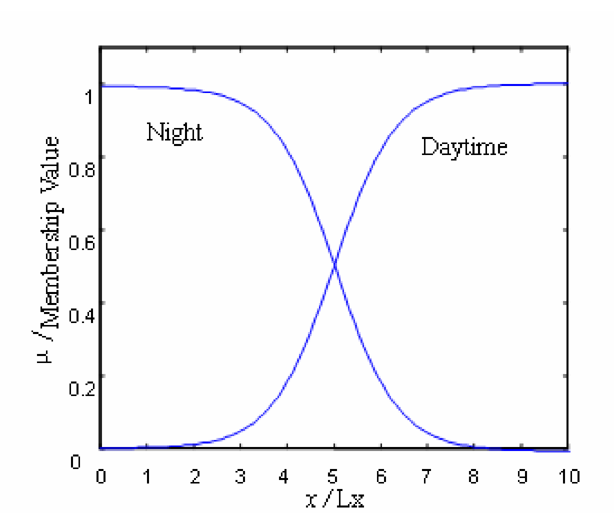


Fig.1 Membership functions of lighting strength

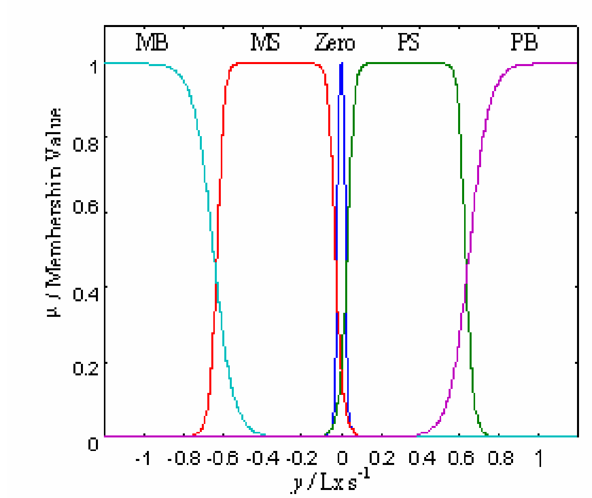


Fig. 2 Membership functions of changing rate of lighting strength

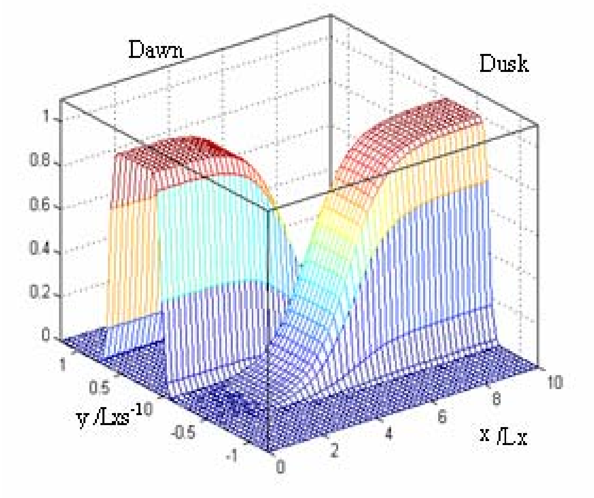


Fig. 3 Membership functions of dusk and dawn

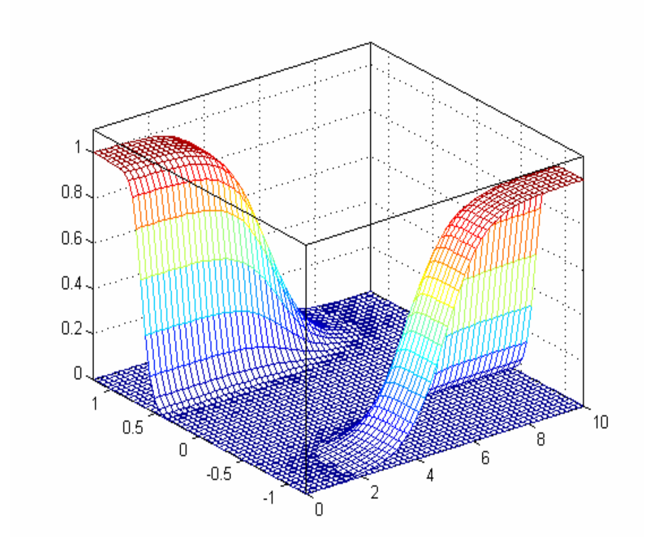


Fig. 4. Membership functions for interferences

$$\mu_{C_3}(x, y) = \mu_{NT}(x)\mu_{PB}(y) \qquad (10)$$

$$\mu_{C_4}(x, y) = \mu_{DY}(x)\mu_{PB}(y) \qquad (11)$$

$$\mu_{C_o}(x, y) = (\mu_{NT}(x) + \mu_{DY}(x))\mu_z(y) \qquad (12)$$

The membership functions for dawn and dusk are shown in Fig. 3 and those for light interference and veiling interference are shown in Fig. 4.

