Journal of computer science and software applications
https://www.mfacademia.org/
ISSN:2377-0430
Vol. 2, No. 1, 2022

Development and Implementation of an Intelligent Monitoring System for Spanning Construction of Low-Voltage Transmission Lines

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Abstract:

To enhance the safety and automation in the construction of transmission lines with voltage levels of 110 kV and below, an intelligent monitoring system for spanning frames has been developed. This system is based on Programmable Logic Controllers (PLC) and configuration software. It facilitates real-time monitoring and early warning of various parameters, including height, inclination, and wind speed at the construction site. Additionally, it controls a series of actions such as synchronous lifting and spanning of the crossing pole, as well as the distribution and collection of insulating mesh. The system employs a distributed structure comprising a central monitoring center and four substations, achieving distributed hybrid networking through the integration of wireless communication, serial communication, and 4G communication.

Keywords:

Transmission Lines; Spanning Frames; PLC; Configuration Software; Measurement and Control System.

1. Introduction

As the scale of power grid construction gets larger and larger, the erection and maintenance of transmission lines are becoming more and more frequent, and the situation where it is necessary to cross the construction during the construction process is also increasing day by day. Therefore, to ensure the normal power supply of the crossing line, the crossing pole is usually used for live crossing construction [1].

In terms of the spanning construction of transmission lines with voltage levels of 110kv and below, scaffolding spanning frames are usually used, which require time and effort to build and dismantle, and the stability is not strong. In case of strong winds, there will be the possibility of collapse, and the transmission lines and construction personnel cannot be well protected. Therefore, to improve the safety of the construction process, some scholars have designed a monitoring system for crossing poles and transmission lines, which can effectively monitor the situation on-site and make corresponding early warnings.

Nowadays, besides the lack of safety, the crossing pole used in transmission lines with voltage levels of 110kv and below usually has problems that are not easy to control. Therefore, a set of intelligent crossing pole monitoring systems are designed in this paper. The system introduces wireless communication and 4G communication to realize distributed hybrid networking [2], which can monitor and control the status of the crossing pole construction process in real-time, and has a remote monitoring function.

2. System Architecture

The intelligent crossing pole monitoring system adopts a distributed structure [3] of one monitoring center and four sub-stations. The monitoring center is an on-site touch screen or a remote mobile phone app. One of the four sub-stations is set as the master station in the four sub-stations, and the PLC controller in the sub-station controls the four sub-stations uniformly. The system is mainly composed of the controller, sensor, actuator, monitoring center [4], and other parts, as shown in Figure 1. The controller part adopts Beijing Jiemai PLC, including one main station PLC and three substation PLC. Among them, the main station PLC model is T64P, which has 485/232 serial port communication, RJ45 network port communication, 4G/WIFI communication, and other communication methods. The controller is mainly responsible for receiving and processing sensor data and various instructions [5]. The sensor part is mainly responsible for collecting the data information such as the height, inclination of the crossing pole support mechanism, wind speed on the construction site, and on-site construction pictures. What is more, the PLC can remotely transmit the data collected by the sensor to the mobile phone app through the 4G network, and can also exchange data with the on-site touch screen through the 485 serial port. Wireless communication between PLC master and slave stations is realized by connecting digital radio. Modbus polling is used to communicate between master and slave stations [6]. The actuator part is mainly the motor of the hydraulic station and the relief valve and throttle valve, etc. PLC connects the intermediate relay through the DO port to indirectly control the motor, relief valve, and throttle valve of the hydraulic station, so as to control the lifting and crossing actions of the support mechanism and the crossing mechanism.

