Research on Green Control Algorithm of Street Lamp

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Abstract. As an important facility of community lighting, street lights can not only provide convenience for pedestrians or vehicles, but also improve the safety of the community. The power consumption of street lamp lighting is one of the important parts of shared power in the community. In order to solve this problem, firstly, we study the lighting control algorithm and establish the energy consumption formula; secondly, we analyse the energy consumption under different lighting control strategies; finally, we design a feasible intelligent green control algorithm. Theoretical analysis shows that intelligent green light control can effectively save energy and prolong the life of lamps and lanterns.

1. Introduction

The State Council regards energy conservation and emission reduction as an important work to optimize the economic structure and promote the green recycling and low-carbon development. With the rapid development of smart city, new smart communities or intelligent buildings continue to appear[1-6]. As an important facility of community lighting, street lights can not only provide convenience for pedestrians or vehicles, but also improve the safety of the community. The power consumption of street lamp lighting is one of the important parts of shared power in the community. However, the street lamp control in most of the residential areas in China is still primitive, and it is still in the stage of manual switch control. Because of the unreasonable lighting design, especially in some high plot ratio residential areas, there are serious energy waste problems such as indoor corridor long lights. In this paper, led green street light control algorithm is studied. Firstly, the energy consumption characteristics of typical street lamp control are analysed, and then a comprehensive energy-saving green street lamp control algorithm is proposed.

2. Research on Light Control

According to the lamps used, street lamps in the community can be divided into high-pressure sodium lamp, incandescent lamp, energy-saving lamp, led, etc. According to the power source, it can be divided into: high voltage (380V) lighting, household (220V) lighting and low voltage (5V / 12V / 24V / 36V, etc. According to the use scenario, it can be divided into indoor and outdoor street lamps. LED lamp has the characteristics of power saving, long service life and fast response. The specially customized LED lamp can also be dimmable. The following uses mathematical tools to study and analyse the control characteristics of different LED lights.

2.1. Simple Control Analysis

Ordinary LED lights only support switch light control. There are two states of LED lights: on (s1) and off (s0). Figure 1 shows the working state conversion diagram of ordinary led.
The simple control state transition can be described as: \( S_0 \xrightarrow{ON} S_1 \); \( S_1 \xrightarrow{OFF} S_0 \).

The energy consumption is analysed as follows:

The state power consumption of LED S1 is \( P_1 \), and the duration of the test \( t_1 \). The power consumption of S0 state is \( P_0 \), and the duration of the test \( t_0 \). In the test cycle \( T \) time, the power \( W \) can be described by Formula 1:

\[
W = P_0 \times \sum t_0_i + P_1 \times \sum t_1_j
\]

\[
T = \sum t_0_i + \sum t_1_j
\]

(1)

When the light is turned off, the power consumption of \( P_0 \) is usually very small, which can be considered as 0. Formula 1 can be simplified as formula 2:

\[
W = P_0 \times \sum t_0_i + P_1 \times \sum t_1_j = P_1 \times \sum t_1_i
\]

\[
T = \sum t_0_i + \sum t_1_j
\]

(2)

The goal of energy-saving control in simple control mode is to minimize \( S_1 \) (on light) working time in \( T \) time of test cycle, that is to extend \( S_0 \) (off light) state (power saving) time as much as possible in \( T \) time of test cycle.

### 2.2. Dimming Control Analysis

Figure 2 shows the switching of dimming control working state. In addition to supporting on-off light control, special LED lights can also continuously or hierarchically adjust the light brightness, that is, in addition to \( S_0 \) and \( S_1 \), a variety of intermediate display brightness states are added to be recorded as \( S_n \) (according to the ratio of \( n \) to full light). In the test cycle \( T \) time, the power \( W \) can be described by Formula 3:

The dimming control state transition can be described as: \( S_0 \xrightarrow{J_1} S_1 \), \( S_1 \xrightarrow{J_2} S_0 \), \( S_0 \xrightarrow{J_3} S_n \), \( S_n \xrightarrow{J_4} S_1 \), \( S_1 \xrightarrow{J_5} S_n \), \( S_n \xrightarrow{J_6} S_1 \), \( S_1 \xrightarrow{J_7} S_n \); Among them, \( J_1, J_2, J_3, J_4, J_5, J_6, J_7 \) are light state jump conditions. On the basis of simple dimming analysis, the state power consumption of LED \( S_n \) is \( P_n \), and the duration of the test \( t_1 \) turn on is \( t_{n_1} \).

