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Application Strategy of PLC Technology in Energy-Saving Control of Tunnel Lighting

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Abstract: In this study, we investigated on the application of planar lightwave circuit (PLC) technology in energy-saving control of tunnel lighting. The application status of PLC in the field of energy saving followed by the necessity of energy saving in tunnel lighting was analyzed. Finally, the application of PLC in tunnel lighting energy-saving control around the three dimensions of system overall architecture design, control scheme, and program control process was investigated. The results showed that the system meets the requirements of control effect, robustness, and visual effect after trial operation, and is suitable for practical applications.

Keywords: Energy-saving tunnel lighting; PLC technology; Control scheme; Program control

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1. Introduction

Tunnel lighting plays an important role in the transportation system, but traditional tunnel lighting equipment like high-pressure mercury lamps has high energy consumption. This is traditional lighting uses electrical energy, and tunnel lighting works for long periods, and the energy consumption is much higher especially at night. At the same time, traditional lighting equipment is not controllable or intelligent, so the lamps cannot be controlled according to lighting requirements. In addition, traditional lighting equipment also has defects such as short service life, low color rendering index, and susceptibility to temperature changes, which requires continuous replacement and maintenance, which is also an important factor of energy waste. These problems lead to high energy consumption of tunnel lighting, difficulty in automatic and effective control, and high operation and maintenance costs. Therefore, exploring how to realize tunnel lighting energy saving based on PLC has important research value for promoting the sustainable development of tunnel lighting system.

2. Application status of PLC in the field of energy conservation

Planar lightwave circuit (PLC) is a programmable logic controller, which is a computerized control system specially used for automation and control of industrial machinery. PLC is widely used in the field of energy saving. For example, PLC can be used to control air conditioners and lights, cleaning systems according to environmental conditions, compressors, and conveyor belts, etc., so as to achieve the goal of energy saving and emission reduction.

In the automation and control of industrial machinery, the PLC system can be integrated with other systems through the network to realize data sharing and remote control. Through the data collection and analysis by the PLC system, enterprises can realize automatic control, optimize energy use, reduce production costs, etc. PLC is widely used in the manufacturing industry, which promotes the development of the manufacturing industry. For example, in the automotive industry, the PLC system can achieve a uniform production speed by controlling the machinery, thereby avoiding wastage. In the textile industry, PLC systems can reduce energy consumption and material waste by controlling the speed of machines. In the metalworking industry, energy consumption and material loss during cutting can be reduced by controlling the speed and temperature of machine tools. In addition, the PLC system also widely applied in the fields of ships and buildings. For example, in the shipping industry, the PLC system can measure multiple parameters such as the wind speed, the depth of the waters, and the ship's center of gravity, and control parameters such as direction and speed of the ship accordingly to achieve efficient use of ship fuel. In the field of construction, the PLC system controls the heating, ventilation, and air conditioning, and other systems in the building to achieve the goal of saving energy, protecting the environment, and reducing the energy consumption of enterprises [1].

The application of PLC in the field of energy-saving is constantly growing, which provides strong support for enterprises to save resources, reduce environmental pollution, and improve economic benefits.

3. Necessity of saving energy in tunnel lighting

Energy consumption figures for tunnel lighting vary depending on different factors such as tunnel length, type of tunnel lighting fixtures, and operating hours of tunnel lighting. Generally speaking, the power of traditional tunnel lighting equipment such as high-pressure mercury lamps is generally between 250 W and 400 W. When the equipment works all night, the energy consumption of a tunnel will reach more than several thousand kWh. For example, a tunnel with a nominal length of 4.5 kilometers is illuminated by high-pressure sodium lamps with a power of 275 W. The tunnel works 18 hours a day and consumes 2,308,457.8 kWh of electricity per year. This shows that the energy consumption of tunnel lighting is massive in the urban traffic system.

Therefore, research was carried out on energy-saving measures for tunnel lighting. In view of globalization, the imbalance between supply and demand of energy resources is becoming increasingly prominent. Energy conservation and consumption reduction are important measures to overcome energy depletion, ensure energy security, and stabilize economic and social development. Energy conservation through tunnel lighting can contribute to alleviating energy pressure. Secondly, energy-saving tunnel lighting technology can reduce the cost of tunnel operating enterprises. If new energy-saving tunnel lighting equipment is used, the cost of enterprises can be reduced and the competitiveness of enterprises can be enhanced. Thirdly, tunnel lighting technology helps to promote environmental protection. Research and promotion of tunnel lighting energy-saving technology can reduce energy waste, carbon emissions, environmental pollution, and ecological damage, promote environmental protection, and achieve harmony between man and nature [2].