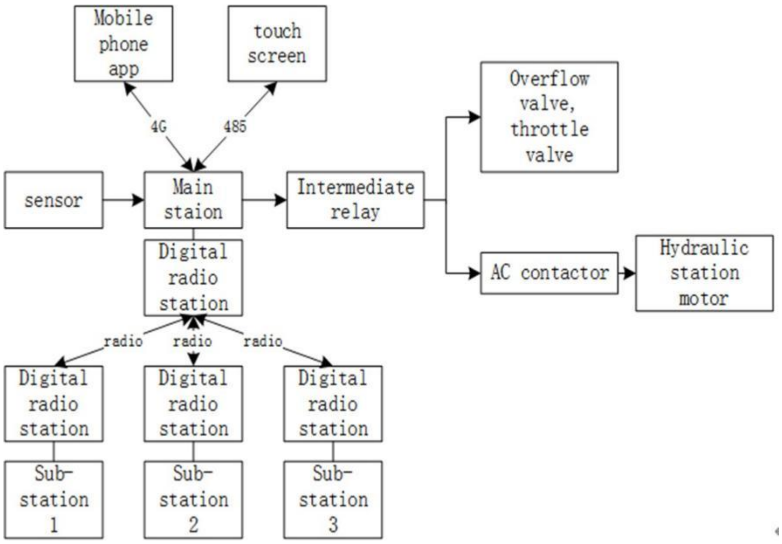

Figure 1. Schematic diagram of the system

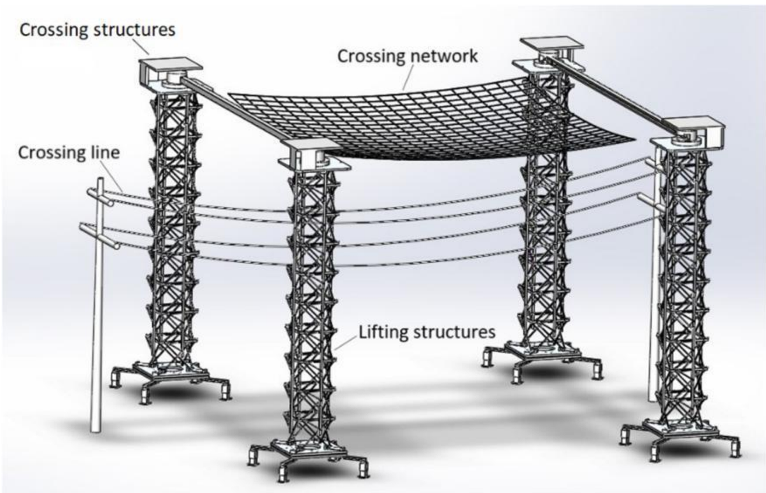

Figure 2. Crossing pole

3. Hardware Design

3.1. Controller

The controller adopts Jiemai PLC with various communication channels, and the whole monitoring system consists of 4 PLC stations, including one master station and three slave stations. In addition, Modbus-RTU communication [7] is used between the master station and three substations, and the touch screen. To realize wireless communication [8], the master station and each slave station are connected to an F21DM data transmission radio through the TTL interface. Within the allowable frequency range, the transmitting frequency of the master station data transmission radio and the receiving frequency of the substation data transmission radio are set to the same frequency, and the receiving frequency of the data transmission radio of the main station and the transmitting frequency of the data transmission radio of the sub- station are set to the same frequency too, so that the wireless communication between the main station and the sub-station can be realized.

According to the input, output, and communication channel requirements of each station [9], the selected PLC master station model is T64P, with eight channels of AI, DI, and DO, which has communication channels of 232, 485, TTL, RJ45, 4G/GPRS, and SMS. The PLC substation model is TZ04, with 4 channels of AI, 6 channels of DI, and 4 channels of DO, which has communication channels of 232, 485, and TTL. Each station is connected with one or two I/O expansion modules KZ04. KZ04 has 4 channels of AI, 6 channels of DI, and 4 channels of DO.

Figure 3. Control panel

3.2. Sensor

Table 1. Parameters of laser ranging sensor

Parameters	Working voltage / V	High measurement range / m	Signal output / mA	Precision / mm
Numerical value	8~30(DC)	0~50	4~20	±2

The laser ranging sensor selects SK-A100 from Shanghai Shenji Optoelectronics Technology Co., Ltd., which has high precision and small size. The measurement range of this sensor is 0~50m, and the output signal is 4~20mA, which meets the requirements of PLC for analog input signals. The relevant performance parameters of the laser ranging sensor are shown in Table 1.

