Application of Broadband PLC Technology in Monitoring Railway Trackside Signal Equipment

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Abstract. It is very important for railway operation and maintenance to monitor railway trackside signal equipment, which is the key foundational part of train control system. But the problem of how to transfer the monitoring data safely and efficiently is difficult to be solved. This paper introduces the technical characteristics of PLC, analyzes and compares the applicability of various communication methods under the application conditions. A scheme of trackside equipment monitoring network is proposed based on the broadband PLC technology and a monitoring system meeting the application requirements is developed.

1. Introduction

In recent years, railway investment and construction have developed rapidly. By the end of 2019, China's railway operation mileage has reached 139000 kilometers, including 35000 kilometers of high-speed railway. It is unrealistic to adopt manual maintenance for all trackside equipment. Analyzing the situation, a Safe, reliable and real-time trackside network based on Broadband PLC (Power Line Carrier Communication) is built and a monitoring system offering data acquisition and communication is developed.

2. Trackside Signal Equipment

Trackside signal equipment mainly includes three categories: track circuit, switch equipment and signal, and has the characteristics of direct impact on safety, large number of equipment, long distance, scattered installation location, wide distribution, diverse climate environment and strong electromagnetic interference. It brings great difficulties to the maintenance, mainly in the aspects of large daily maintenance workload, high failure probability and difficult fault location [1]. Therefore, it is very urgent to realize the functions of operation data acquisition, working condition monitoring, fault diagnosis and maintenance prediction of trackside signal equipment by advanced technical means, which is of great significance to ensure the safe and efficient operation of the railway [2].

According to the above characteristics of trackside signal equipment, the communication of monitoring system faces the following problems:

- Long transmission distance
- High proportion of bridges and tunnels
- Less cable resources
- Difficult construction
- High rebuild cost
3. BPLC Technology and Communication Comparison
PLC is a kind of communication technology which uses power wire as the transmission medium to transmit data. In the early stage, it used the existing distribution network infrastructure to transmit data, saving a lot of communication network construction costs, and widely used in load management, remote meter reading and home automation [3]. According to the different frequency bands used, PLC is generally divided into NPLC (narrowband PLC) and BPLC (broadband PLC).

3.1. Comparison of NPLC and BPLC
Select typical NPLC and BPLC products for data comparison, which is shown in Table 1.

| Type  | Frequency | Speed          | Modulation    | Maximum relay level | Communication distance limit |
|-------|-----------|----------------|---------------|---------------------|-----------------------------|
| NPLC  | 10-500KHz | 330/1000/1500bps | BFSK/DBPSK    | 7                   | 8km                         |
| BPLC  | 2-30MHz   | 500kbps-10Mbps | OFDM          | 16                  | 5km                         |

NPLC adopts FSK, spread spectrum communication and LFM technology, which has limitations: low communication rate, easy to be interfered, slow networking process, etc [4]. BPLC adopts modulation technology such as spread spectrum and OFDM, which not only improves the utilization of frequency band, but also eliminates the interference between sub channels, so as to achieve high-speed and reliable data communication [5].

Compared with NPLC, BPLC technology has the following advantages:
- Strong anti attenuation ability.
- High frequency utilization.
- High-speed data transmission.
- Strong resistance to ISI.

3.2. Constraints Analysis of Monitoring System for Trackside Signal Equipment
The requirements of trackside signal equipment monitoring system and characteristics of various communication technologies are analyzed comprehensively as Table 2.
Table 2. Constrains of communication technologies camparison

| Communication Technologies | Constraints |
|----------------------------|-------------|
| NB-IoT/GPRS                | 1. Public network communication faces network security problems.  
2. Uncontrollable signal coverage.  
3. Short communication distance in tunnel.  
4. Poor real-time performance.  
5. Power supply is needed. |
| RoLa                      | 1. Unauthorized spectrum is vulnerable to interference.  
2. Short communication distance in tunnel.  
3. Poor real-time performance.  
4. Power supply is needed. |
| Optical fiber             | 1. Large construction difficulty and workload.  
2. High requirements for optical fiber connection process, makes nodes difficult to access the network flexibly.  
3. Power supply is needed. |
| NPLC                      | 1. Poor real-time performance.  
2. Low communication rate limits data type and amount. |

In summary, the above communication technologies are not applicable to rackside signal equipment monitoring system. BPLC, which can realize the function of stable power supply and real-time data transmission by using trackside 2-core standby cable, is the most reasonable communication solution.