4. Application strategy of PLC technology in tunnel lighting energy-saving control system

4.1. Construction of a PLC-based tunnel lighting energy-saving control system

A PLC-based tunnel lighting control system uses PLC as an actuator to control the brightness of the lamps in the tunnel, which achieves intelligent control of the tunnel lighting equipment.

First, data in the tunnel will be collected by sensors. In the PLC-based tunnel lighting energy-saving control system, multiple sensors will be installed in the tunnel during the layout stage to collect real-time data of the environment in the tunnel, such as illuminance and vehicle information. The collected data will then be transmitted to the central processor through the signal transmitter for processing [3]. The central processor processes the data according to preset rules and parameters, and performs real-time monitoring and control according to the traffic flow and brightness in the tunnel. Then, the PLC will automatically control the brightness and number of lamps in the tunnel accordingly in real time, which ensures the brightness and flexibility of tunnel lighting. **Figure 1** shows the architecture of this PLC-based tunnel lighting energy-saving control system.

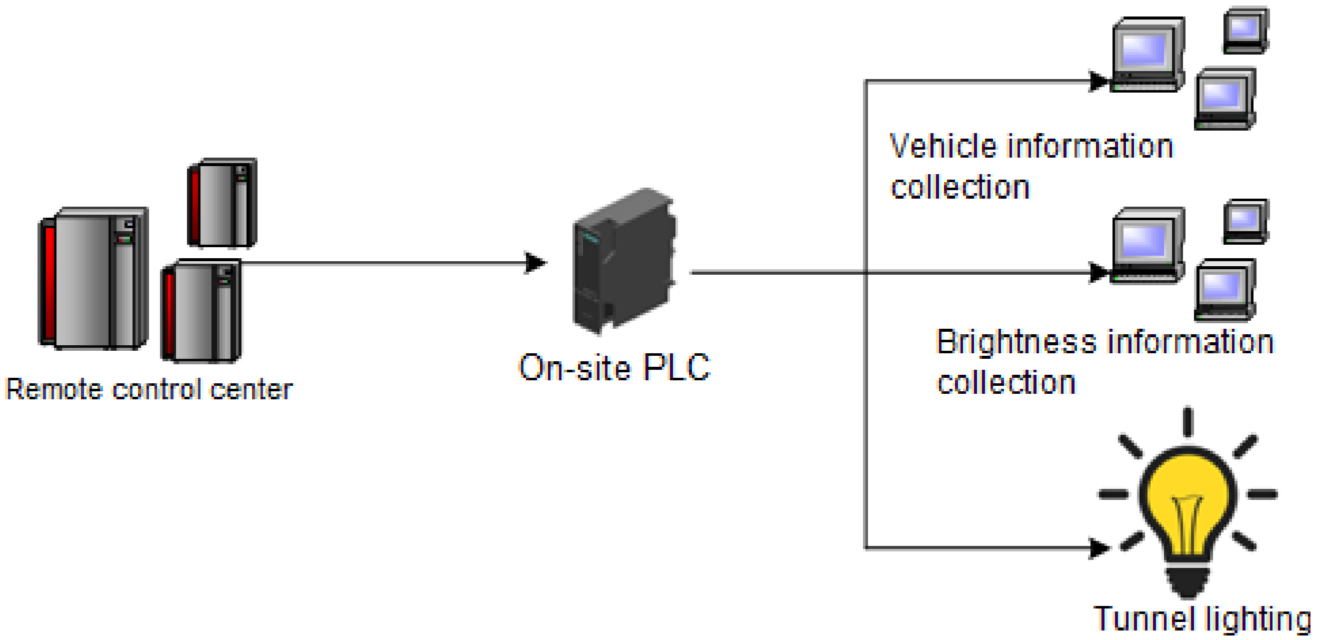

Figure 1. PLC-based tunnel lighting energy-saving control system architecture

During the signal output, the PLC central processor will output the corresponding signal after processing the sensor data to control the brightness of the lamp. The remote-control center acts as the host to collect various data instructions from the PLC control system in the tunnel, analyze and process them, and send instructions to the PLC control system in the tunnel remotely through the network.