The inclination sensor adopts the BWL328 dual-axis inclination sensor from Beiwei Sensing, which is used to measure the inclination of the supporting structure. The selected BWL328 inclination sensor has a measurement range of -15°~+15°, an accuracy of 0.01°, and an output signal of 4~20 mA, which meets the PLC requirements for analog input signals. The relevant performance parameters of the inclination sensor are shown in Table 2.

Table 2. Parameters of tilt sensor

Parameters	Working voltage / V	Angle measurement range / (°)	Signal output / mA	Precision / (°)
Numerical value	9~35(DC)	-15~15	4~20	±0.01

The wind speed sensor uses Jianda PeopleSoft RS-CFSFX-120-2 ultrasonic wind speed sensor, which is a wind speed measuring instrument developed based on the principle of ultrasonic. Since the sensor adopts an engineering plastic shell, the equipment is light in weight, small in size, and easy to install. The output signal is 4~20 mA current, which meets the requirements of PLC for the analog input signal. The relevant parameters of the wind speed sensor are shown in Table 3.

Table 3. Parameters of wind speed sensor

Parameters	Working voltage / V	Wind speed measurement range / (m / s)	Signal output / mA	Precision / (m / s)
Numerical value	10~30(DC)	0~60	4~20	±0.2

3.3. Actuator

The actuator part includes each support mechanism and the hydraulic station three-phase motor of the crossing. The PLC controller connects the intermediate relay through the DO channel and then connects the AC contactor through the intermediate relay to control the three- phase motor of the hydraulic station. To prevent the motor from working for a long time and malfunctioning, a thermal overload protector is connected to the AC contactor. Moreover, the hydraulic cylinder relief valve, throttle valve, speed regulating motor crossing the network are all connected to the DO of the PLC controller or I/O expansion module through the intermediate relay. Through the PLC controller or the DO of the I/O expansion module, the lifting and lowering of the support mechanism, the crossing of the crossing mechanism, and the retracting of the crossing network are controlled.

4. Software Design

4.1. The Development of Touch Screen

The touch screen is used for on-site monitoring [10], mainly including several major functions such as parameter setting, equipment self-checking, data monitoring, fault warning, and equipment operation. According to the selection of parameters such as the voltage level of the line to be crossed and the voltage level of the new line, the parameter setting system automatically completes the calculation of parameters such as the lifting height of the support mechanism, the minimum safety distance from the object to be spanned, the distance between the two support mechanisms on the same side, the width of the protective net, and the spanning width of the spanning frame, improving the degree of automation. Moreover, the equipment self-inspection system pre-inspects the communication, sensors, and actuators of the system before construction so as to ensure the safe and reliable operation of the system. The data monitoring system is responsible for monitoring the levelness of the support mechanism, the lifting height, and the operation status of various equipment during the construction process. Meanwhile, the monitoring data can be retained for subsequent analysis.

The fault early warning system can provide early warning and fault handling for faults that occur during the construction process, such as the excessive inclination of the support mechanism, excessive on- site wind speed, and improving the safety of the system. The equipment operating system is used to control the start and stop of the actuator and provide different control strategies in manual, semi-automated, and fully automated states. In the manual state, the control box controls the actuator. In the semi-automated state, it can be controlled by the touch screen. In the fully automated state, once the start or end is pressed, the system will automatically act according to the process.