4. Application
PLC technology is widely used in the civil field, mainly in power meter reading, street lamp detection, power generation monitoring, home network and other scenarios. The PLC application in railway field is still in the initial stage, there is no ready-made scheme for reference. On one hand, the railway application environment conditions are harsh, and there are very high requirements for safety and reliability. On the other hand, the cables can be used to build a private network and there is no other load on the line, which means the impedance will not change obviously. Therefore, the BPLC devices need to be designed according to the actual application requirements.

4.1. System Structure Design
Considering the distribution characteristics, cable conditions, operation environment and monitoring requirements of trackside signal equipment, the monitoring system is divided into monitoring diagnosis host, communication host and outdoor acquisition device. The communication host includes the BPLC master module, and the acquisition device includes the BPLC slave module. The system structure is shown in the Figure 1.
The acquisition device collects the operation state parameters of trackside signal equipment through a variety of sensors, such as current, voltage, temperature, vibration, pressure, displacement and image, etc. After local preprocessing such as analog-to-digital conversion, decoding, compression and packet grouping, the collected data is transmitted from the acquisition device to BPLC channel by the BPLC slave module, which is received and managed by the BPLC master module. The functions of subcarrier SNR and signal attenuation indication, frequency offset correction, automatic relay and collision avoidance are supported by the BPLC slave module.

The communication host is capable of data receiving, interface conversion, operation processing and protocol analysis of multiple BPLC channels. Each channel of BPLC is equipped with an independent isolation power supply to avoid the mutual influence between channels and protect other equipment. The BPLC master module is responsible for fast networking, path maintenance, dynamic routing, network management and communication transceiver of all BPLC slave modules in the channel. Slave modules can be up to 1024 for each master module, and remote online upgrade of slave software is available.

4.2. BPLC Design
The hierarchical structure design of BPLC in the system is shown in the Figure 2.
4.2.1. Hardware design of BPLC module
BLPC module consists of XC6300 processing chip, carrier receiving filter circuit, carrier amplifier sending circuit, power conversion circuit, crystal oscillator circuit, reset circuit, peripheral interface circuit and FRAM memory circuit. Carrier receiving filter circuit uses 8-order filter, it passes through a 5-order high-pass filter and a 3-order low-pass filter to realize stable data reception under multi-noise interference conditions. Carrier power amplifier circuit uses THS6212 differential amplifier of TI to amplify power. The amplification gain is preset at 14 times and can be adjusted by software according to actual conditions to improve the actual transmission distance effectively.

4.2.2. Software design of BPLC module
Frequency offset correction algorithm is used to increase carrier allowable frequency offset range. Combined with RSSI and SNR, the link channel condition is comprehensively evaluated. In the case of strong interference, the reasonable relay agent node can still be evaluated to make the network more robust. Time slot allocation based on TDMA and CSMA/CA collision avoidance mechanism are used to effectively avoid collision between different carrier communication nodes when transmitting signals.

5. Summary
This paper analyses the monitoring system communication problems of railway trackside signal equipment and the performance advantages of BPLC. A monitoring system design scheme based on BPLC is proposed, and a monitoring system of trackside signal equipment is designed and realized based on the scheme. The system has been tested for communication on several high-speed railway lines. The test results show that, on the premise of data stability, the maximum point-to-point communication distance of the system is about 7km (less than 500kbps) and the maximum communication rate is 2.6Mbps (within 2km), which meets the communication requirements of different trackside signal equipment monitoring systems.
6. References

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