It can be seen from the figures that the above fuzzy sets can describe the concepts accurately. Compute each membership value according to the detecting values of every sampling period and select the appropriate fuzzy set based on the principle of maximum membership value, adopting the fuzzy set C_o as the decision result which has the maximum membership value.

$$\mu_{C_o}(x, y) = \max_{1 \le i \le 5} \mu_{C_i}(x, y) \qquad (13)$$

Then the single-chip microprocessor produces the corresponding switching signal to turn on or off the breaker.

III. Configuration and Principles of Hardware

The hardware of control system is mainly composed of 80C51 single-chip computer, periphery circuits, photoelectric coupling output circuits, display circuits and failure alarm circuits, as shown in Fig. 5.

80C51 single-chip computer and its periphery circuits are the kernel parts of the control circuits. Firstly, The pulse interferences are eliminated by time delay filter. Then, dusk, dawn and persistent interferences are distinguished by fuzzy decision, which avoids mistaken action reliably. The on-values and off-values of time-lapse filters are different in the lighting circuits for various streets, warehouses and office buildings, which can be conveniently regulated online through the keyboard .

The main loop circuit is composed of high-power TRIAC and their protection circuits. The lighting strength circuits adopt photosensitive resistances as the detecting elements, which have high sensitivity and good spectrum characteristics,from ultraviolet area to infrared area. It is also compact, cheap and feasible for switching control in the lighting system. There is a chip of 27C64 as program memory, with a chip of 82C55 as the interface between the keyboard, display element and 80C51. The detecting signal of lighting strength is converted into digital signal by AD1674, a 12-bit A/D converter that costs only 25μs to do each conversion and can be used for multi-point detection. The lighting strength value can be obtained after processing the A/D converting results through numerical filter by 80C51.

IV. Design of System Software

The system software is composed of main program, external interrupt service program and timer interrupt service program. The main program is engaged for initialization, numerical filtering, fuzzy decision and signal output. The flowchart is shown in Fig. 6.

The response of the system of the keyboard is implemented by external interruption. The external interruption service program is in charge of regulation of the constant time value of on-delay and off-delay and reset of the system. The timer interruption service program is in charge of fault detection, processing and display. The timing period is set to 5ms. In the interruption service program, the A/D conversion is started and the voltage and current of the main loop circuit are detected.

If there is some kind of malfunction, the corresponding processing program is executed and the voice and light alarming signal is output through the port P1.1. In addition, the photoelectric automatic control system can be connected

