Research on Power Line Carrier Communication Based on HVDC

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Abstract. This paper mainly studies the control of LED lamps under the condition of centralized DC power supply by power carrier mode, and modifies the mature power carrier scheme in AC system to adapt to the DC system environment and realize reliable communication in DC system. Through the analysis of system functional requirements and the comparison of existing communication technologies, the overall architecture of DC tunnel lighting system is proposed. The system adopts two-tier structure, including monitoring center, communication controller and HVDC tunnel lighting control terminal. This system realizes the master-slave monitoring of the communication controller to the control terminal of HVDC tunnel lamps, and puts forward the modification scheme to the conventional power carrier scheme, and verifies the improved power carrier scheme of DC system through the Qijiashan tunnel lighting project.

Keywords: DC power supply, power line carrier communication, intelligence.

1. Introduction

In the early days, LED was controlled by switching on and off the power supply, and then there was a dimming power supply. By connecting the dimming power supply with external dimming, the output current of the power supply was controlled to achieve the effect of adjusting LED brightness [1]. In practical engineering, the power carrier scheme is practical. Its principle is to modulate the data into high frequency signal, and then load it to the power line, so as to transmit it to the whole line. In this way, the power supply on each lamp can demodulate the signal, so as to realize communication. Different from simple dimming, power carrier can realize two-way communication, that is, it can send dimming command to lamps, and obtain operation data and status from lamps, so as to realize intelligent control [2]. Although the power carrier scheme has been relatively mature in the AC system, the DC system has different characteristics from the AC system, so it is necessary to study whether the existing scheme can adapt to the DC system, and if not, how to make changes.

At present, most of the tunnel lamp systems in China have the following problems:

(1) Simple management: the lighting and extinguishing of tunnel lights are basically controlled by PLC timing, which has low level of automatic management and can’t control the tunnel lights intelligently.
(2) Inconvenient control: insufficient control ability, unable to flexibly adjust and modify the light on/off time according to the actual situation, such as the change of external illumination.

(3) Unclear lamp condition: under the existing conditions, the main way to understand the working state of tunnel lamp is regular manual inspection. This method not only wastes a lot of human and material resources, but also can not accurately grasp the operation of each tunnel lamp in real time.

The research content of this paper is to carry out power carrier communication with HVDC as the carrier. We need to get the communication rate, signal attenuation rate and other indicators, and compare with the common power grid carrier communication scheme [3]. At the same time, through the research on intelligent control of lamps and lanterns, the application scheme of laying cables, saving electric energy and improving lamp life under HVDC lighting system is proposed to improve the intelligent level of tunnel.

2. Put forward the overall design scheme of the system

2.1. Power line carrier communication technology
Power line carrier communication technology is a kind of communication technology for signal transmission through power line network. Power line carrier communication rate is affected by many factors, such as the specific equipment and modulation method. By using spread spectrum, frequency selection, adaptive modulation and relay technology, the problems of noise interference and signal attenuation in the transmission process of power line carrier are basically solved. Through the comparison of the above communication technologies, it is not difficult to see that in the specific application of tunnel lamp monitoring system, the low-voltage power carrier communication technology has the following advantages compared with other communication methods:

(1) Price advantage: power line carrier communication uses power line as carrier, no need to lay additional broadband and optical cable lines, low cost and short construction period.

(2) Advantages: when the device is connected to the power supply, the device is connected to the power carrier communication network.

(3) High coverage: the power network has high coverage and is not affected by the wiring and wireless environment. In addition, the power line carrier communication is applied to the tunnel lamp monitoring system, the anti-interference ability and communication rate can also meet the needs of tunnel lamp monitoring.

2.2. Selection of system scheme
The scheme adopts Ethernet technology and power carrier communication technology to design the tunnel lamp monitoring system, which is divided into three layers: tunnel management office, tunnel lamp centralized controller and HVDC tunnel lamp control terminal. The tunnel lamp centralized controller includes Ethernet interface, power carrier communication module and carrier modulation module [4]. The tunnel management office is connected with the tunnel lamp centralized controller through Ethernet, and the communication between the tunnel lamp centralized controller and the HVDC tunnel lamp control terminal is carried out through the power carrier network. The scheme adopts Ethernet technology to realize remote data transmission, and realizes the control of tunnel lamp through power carrier communication technology, which has the characteristics of no additional wiring, long transmission distance, high data transmission rate and low cost [5]. Based on the comprehensive comparison of the above three schemes, considering the cost of system development, data transmission rate and reliability, this paper adopts the third scheme to design the tunnel lamp monitoring system [6].

