Modeling of Lighting Load in Office and Living Area Based on Multi-region

Feng Jin¹,a, Li Kang¹,b and Biwu Hu¹,c

¹School of Electronic Engineering & Intelligentization, Dongguan University of Technology, Dongguan, China
Email: a362030890@qq.com; bqliguangbox@qq.com; c1966494413@qq.com.

Abstract. Driven by the third round of industrial revolution, the Power supply-distribution network-load connection has become more and more tight, and the development of microgrid has become an inevitable trend. It can supplement the shortage of large power grids in response to fragmentation load. The load characteristics under the power grid also play an extremely important role in the distributed system. Studying the load in the microgrid not only has a positive effect on the construction and planning of the microgrid, but also has a guiding role on the economic dispatch of the microgrid. The paper investigates the lighting situation in the office and living area, and divides the office and living area into multiple areas for detailed modeling. Firstly, the working time, building condition and lighting equipment in different areas were studied. Secondly, the probability model of the lighting load was established. Finally, Monte Carlo was used to establish the multi-area office and living park lighting load model.

1. Introduction

Countries around the world are taking measures to deal with the environmental pollution crisis and the challenges of sustainable energy supply in the future. The development of integrated energy is an important response in the context of the third industrial revolution, such as the comprehensive energy development plan proposed by the United States [1]. Canada [2] has enacted a number of bills to promote the development of integrated energy to achieve its 2050 emission reduction plan, and European countries [3] have also carried out related research. In the integrated energy system, the terminal link is an extremely important component. It includes: microgrid and regional integrated energy systems, which can handle fragmented loads well and can solve the problem of large grids. The problem is insufficient. However, with the increasing use of new energy power generation, these new energy sources bring challenges to the reliability, safety and economy of large power grids when they are integrated into the power grid, and the implementation of “source-load” coordinated scheduling is faced. One of the important measures of this challenge, the load studied is electric vehicle load, air conditioning load and lighting load.

With the development of social economy and the advancement of power electronics technology, the power of lighting equipment is getting larger and larger, and the total amount of power generated by lighting load is gradually increasing. So far, it accounts for 20%-25% [4-9]. Its influence on the operation of the power grid is also increasing. The paper [10-12] uses the lighting load as a controllable load, and analyzes the frequency modulation involved in the power system. The research shows that the flexibility and rapid response of the LED lighting load have great potential in this respect. In reference [13-14], authors analyzed the modeling of lighting load, and analyzed and designed the energy-saving control technology and control strategy of lighting load under the premise
of satisfying the lighting comfort of lighting equipment users. In reference [15], authors studied the differences in power quality characteristics between incandescent lamps, compact fluorescent lamps (CFLs) and LED lamps in terms of power and harmonics (including superharmonics), and established a circuit model. In reference [16], authors on life. Experimental studies have been carried out on common lighting equipment such as incandescent lamps, gas discharge lamps (electronic ballast fluorescent lamps, energy-saving lamps, inductive ballast fluorescent lamps, inductive ballast sodium lamps), and they have been established by least squares method. Static load model. In reference [17], authors established a circuit model for energy-saving lamps, metal halide lamps and LED lamps, focusing on its working principle. In reference [18], authors analyze the topology of new lighting equipment, introduce its working principle, and establish the corresponding simulation model. Finally, it verifies the new characteristics of lighting equipment and analyzes the necessity of modeling new lighting equipment. In reference [19-20], authors although the lighting equipment such as energy-saving lamps and LED lamps were also analyzed, the corresponding circuit models were not established, and the LED load was not discussed and model analysis. In reference [21], authors were used for four commonly used LED lights. The test was carried out under AC and DC, and the line loss, power factor and harmonic emission characteristics were studied. The AC constant power model of LED lamp was established. In reference [22], authors proposed a lighting load model based on illumination power density, using Monte Carlo calculation method to aggregate the random lighting load of working state, but this paper does not consider the impact of different people on the load, that is to say The author did not consider that the random opening time of lighting equipment is affected by the crowd, and the lighting time of different people is also different. The requirements for comfortable illumination are different in different places. In reference [23], authors takes the LED lamp load as a controllable load, studies the circuit model of the LED lamp, and analyzes the control strategy for controlling the frequency of the micro-grid by controlling the LED lamp. Although the load model of the lighting equipment is established in the above papers, most of them are to analyze the physical characteristics of the lighting equipment to establish the load characteristics of the lighting. This method is too demanding and the parameters required for modeling are too complicated. Although some papers have established lighting load models, they do not consider the impact of different areas on the lighting load, nor the impact of the building itself on the lighting load.