4.2. Control plan

4.2.1. System control

In the PLC-based tunnel lighting energy-saving control system, vehicle information will first be collected from the sensors installed in the tunnel that will detect the number of vehicles passing through. After collecting vehicle information, the lighting will automatically adjust by a central processor. Besides, this system also includes detectors to detect the illuminance and brightness of the tunnel lighting at all times. The collected data is transmitted to the PLC central processing system for processing, and the brightness and number of lamps in the tunnel will then be automatically adjusted according to preset rules and parameters, so as to achieve the optimum brightness, energy consumption, and reliability of the tunnel lighting system. In terms of energy-saving, the PLC central processor automatically controls the number of lamps in the tunnel that should be turned on with high brightness, low brightness, or turned off according to the collected data. The signal will then be transmitted to the lamp controller to drive the brightness and color temperature of the lamps to ensure optimum brightness and color temperature of the lamps, so as to visual comfort and energy efficiency [4].

The PLC-based tunnel lighting energy-saving control system involves three layers of software. The first layer is the main control program layer, which is responsible for executing the main loop program and controlling the entry 41 and start flag of the subroutine. The second layer is the “common control mode” layer, which is responsible for executing the tasks required by the PLC system under normal circumstances, including information transmission under normal conditions, on-site lamp communication, etc. The third layer is the "special control mode" layer, which allows PLC to communicate with other devices under special circumstances.

4.2.2. System control logic

This PLC-based tunnel lighting energy-saving control system is designed to adjust the lighting in the tunnel as a normal control mode and a special control mode.

The ordinary control mode involves conventional lighting control on the tunnel lamps, the weather and traffic conditions will be monitored in real time. Besides, the temperature, humidity, rain, snow, and other weather factors inside and outside the tunnel, and the traffic flow in the tunnel can also be monitored in real time using sensors or other equipment. The light intensity will be adjusted based on weather and traffic conditions [5]. For example, the light brightness can be lowered in sunny day at night and when there are few vehicles to save energy; in rainy and snowy weather or nights when there are many vehicles, the brightness of the light can be increased to improve traffic safety.

In addition to adjusting the brightness of the light according to the weather and traffic conditions, it is also possible to turn the lights on and off through the PLC system. For example, turning on high-brightness lighting during morning and evening peak hours and late evening hours, and using low-brightness lighting at ordinary times. In addition, the system has a fault alarm function in normal mode. When a lamp or controller fails, a fault alarm signal will be sent by the system for timely maintenance and repair.

The special control is mainly designed for emergencies where the host computer disconnects from the PLC, and the lighting equipment in the tunnel will be controlled according to the preset program [6]. There are four steps involved in the special control mode. (i) When the host computer disconnects from the PLC, the personnel at the workstation manually check whether there is a physical connection failure between the PLC and the computer. If a physical connection failure is detected, the connection failure shall be repaired as soon as possible. If no physical connection fault is detected, Step 2 is applied. (2) The system will send a query command after a set period of time, and then wait for a reply. If a reply message is received, it means that the communication between the computer and the PLC is normal, and lighting control can be continued; if no reply message is received, Step 3 is applied. (3) The system will send a second query command after a set period of time, and then wait for the reply message. If a reply message is received, it means that the communication between the computer and the PLC has returned to normal, and the lighting control can be continued. If there is still no reply message, Step 4 is applied. (4) At this moment, the PLC will judge that the computer has been disconnected and perform, automatic lighting control on different sections of the tunnel according to the preset program.

Through the implementation of the steps above, the normal operation of the PLC-based tunnel lighting energy-saving control system can be guaranteed even when the computer is disconnected from the PLC. At the same time, in terms of energy-saving control, the lighting control strategy should be evaluated even after it is put into use, so as to improve energy efficiency and save resources.

4.2.3. Program control process

Based on the functions and working principle this tunnel lighting energy-saving control system design, the specific program control process is designed into nine modules, as shown in **Figure 2**.