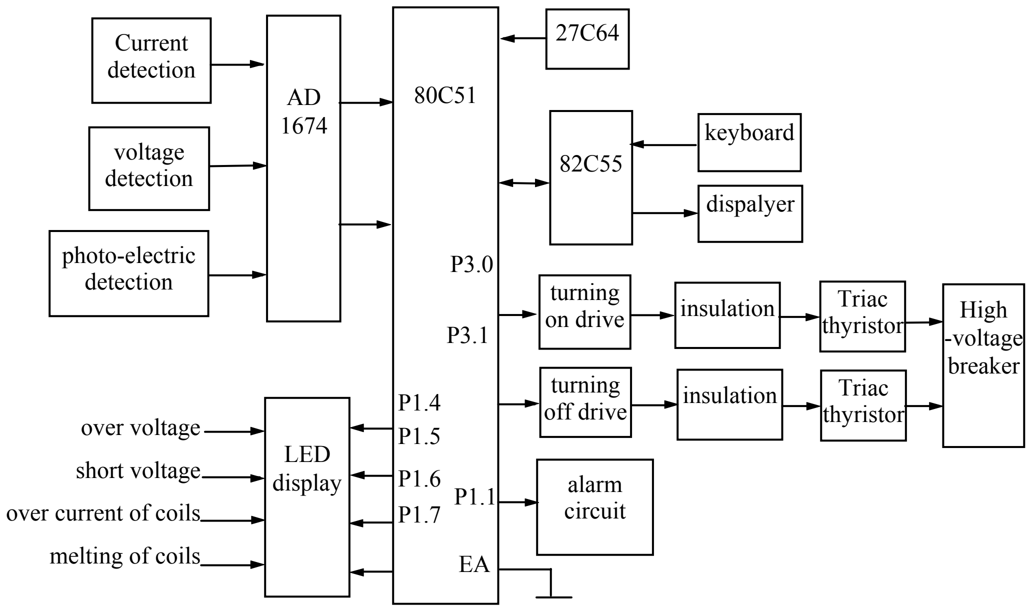


Fig. 5 Hardware configuration of microprocessor control system of breaker

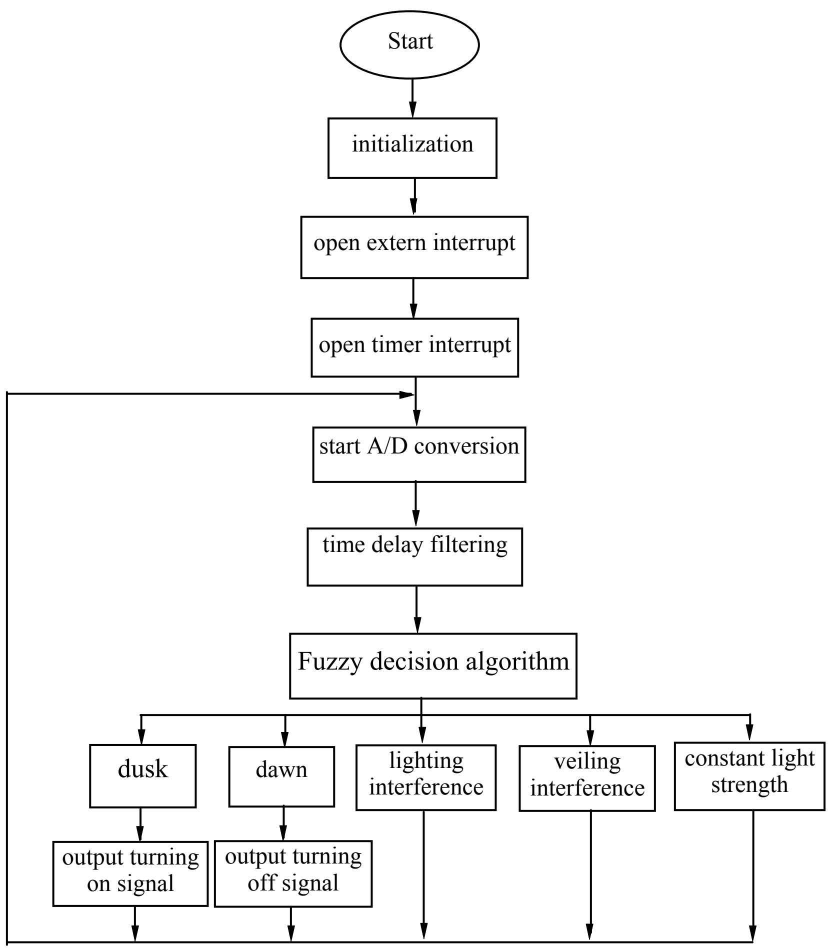


Fig. 6 Flowchart of the main progr

with other computers, composing Distributed Control System(DCS) and implementing united control and administration in a whole city or area, which can save much more energy and has better effect with reliable characteristics.

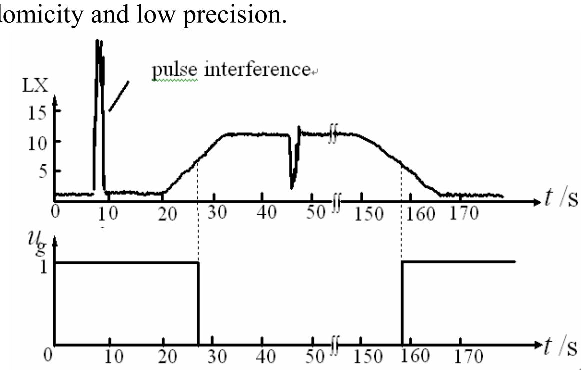
V. Experimental Results

This control device can be used for lighting system in the street, warehouse or office building. The experiment results of relation between the open/close driving signal u_g and the lighting strength is shown in Fig. 7.

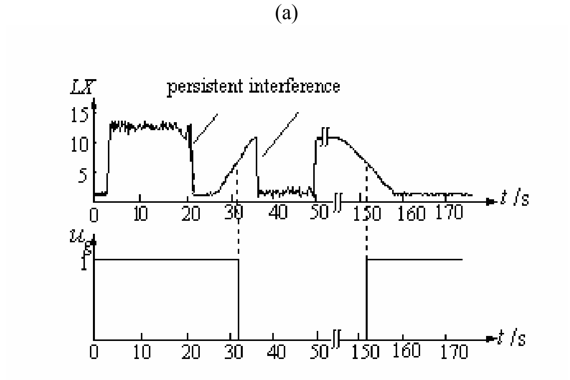
According to the Fig. 7, pulse and persistent interferences can be distinguished and reduced by the system. The slow variation of the lighting strength of dusk and dawn can also be distinguished and responded correctly and the breaker is closed or opened duly, realizing the expected control effect.

VI. Conclusion

The transformer cannot be disengaged from the high-voltage power grids which results in great energy loss when operating idly during the daytime. Some systems adopt high-voltage special line for power supply but they are constricted to manual timing control which laborious, high randomicity and low precision.



(a)



(b)

Fig. 7 Driving signal of opening/closing switch and time sequence of lighting strength (a) driving signal u_g and pulse interferences (b) driving signal u_g and persistent interferences

The paper designs a high-voltage breaker control device, which applies fuzzy decision to distinguish environmental interferences, avoiding the fault action and jittery and improving the reliability. The control device can be used to reconstruct the lighting system, making the power supply transformer disengaged from the high voltage power grids and saving the power. The device is reliable and convenient for maintenance. Up till now, there have been more than twenty devices used in the field, which worked reliably and had obtained good effect of energy saving.

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