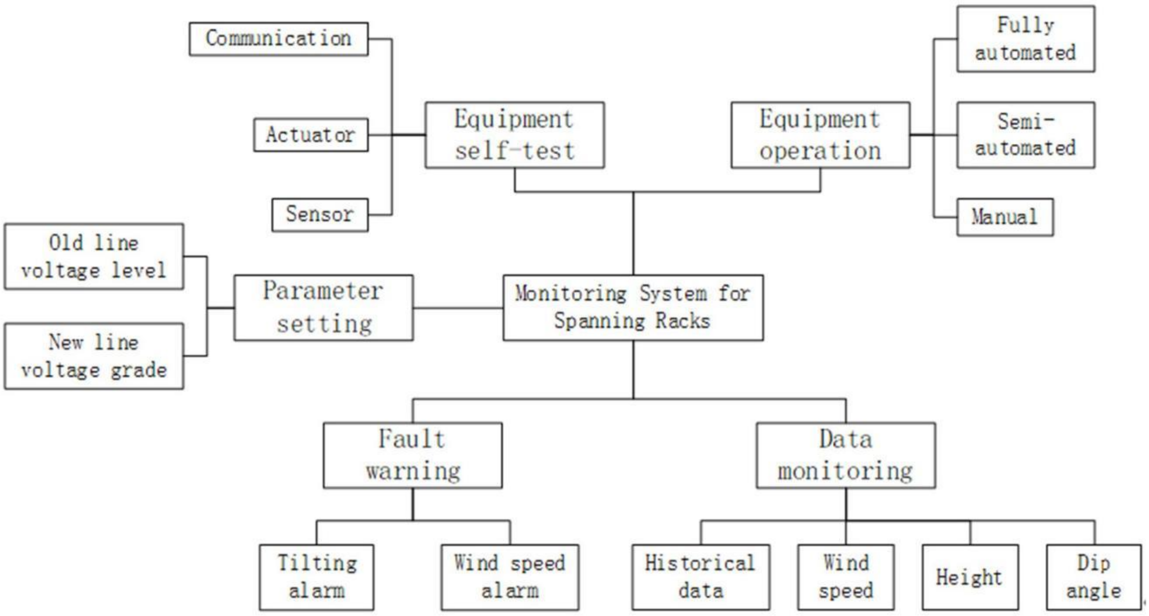

Figure 4. Function design of touch screen

4.2. Mobile App Design

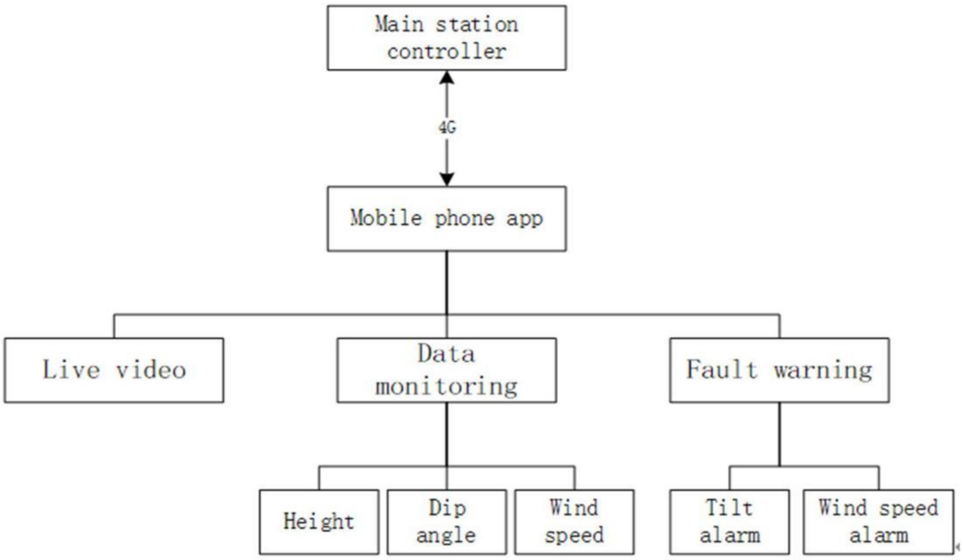

Figure 5. Function design of mobile App

The remote host computer of this system adopts the mobile phone app, which is designed by the special configuration software designer for the measurement and control communication provided by Jiemai, and the mobile phone app and the master station controller use Modbus- TCP for 4G communication. Moreover, the mobile app is used to monitor the construction site remotely, including monitoring the video of the construction site, displaying alarm information, and displaying the inclination and height of the support mechanism, which is convenient for staff outside the construction site to control the construction quality.