It can be seen from the above comparison project that the tunnel lamp scheme using Ethernet technology and power line carrier communication technology has the following advantages:

(1) The cost of a single intelligent tunnel lamp ballast is low.

(2) The communication between tunnel lights is stable.

(3) The area controller supports multiple WAN connections.
(4) The monitoring center software has a ready-made scheme which has been verified by a large number of application cases, and also supports the independent research and development of customers.

(5) It does not occupy the radio frequency resources.

3. Similarities and differences of power carrier in AC / DC system

The power carrier scheme in AC system is relatively mature [7-8], and its simplified schematic diagram is shown in Figure 1.

In Figure 1, TS is the AC side transformer, which is the power supply of the whole AC system, and its output impedance is inductive; R, l, C are the distributed impedance of the power supply line. T1 and C1 are the power carrier coupling circuits on the power supply side. The primary side of T1 is a small signal high frequency carrier signal, which is isolated by the 1:1 transformer T1 and then transmitted to the secondary side, which is connected to the power supply line through the capacitor C1. At the same time, capacitor C1 has low impedance to the high frequency signal on T1, which is close to short circuit. Therefore, the high frequency carrier signal loaded on T1 can be loaded on the power supply line almost losslessly. T2 and C2 are coupled circuits, and their working principle is exactly the same as T1 and C1. The interface components between AC / DC circuit and power supply circuit are series inductor Lin and parallel capacitor CIn. Lin is the differential mode inductor at the input end of AC / DC circuit, CIn is the X capacitor at the input end of AC / DC circuit. Lin and CIn are used to filter the high-frequency current caused by high-frequency switch in AC / DC circuit.

When the power supply and driving power are changed to DC, the parameters of power supply line do not change, but the impedance of power supply and driving power change. The output of the power supply is DC, which is usually a large electrolytic capacitor at the output end. The input end of the driving power supply is also a large electrolytic capacitor. If the power carrier circuit in AC system is directly connected without any modification, the output and input capacitance of power supply and driving power supply are equivalent to short circuit for high frequency power carrier signal, so the signal can’t be transmitted in the power supply line. In order to ensure the normal transmission of signal, the system impedance must be adjusted properly. The transformed DC system with power carrier is shown in Figure 2.
Figure 2 Schematic diagram of DC system power carrier scheme

The gray part in Figure 2 includes the DC main power supply on the left and the drive power supply on the right. The yellow part refers to the components added according to the characteristics of DC system. L1 is an inductor connected in series between the DC main power supply and the power supply line, which is used to block the high frequency carrier signal and prevent the signal from entering the output capacitor Cout of the DC main power supply. Lin is an inductive element added in the driving power supply to block the high frequency carrier signal and prevent the signal from entering the input capacitor Cin of the driving power supply. After adding L1 and Lin, the application effect of power carrier in DC system is consistent with that in AC system.

4. Implementation of power line carrier in DC system
In the AC system, there are two implementation schemes of power carrier. One is the scheme of single lamp controller, which connects a single lamp controller to each driving power supply. The single lamp controller is integrated with power carrier communication module, which is responsible for the dimming control and data acquisition of the driving power supply. The other is the scheme of power carrier communication module built in the driving power supply the wave module is directly integrated into the driving power supply. The advantage of scheme 1 is low R & D cost. It only needs to connect a single lamp controller outside the conventional dimming power supply. The disadvantage is that the cost is high, and the price of single lamp controller may be more expensive than the driving power supply. The advantage of scheme 2 is high integration, low product price, and the disadvantage is high R & D cost. In order to carry out power carrier communication, all driving power supplies need to be redeveloped.

At present, the system using power carrier communication in the market mainly adopts the single lamp controller scheme, only Maoshuo power has introduced the power supply with built-in power carrier.

The research and development cycle of power supply with built-in power carrier is long, and the research and development cost is high. Because the main focus of this paper is DC power supply, the power carrier is only to verify whether it can work normally in DC environment, so the scheme of built-in power carrier is not adopted, but the scheme of single lamp controller is selected as the same as most systems.