This paper focuses on the modeling and analysis of the lighting load of office and living area. Firstly, the office and living area are divided into three areas: living area, working area and school area. The living area is divided into one type of living area and two types; the school area also is divided into a teaching area and a residential area. Then analyze the factors affecting the lighting load of each area, and the factors affecting the LED light load can be divided into: illuminance level, human factors, and lighting time, number of LED lights, duration of lighting, and establish the probability model of its influencing factors. Finally, the Monte Carlo calculation method is used to model the LED lamp load. The next work arrangement of the thesis is as follows: Chapter 2 is the division of office and living area and the probabilistic modeling of influencing factors; the third chapter is to construct the specific method of Monte Carlo to establish the lighting load of office and living area, and case analysis; Chapter, summarize the paper.

2. Office and Living Park Area Division and Impact Factor Modeling

2.1. Office and Living Area Division

2.1.1. Living area. The paper divides life into the first type of living area lighting load and the second type of living area lighting load. The specific division is based on: all working outside (no one in the room during work) and some outside or not working outside (there are people in the room during work), here The housing areas that are all working outside are defined as a type of living area, and the part of the housing area that is partially or not working outside is defined as a second-class living area. The lighting load of the second type of living area is basically only related to the illuminance level, and the lighting load of the living area of one type is greatly affected by the company's working time schedule, and also depends to some extent on the illuminance level.
2.1.2. Work area. The living habits of most work areas are 9:00 am to 5:00 pm, and the LED lights are generally on during work, and are basically not affected by the illumination level.

2.1.3. School area. The living habits of the school teaching area are related to the school’s prescribed class time. Generally speaking, the class time is daytime, and the class is basically not in the evening (ignoring a small part of the evening self-study); the living time of the school dormitory area is basically complementary to the teaching area, and The LED light load in the teaching and dormitory areas is affected by the level of illumination.

2.2. Influencing Factors

2.2.1. Illumination level. It can be said that in most cases, the illuminance level of the room (that is the indoor brightness is often said) is the decisive factor for turning on the light, and the illuminance level is related to two factors, one is the "light generator". That is what we call “light source”. The other is the "receiver of light", which is the acceptance surface (also called the interface) of each light in the room. The former depends on the weather, and the latter depends on the indoor lighting material (light-transmitting material, non-light-transmitting material). Different regional rooms have different standard critical illuminances. When indoor lighting is lower than the standard critical illuminance, it is necessary to turn on the lighting equipment to increase the indoor brightness.

Assuming that the illumination of the outdoor lighting point is the same, the calculation of indoor lighting is as shown in equation (1):

$$C = \frac{E_n}{E_w} \times 100\%$$

Where: $C$ indicates the daylighting coefficient, $E_n$ indicating the indoor illuminance at a certain point, $E_w$ indicating the illuminance of the entire outdoor.

Therefore, equation (1) can be transformed into equation (2):

$$E_n = C \times E_w \times 100\%$$

The value of the $C$ in the formula: has different values in different housing areas According to the “House Design Code”(GB 50096-2011), the lighting coefficient of the general staircase aisle is not less than 0.5%, and the bedroom, living room, kitchen, etc. The lighting requirement is higher, the value is generally not less than 1%, and the lighting requirements in the workplace are more precise, and the coefficient is within 5%-10%.

For the lighting situation of the living area, it is more seriously affected by light. It can also be said that whether the light is turned on or not is closely related to the light. When the illumination level is lower than the critical level, people need to turn on the lighting device to enhance the illumination. For the work area, it is basically in the normally open state regardless of the light. The influencing factors of the light-on are only related to the company's prescribed work and off-duty hours. The school's teaching area has a shallow relationship with light. The illumination of the light is much higher than that of the general living area. It can be expressed by the lighting coefficient. When the illumination level is lower than the critical illumination, people need to turn on the lighting equipment to enhance the illumination. The dormitory area of the school has a strong relationship with light. When the illumination level is lower than the standard, people need to turn on the lighting equipment to enhance the illumination. The second edition of the Lighting Design Handbook and the Architectural Lighting Design Standards--GBT-50033-2001 propose standard illuminance values for each building, as shown in Table 1 below:
Table 1. Standard illuminance and critical illuminance tables for each region

| area                  | Standard illumination(lx) | Critical illuminance(lx) |
|-----------------------|----------------------------|--------------------------|
| Work area             | 300                        | 100                      |
| Living area           | 100                        | 50                       |
| School teaching area  | 300                        | 100                      |
| School dormitory area | 100                        | 50                       |