\[
W = P_0 \times \sum t_0_i + P_1 \times \sum t_1_j + \sum P_n \times \sum t_{n_k}
\]

\[
T = \sum t_0_i + \sum t_1_j + \sum P_n \sum t_{n_k}
\]

(3)

When \( P_0 = 0 \), it can be simplified as follows:
The goal of energy-saving control in dimming control mode is not only to reduce the working time $S_1$ and $S_n$ in the test cycle $T$, but also to select the power-saving brightness $n$ that meets the lighting demand as much as possible; that is to say, not only to extend the state $S_0$ as much as possible in the test cycle $t$, but also to select the most power-saving brightness $n$ that meets the lighting requirements.

3. Analysis of Light Control Strategy

In the practical application of light control, delay control has a special function. Strategy analysis assumes that $S_0$ is off, $S_1$ is on, $S_n$ is $n\%$ brightness, $T_x$ is delay, and $A_i (i \in [1,2,3,4,5,6,7,8,9,10,11,12])$ is state change adjustment command, which are recorded as $A_1(s_1, s_0), A_2(s_0, s_1), A_3(s_0, t_x), A_4(t_x, s_1), A_5(s_1, t_x), A_6(t_x, s_0), A_7(t'_x, t_x), A_8(s_0, s_0), A_9(s_0, s_1), A_{10}(s_1, s_0), A_{11}(s'_n, s_0), A_{12}(s_n, s_0)$.

Dimming control topology is shown in Figure 3.

![Figure 3. Dimming control topology](image)

3.1. Control Strategy Analysis

Typical control strategies can be divided into: simple control strategy, delay simple control strategy, dimming control strategy and delay dimming control strategy. The control functions are described as follows:

i. Simple control strategy: $s_x \Rightarrow s_y | A_l \in (A_1, A_2), s_x, s_y \in (s_0, s_1) \Rightarrow \{A_1 \Rightarrow \{s_0 \Rightarrow s_1, s_1 \Rightarrow s_0\}\}. The simple control strategy only includes 2 kinds of control, such as: on and off.

ii. Delay simple control strategy: $s_x \Rightarrow s_y | A_l \in (A_1, A_2, A_3, A_4, A_5, A_6, A_7), s_x, s_y \in (s_0, s_1, t_x) \Rightarrow \{s_0 \Rightarrow s_1, s_1 \Rightarrow s_0, s_0 \Rightarrow t_x, t_x \Rightarrow s_1, s_1 \Rightarrow t_x, t_x \Rightarrow s_0, t'_x \Rightarrow t_x\}. The simple control strategy of delay includes 7 kinds of control, such as: on, off, on delay, delay on, off delay, delay off, repeat delay, etc.

iii. Dimming control strategy: $s_x \Rightarrow s_y | A_l \in (A_1, A_2, A_3, A_4, A_5, A_6, A_7), s_x, s_y \in (s_0, s_1, s_n) \Rightarrow \{s_0 \Rightarrow s_1, s_1 \Rightarrow s_0, s_0 \Rightarrow s_n, s_n \Rightarrow s_1, s_1 \Rightarrow s_n, s_n \Rightarrow s_0, s'_n \Rightarrow s_n\}. The dimming control strategy includes 7 kinds of control, such as: on, off, on dimming, dimming on, off dimming, dimming off and continuous dimming.
iv. Delay dimming control strategy: \[
(A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8, A_9, A_{10}, A_{11}, A_{12}), s_x, s_y \in (s_0, s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, s_9, s_{10}, s_{11}, s_{12}) \Rightarrow \{ s_0 \Rightarrow A_1, s_1 \Rightarrow A_2, s_0 \Rightarrow s_2, s_1 \Rightarrow s_3, s_2 \Rightarrow s_4, s_3 \Rightarrow s_5, s_4 \Rightarrow s_6, s_5 \Rightarrow s_7, s_6 \Rightarrow s_8, s_7 \Rightarrow s_9, s_8 \Rightarrow s_{10}, s_9 \Rightarrow s_{11}, s_{10} \Rightarrow s_{12}, s_{11} \Rightarrow s_{12}, s_{12} \Rightarrow s_n \} \].

The delay dimming control strategy includes 12 kinds of control, such as: on, off, on delay, on delay, off delay, off delay, repeated delay on dimming, on dimming, off dimming, off dimming, continuous dimming.