The core component of single lamp controller is a power carrier chip, as shown in the red part of Figure 3, which realizes the basic functions of signal modulation and demodulation, which is the core technology of power carrier. The chip design companies include Riscom in China and Yamar in foreign countries. At the periphery of these companies, there are also some solution providers, such as Shenzhen Huazhi and Zhilian Xintong. Their work is to design the circuit module of the whole power carrier function with ready-made chips, that is, the power carrier module, as shown in the yellow part in Figure 3. At the same time, the module design company can design some dimming control and...
signal acquisition circuits around the module to form a single lamp controller, as shown in the green part in Figure 3. It can also provide the module to the power company, so that the power company can integrate the module into the driving power supply to form a driving power supply with built-in power carrier.

![Figure 3 Structure diagram of single lamp controller](image)

As the main focus of this project is to verify the application of power carrier, rather than developing the corresponding power carrier products, power carrier is not the focus of this project, so it is not allowed to spend too much time and money on power carrier, so the strategy is to cooperate with power carrier module company to modify the existing products.

The selected partner is Zhilian Xintong. They have off the shelf single lamp controllers for AC systems. It only needs to modify the power input interface of single lamp controller slightly without modifying the power carrier module. The principle block diagram of single lamp controller and driving power supply in the system is shown in Figure 4.

![Figure 4 Schematic diagram of single lamp controller and driving power supply](image)

In order to minimize the part of customized design, this paper selects the single lamp controller of Zhilian Xintong which needs external control power supply, and provides control power through the drive power supply. For this reason, the driving power supply is modified in two ways:

1. A 15V / 6W regulated power output is added to provide control power for single lamp controller;
2. A differential mode inductor is added at the input end of the power supply to ensure the normal transmission of power carrier signal in the power supply line.

At the same time, Zhilian Xintong is required to modify the single lamp controller as follows:

1. The parameters of coupling circuit components are modified to adapt to DC high voltage input;
(2) Modify the parameters of data acquisition circuit components to adapt to the DC high voltage input.

In the process of implementation, limited by the schedule and funds, what Zhilian Xintong has actually done is to modify the parameters of the coupling circuit components to adapt to the DC high voltage input, and remove the data acquisition circuit, so as to remove the function of data acquisition.

At the same time of providing single lamp controller, we need to customize a centralized controller suitable for HVDC system through Zhilian communication, and provide a set of corresponding upper computer software for this subject to monitor all single lamp controllers. The software part of the upper computer has nothing to do with the DC power supply system, and belongs to the mature product before Zhilian communication. Because the single lamp controller has no data acquisition function, the upper computer software cannot display the system operation data accordingly.

The schematic diagram of HVDC power supply system to realize power carrier is shown in Figure 5.

![Figure 5 Schematic diagram of HVDC system for power line carrier](image)

The green parts in Figure 5 include the centralized DC power supply and the DC drive power supply at the lamp end. Compared with the power supply without power carrier, the DC power supply adds a differential mode inductor on the output side of the power supply. Compared with the power supply without power carrier, the DC drive power supply adds a differential mode inductor at the input end of the power supply and a set of control circuit with single lamp controller interface. The driving power is no longer directly from the DC bus, but connected in series behind the single lamp controller, which supplies power to the driving power. The gray part in Figure 5 is the customized part of Zhilian Xintong. According to the requirements of HVDC system, the centralized controller and single lamp controller are modified, and the data acquisition function is removed. At the same time, the data display function is also removed from the man-machine interface software.

4.1. System hardware design

This paper presents a tunnel lamp monitoring system based on power carrier communication technology. The system is mainly composed of three parts, namely the control terminal of HVDC tunnel lamp, communication controller and municipal monitoring center. The control terminal of HVDC tunnel lamp controls each sensor module through microprocessor to monitor the light intensity and sound in real time, and then sends these data to the centralized controller of tunnel lamp through power carrier network. Tunnel lamp centralized controller is composed of carrier communication module and Ethernet interface. On the one hand, it is responsible for the construction of power carrier network; on the other hand, it is responsible for data forwarding. If it receives the information sent by
HVDC tunnel lamp control terminal, it will forward the data center through Ethernet. If it receives the information sent by monitoring center, it will forward the data center through power carrier network. This paper introduces the control terminal of HVDC tunnel lamp. The host computer of remote monitoring center processes, stores and analyzes the received data through Ethernet interface, and finally works out a reasonable tunnel lamp scheduling scheme.