2.2.2. Human factors. When the illuminance does not satisfy the comfortable illumination, whether there is someone in the room is another important factor. This is the so-called human factor, and the human factor mostly depends on people's life, so this kind of human factor can be used by people. According to the law of work and rest, this paper will fully consider the impact of human factors on the lighting load in the work area, living area, school teaching area and school dormitory area. The human factor is approximately normal distribution, and its probability density expression is as follows (3):

\[
f(t_r) = \frac{1}{\sqrt{2\pi\sigma_{t_r}}} \exp\left[-\frac{(\ln t_r - \mu_{t_r})^2}{2\sigma_{t_r}^2}\right]
\]

Where: \(t_r\) indicates the human factor; \(\mu_{t_r}\) indicates the expected value; \(\sigma_{t_r}\) indicates the variance.

2.2.3. Number of lights in the lighting unit.. The paper uses the number of rooms as the minimum unit, and the number of LED lights in the room depends on the average illuminance of the entire room. According to formula (4), the average illuminance of each room can be obtained.

\[E_{av} = LPD \times \eta \times U \times K\]

Where: \(E_{av}\) indicates the average illuminance; \(LPD\) indicates the illumination power density; \(\eta\) indicates the luminous efficiency; \(U\) indicates the utilization of the LED lamp; \(K\) indicates the maintenance factor of the selected room.

\[LPD = \frac{N \times P_l}{A}\]

Where: \(N\) indicates the number of lights; \(P_l\) indicates the power of the selected fixture; \(A\) indicates the area of the selected room.

It can be seen from equations (4) and (5) that the number of lamps is proportional to the room area. According to the “Office Building Design Code”, the area of the office room is assumed to be 70 square meters, the general housing area is 60 square meters, the classroom area is 80 square meters, and the dormitory area is 30 square meters; the maintenance factor of the room is 0.7; the luminous efficiency is 0.8, the store's The maintenance factor is 0.7; the luminous efficiency is 100; the utilization factor is 0.4; the power of the LED lamp is 64W; according to Table 1, the number of LED lights in each room can be obtained, and the office room has 10 LED lights, and the living room room There are 3 LED lights inside, 12 LED lights in the classroom, and 2 LED lights in the dormitory.
2.2.4. Turn off the light time. As far as working days are concerned, the time of turning off the lights in the work area is related to the time of work. When the overtime is not considered, the lights in the work area are usually turned off at around 5 o'clock, and the school teaching area is also the same. Next, turn off all the lights around 5 o'clock. The school dormitory area considers the school’s working schedule. Take the general colleges and universities as an example. It is required to turn off the lights at 11:30, and the lighting time in the living area is basically concentrated at 9 o'clock. The above turn-off time is normally distributed, and its expression is as follows:

$$f(t_g) = \frac{1}{\sqrt{2\pi}\sigma_{t_g}} \exp\left[-\frac{(\ln t_g - \mu_{t_g})^2}{2\sigma_{t_g}^2}\right]$$  \hspace{1cm} (6)

Where: \(t_g\) indicates the light-off time; \(\mu_{t_g}\) indicates the expected value of the light-off; \(\sigma_{t_g}\) indicates the variance value of the light-off.

2.3. Description of Lighting Load

According to the descriptions of (1) to (4), the probability that the illumination switch is turned on at a certain time can be described by the following expression.

$$F(t) = 1 - F(t_0 > t & t_0 + T \leq t + 24) - F(t_0 + T \leq t)$$  \hspace{1cm} (7)

Where: \(F(t)\) indicates the probability of turning on the light at time \(t\); \(t_0\) indicating the time of turning on the light; \(T\) indicating the duration of the light-on, \(T = t_g - t_0\); which \(t_g\) is the time for turning off the light; and the sum are independent of each other.