4.3. Control Flow

The control flow is shown in Figure 6. After the system is powered on, the controller, sensors, and actuators will be self-checked first, and the parameters will be set after the self-check is passed. What is more, different control strategies are provided in fully automated, semi- automated, and manual states. When it is determined that the system is safe and reliable, it can work in a fully automated mode, and the system will automatically act according to the process. Enter semi-automatic mode when testing the system, in semi-automated mode, the crossing pole movement can be controlled on the touch screen as needed to test the various actions of the system. In manual mode, a simple operation can be performed directly in the control box to prevent the crossing pole from being uncontrollable when the automatic transmission fails. The working mode can be set according to the site conditions, which not only improves the degree of automation but also makes it more user-friendly.

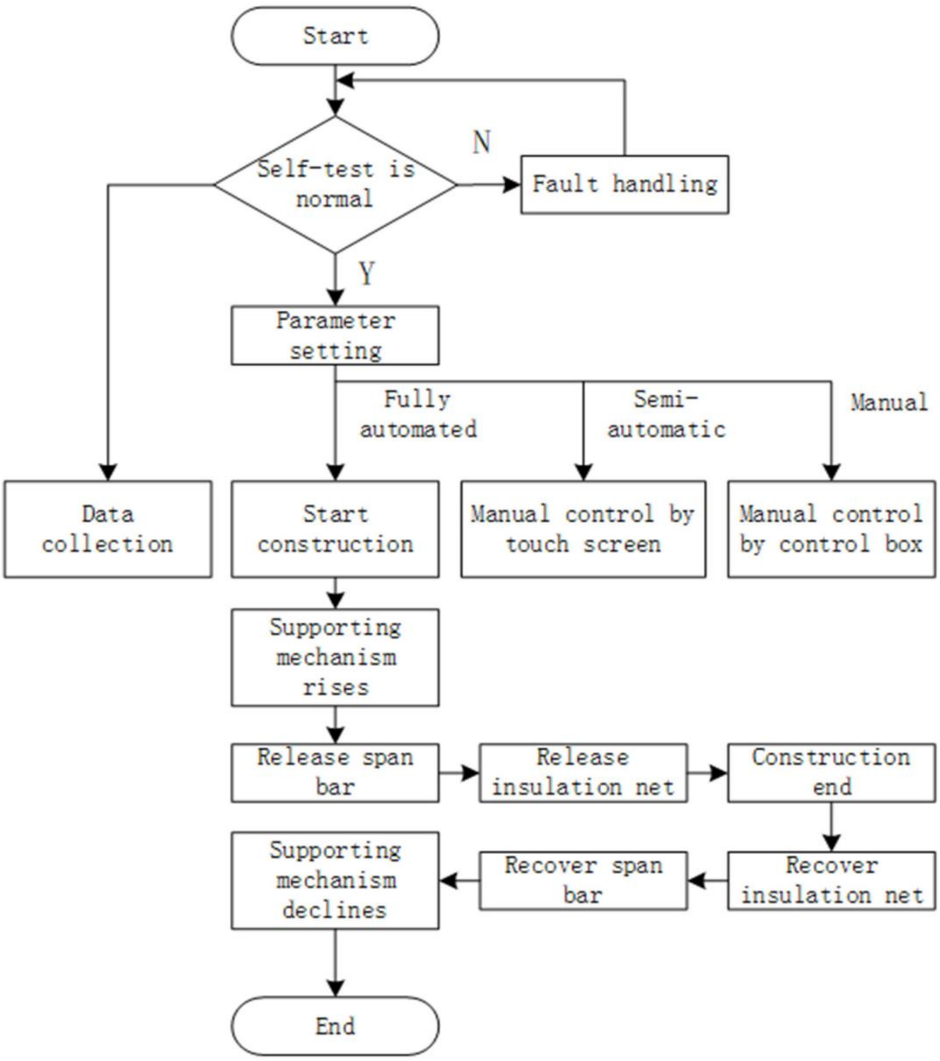

Figure 6. Control Flow

5. Conclusion

The multi-channel PLC controller is used to realize the distributed hybrid networking that integrates various communication methods such as 4G communication, wireless communication, serial communication, etc., so that the crossing pole can be monitored on-site and remotely. Moreover, different control strategies are provided under the three working modes of being automated, semi-automated, and manual, which are convenient for debugging and troubleshooting, making the use of the system more user-friendly and improving the safety and reliability of the system while taking into account the degree of automation.

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