4.2. Software design of upper computer
In the tunnel lamp monitoring system, the upper computer software mainly realizes human-computer interaction, including data display, user management, parameter setting, manual / automatic switching and other functions. The report menu can query and print historical reports, the data analysis menu can view history and real-time curves, and the database operation menu can query, condition search, save and print the database and so on.

System development process:
(1) Demand analysis according to the actual daily life of the tunnel lamp monitoring system function requirements, first determine the need to use technology and sensor type selection, and then the feasibility analysis of the whole system.
(2) The overall design determines the overall feasible design scheme by comparing the current communication technology and comprehensively considering various factors.
(3) Hardware design and debugging system hardware circuit design mainly includes the sensor module circuit design, power carrier module design and function module design, and then make the circuit board according to the design, and test the correctness of each part of the circuit.
(4) Software design and debugging the system uses C language to write the control program, sensor acquisition program and the receiving and sending program between nodes of HVDC tunnel lamp control terminal, and then tests the program according to the sub module. When the part is correct, the next part is added for testing until all functions are realized.
(5) After completing the above steps, a lot of experiments need to be done, including different test conditions and different control modes. According to the problems found in debugging, improve the system continuously until the system passes all tests.

5. System test and result analysis
The hardware experimental platform of tunnel lamp monitoring system includes HVDC tunnel lamp control terminal and tunnel lamp centralized controller. In order to ensure the normal operation of the system, before using, it is necessary to complete the hardware and software debugging of the whole circuit.

In hardware debugging, firstly, check whether the connection between chips on the circuit board is correct according to the schematic diagram; secondly, weld the circuit board in blocks according to the function; firstly, weld the power part of the circuit to check whether the power output voltage is stable and correct; secondly, weld the circuit in blocks according to the circuit function to gradually detect; finally, measure whether the power supply and ground of each main chip are correct.

Test environment: in the laboratory, including 10 LED lamps. The communication controller is connected with PC through RS232, and connected with the control terminal of HVDC tunnel lamps to different patch boards in the laboratory. The stability of communication is tested through different load combinations.

Experiment content: through the serial port assistant, the PC sends the switch lamp control command to the target HVDC tunnel lamp control terminal by power carrier, and checks the response signal returned by the corresponding HVDC tunnel lamp control terminal from the data monitoring window of the upper computer software to judge whether the power carrier communication is successful. The test results of power carrier communication are shown in the table. It is not difficult to see from the implementation results that in the laboratory, due to the close distance between the carrier transceiver modules, the communication success rate is 100%.
Table 1 Test results of power line carrier communication

| Group number | Number of tests | Times of success | Number of failures | Success rate | load          |
|--------------|-----------------|------------------|--------------------|--------------|---------------|
| 1            | 500             | 500              | 0                  | 100%         | Fluorescent lamp |
| 2            | 500             | 500              | 0                  | 100%         | PC            |
| 3            | 500             | 500              | 0                  | 100%         | Heating stove  |
| 4            | 500             | 500              | 0                  | 100%         | Electric furnace |
| 5            | 500             | 500              | 0                  | 100%         | PC + heater    |
| 6            | 500             | 500              | 0                  | 100%         | All of the above |

6. Summary
The research task of this paper is to confirm whether the power carrier scheme can operate normally in HVDC system. Through the research and analysis of the development status of tunnel lamp monitoring system at home and abroad, aiming at the current situation of tunnel lamp control in China, this paper expounds the feasibility and urgency of tunnel lamp power carrier monitoring system, and puts forward a tunnel lamp monitoring system scheme based on power carrier communication technology. According to the requirements of tunnel lamp system design, the hardware design, software programming and overall system test of the whole system are completed. The conclusions are as follows

(1) The existing power line carrier scheme in the system can only be used in DC system after some local modification;
(2) The local modification mainly includes connecting inductors in series at the output end of the centralized power supply and the input end of the driving power supply at the lamp side;
(3) Other modifications in the Qijiashan project, such as power supply to the single lamp controller through the driving power supply, removing the data acquisition function of the single lamp controller, are only for the smooth implementation of this topic in the shortest time and at the lowest cost, and can complete the verification of the feasibility of power carrier communication. These modifications are unnecessary in practical engineering.
(4) The operation results show that the power carrier can operate normally in HVDC system, which is consistent with the operation performance of AC system.

This system not only saves the cost of additional wiring, but also has the advantages of simple installation, easy operation and energy saving. It can effectively complete the remote monitoring of the tunnel lamp and meet the design requirements of the intelligent tunnel lamp system.

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