3.2. Energy Consumption Analysis

The energy consumption of simple control strategy and dimming control strategy is analyzed as follows:

i. Energy consumption of simple control strategy: only when the light is on, the power consumption can be expressed as follows:

\[
W = P_1 \times \sum t_{1i} \tag{5}
\]

ii. Energy consumption of dimming control strategy: the power consumption in all-optical and dimming States is different, and the energy consumption can be expressed as follows:

\[
W = P_1 \times \sum t_{1j} + \sum (P_n \times \sum t_{nk}) \tag{6}
\]

PN with P1 as 100% brightness can be abbreviated as:

\[
W = \sum (P \times \sum t_{xk}) \tag{7}
\]

3.3. Life Analysis

The following respectively analyses the life of simple control strategy and dimming control strategy:

i. Simple control strategy life:

\[
\begin{align*}
T &= \sum t_{0i} + \sum t_{1j} \\
L &= \sum t_{1j}
\end{align*} \tag{8}
\]

ii. Dimming control strategy life

\[
\begin{align*}
T &= \sum t_{0i} + \sum t_{1j} + \sum (P_n \times \sum t_{nk}) \\
L &= \sum t_{1j} + \sum (P_n \times \sum t_{nk})
\end{align*} \tag{9}
\]

Note: T is the actual use time of the lamp, and L is the ideal working time of the lamp provided by the manufacturer.

4. Green Control Algorithm

At present, most of the intelligent light sources have dimming function. Using the dimming function of the intelligent light source, complex green energy-saving control can be realized. green control strategy is shown in figure 4.
Intelligent control algorithm 1: \( s_0 \rightarrow s_1 \rightarrow s_n \rightarrow s_0 \)
Intelligent control algorithm 2: \( s_0 \rightarrow s_n \rightarrow s_1 \rightarrow s_n \rightarrow s_0 \)
Intelligent control algorithm 3: \( s_0 \rightarrow s_n \rightarrow t_x \rightarrow s_0 \)
Intelligent control algorithm 4: \( s_0 \rightarrow t_x \rightarrow s_n \rightarrow t_x \rightarrow s_0 \)
Intelligent control algorithm 5: \( s_0 \rightarrow t_x \rightarrow s_n \rightarrow s_0 \rightarrow t_x \rightarrow s_0 \)
Without considering the influence of LED switch on its life, the use cost of simple control can be described as the formula:

\[
C_0 = C_P \frac{T}{L} + W \times C_E
\]  

(10)

When the influence function of switch on lamp life is \( f(n) \), the simple control cost can be described as the formula:

\[
C_1 = C_P \frac{T}{L-f(n)} + W \times C_E
\]

(11)

Note: \( C_0 \) or \( C_1 \) is the use cost of LED, \( L \) is the service life, \( C_P \) is the purchase cost and \( C_E \) is the electricity fee.

The lighting time of the street lamp in my place is 18:00 ~ 06:00. Five 50W LED street lamps are selected for the experiment. Table 1 shows the average data comparison of actual control measurement of LED street lamps under different control algorithms in a week. It can be seen from table 1 that intelligent control algorithm can effectively save energy consumption. Although intelligent control algorithm 5 has a longer lighting time, it has a lower measured energy consumption due to power control and on-demand lighting.

**Table 1.** Comparison of different control algorithms

| No | Auto-Control Sensor | T (Lighting Hours) | W (Energy Consumption) |
|----|----------------------|-------------------|------------------------|
| 0  | No                   | -                 | 12                     | 600                     |
| 1  | Yes                  | √                 | 6                      | 241                     |
| 2  | Yes                  | √                 | 6                      | 246                     |
| 3  | Yes                  | √                 | 6.2                    | 234                     |
| 4  | Yes                  | √                 | 6.3                    | 232                     |
| 5  | Yes                  | √                 | 6.5                    | 228                     |

5. Conclusion

Compared with traditional lighting, LED lighting has the advantages of low energy consumption under the premise of ensuring the same lighting effect. At the same time, it also has the characteristics of rapid response of switch control and small impact of switch on-off on life. This paper studies how to use the characteristics of LED lighting through more effective control of lighting control strategy to further reduce energy consumption and improve the service life of LED lighting fixtures.

The specially customized LED lamp can also be dimmable. The following uses mathematical tools to study and analyse the control characteristics of different LED lights. Theoretical analysis shows that the dimming technology can maximize energy consumption while prolonging the service life of lamps and lanterns while meeting the needs of lighting. Green energy-saving control saves more than 50% of electricity compared with long-term lighting. The next step is to develop the street lamp system controlled by intelligent green algorithm.
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