The lighting time is affected by the level of illumination and human factors. The expression is as follows:

$$F(t_0) = \begin{cases} 1, & E_n < E_h & \text{and } t > t_r \\ 0, & \text{其他} \end{cases}$$  \hspace{1cm} (8)

Where: \(E_n\) indicates the indoor illuminance level; \(E_h\) indicates comfortable illuminance.

3. Monte Carlo-based Lighting Load Model

3.1. Specific Modeling steps

1) Initialize \(i\) (\(i\) is the number of simulations, \(i=1 \cdots M\)).

2) Initialize \(j\) (\(j\) is the number of lighting units, \(j=1 \cdots N\), with one room lighting as a single unit).

3) Differentiate the type of selected room. This article selects 4 categories for analysis (living area, working area, school teaching area, school dormitory area).

4) The human factor is derived by formula (3).

5) The time to turn off the light is obtained by the formula (6).

6) Determine whether the human factor is met, that is, whether it is established, if it is established, proceed to the next step, otherwise return to (4).

7) Determine whether the illumination requirement is met. If yes, proceed to the next step, otherwise return to (4).

8) After the(4) and (5) are met, the light-on time can be output.

9) Superimpose the daily load of all individual lighting.

10) Determine whether the load overlay calculation is completed. If \(j=N\), it means that the load calculation is completed, otherwise \(j=j+1\), return to (4).
11) Determine if the simulation is over. Whether i is equal to M, if i=M, it means completion, otherwise i=i+1, return to (2).
12) Take the average of the last obtained matrix, which is the power level. t

The lighting load modeling flow chart is shown.

![Lighting load calculation flow chart](image_url)

**Figure 1.** Lighting load calculation flow chart

### 3.2. Case Simulation Analysis

Assume that there are 10,000 lighting units in the living area, and living areas account for 60%, of which one type of living area accounts for 80% of the living area, the second category accounts for 20%; the work area accounts for 30%; the school teaching area accounts for 3%; The district accounts for 7%. According to the survey and analysis, the expected values of human factors in the living area (part of the working class), dormitory areas and classrooms are shown in Table 2. The time for turning off the lights in each area is shown in Table 3.

| area                        | Expected value | variance |
|-----------------------------|----------------|----------|
| a type of living area       | 17.00          | 0.66     |
| Work area                   | 8.39           | 0.37     |
| School dormitory area       | 17.47          | 3.41     |
| School teaching area        | 8.39           | 0.37     |
Table 3. Light off time in each area

| area                        | Expected value | variance |
|-----------------------------|----------------|----------|
| a type of living area       | 21.39          | 0.61     |
| Work area                   | 17.47          | 3.41     |
| School dormitory area       | 23.01          | 0.61     |
| School teaching area        | 17.47          | 0.37     |

The Monte Carlo calculation can be used to obtain the lighting load curve as shown in Figures 1 to Figures 6.

As can be seen from Figure 2-3, the lighting load of the living area is basically concentrated at 18:00-23:00. The load curve of the first-class living area is very fast after 18 o'clock, but it still has a certain slope. The load curve of the second-class living park increased linearly after 18 o'clock, because the weather selected in the paper did not meet the illumination level after 18 o'clock.
Figure 4. Work area lighting load curve

Figure 4 shows the lighting load curve of the work area. The load is basically maintained from 9:00 to 17:00, which basically conforms to the lighting law of the work area.

Figure 5. School teaching area lighting load curve

Figure 5 - 6 shows the lighting load in the school district. The load in the school teaching area is basically maintained from 8:30 to 17:30, which basically meets the teaching time of the school. The load in the dormitory area is maintained from 19:00 to 22:30 which is basically in line with the student's work schedule law.
4. Conclusion
This paper models the lighting load of office and living parks. First, it divides the office and living park into two areas, which are divided into living area, working area and school area. The living area includes a living area and a second-class living area. The school is divided into a school teaching area and a school dormitory area, which are generally divided into five categories. Then, the influencing factors of the lighting load are modeled, including the illumination level, human factors, the number of lighting equipment, the lighting time, and the lighting time. The factors that determine the lighting time are analyzed and modeled. Finally, Monte Carlo is used to construct the simulation method. The case shows that the lighting load curve obtained by the paper method basically meets the actual living conditions.

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