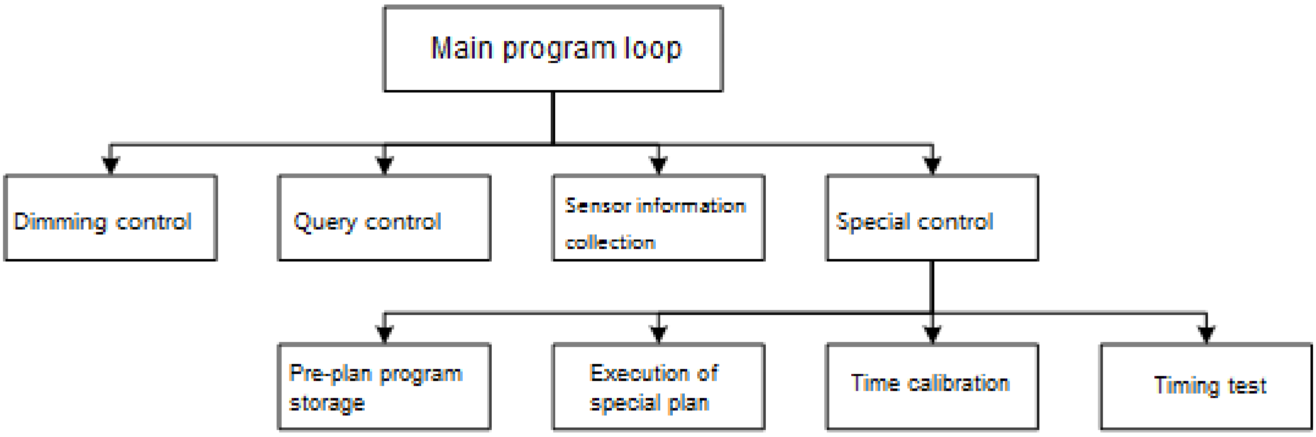

Figure 2. Program control flow

As shown in **Figure 2**, the main program loop is the most basic program in the PLC, and it is also the core of the control program, which is mainly responsible for the overall control of the tunnel lighting. This program includes basic functions such as adjusting the brightness of the tunnel lights and detecting faults through continuous loop operation [6]. Secondly, in terms of the dimming function, the brightness of the lights needs to be controlled according to different situations to achieve the purpose of saving energy and reducing consumption. The dimming control program adjusts the brightness of the lights in real time according to the information obtained by the main program loop. Third, the sensor information acquisition program is responsible for obtaining real-time data such as weather, traffic flow, and brightness from the sensor, processing it through the main program loop, and transmitting it to the dimming control program, which plays an important role in real-time adjustment of the lighting brightness in the tunnel [7]. Fourthly, the timing test program can detect the fault points in time when the PLC experiences failures by testing and checking the internal hardware and software systems, which will reduce the duration of system failure and ensure the safe and stable operation of the system. Fifth, under the special control program, when the PLC core controller receives the special case keyword, it will automatically activate the special control program stored in the system table and enter the third-level program under the control flow [8]. Sixthly, the query control program is used to query the status of various equipment and sensors. In the query control program, the status of the dimming controller or other equipment status will be monitored. This method can not only monitor the working status of each device in real time, but also provide real-time data for use by other control programs. For example, whether the brightness value of the lighting component has reached the preset value; if not, one of the subsequent control programs will control the lamps accordingly [9]. Seventh, the function of the time calibration program is mainly to send an instruction to calibrate the time to the clock controller in the PLC. The time calibration program can ensure the accuracy of the internal time of the PLC system by sending time correction instructions to the PLC regularly. At the same time, the time calibration program can also automatically correct the timing inside the PLC system to avoid the impact of some unexpected conditions on the system's timing, such as power failure.

5. Conclusion

After the design is completed, this set of PLC-based tunnel lighting energy-saving control system can be applied to a completed and open-to-traffic tunnel. In terms of lighting control, the system can control the brightness of the lighting equipment in the tunnel in real time according to the weather and the traffic flow in the tunnel. In terms of robustness, the system can still operate normally under severe weather conditions, which makes it highly reliable. In terms of visual effects, the lighting in the tunnel will have a good visual effect under the control of this system, which ensures the visual comfort of drivers. Therefore, it can be concluded that this system can operate efficiently and stably, can meet the energy-saving control requirements of tunnel lighting, and has practical application value.

Disclosure statement

The author declares no conflict of interest.

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