Research on Intelligent Communication System for Circuit Breaker Condition Monitoring

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Abstract. Based on the research of vacuum circuit breaker condition monitoring, a circuit breaker state monitoring intelligent communication system using ZigBee+SWM61850 communication configuration is proposed. Under the IEC61850 modelling specification, the state monitoring intelligent electronic device (IED) model is constructed. Combined with the experimental system, data read and write service and message transmission operation of the insulating gas monitoring logic node are simulated. At the same time, the communication system can avoid signal interference in complex electromagnetic environment, reduce data transmission delay, and share real-time monitoring data to multiple functional nodes. These features are beneficial for the improvement of equipment status warning, protection actions, and comprehensive performance evaluation. The communication system integrates the control command transmission with the on-site measurement mode. Simultaneously, the system uses the monitoring data as a constraint for implementing the adjustment operation mode. And the operational stability of the power equipment can be further improved.

1. Introduction

The normal operation of the circuit breaker is related to the overall stable operation of the power system. [1] With the in-depth promotion of intelligent substations, online monitoring technology for primary equipment status such as transformers and GIS switches in the station has become increasingly mature and stable[2,3].

This paper designs an integrated functional IED model for protection and measurement on integrated circuit breaker. Based on the synchronous sampling technology [4-6], data such as current and voltage are collected by sensors, and the switch position signal is collected by auxiliary contact. After analysing and processing the collected signals, real-time circuit breaker characteristic state monitoring and early warning state evaluation are realized. The focus of this paper is to combine the IEC61850 communication protocol and the Internet of Things (IoT) communication method to construct an intelligent communication system for condition monitoring sampling data sharing and comprehensive evaluation of equipment performance.
The goal of this design is to reduce the data transmission interference in complex electromagnetic environment to provide real-time monitoring information for system operation, and to use real-time monitoring data as an important parameter of system operation mode and protection action.

2. Data acquisition system
The vacuum circuit breaker condition monitoring experimental system is shown in Figure 1. The experimental system mainly consists of signal acquisition and processing system, power supply system, chamber and vacuum maintenance system. The voltage on coupling capacitor 6 is handled with the signal processing circuit including a power amplifier, low pass filter and some circuits to improve the loading capacity. The voltage signal is transferred to the processor to calculate effective voltage.

![Diagram of condition monitoring experiment](image)

Figure 1. Diagram of condition monitoring experiment
This design uses a coupled capacitive sensor to measure the voltage signal and send the data to the IEDSout by the ZigBee+SWM61850 communication module. The measured data is also converted into a vacuum pressure signal by circuit processing and program analysis, which can implement functions such as circuit breaker insulation gas alarm and protection action.

3. Communication system
The condition monitoring of vacuum circuit breakers is also an important task in the monitoring of the substation equipment. Combined with substation IEC61850 communication system, the construction of an all-round condition monitoring system for vacuum circuit breakers will be indispensable for future state monitoring of substation process layer equipment.

In order to adapt to the complex working environment of the circuit breakers, the current vacuum detection system mainly has two communication modes, the ZigBee wireless communication based on the Internet of Things (IoT), and the scalable intelligent substation system IEC61850 communication.

ZigBee communication has the advantages of low power consumption, various connection forms, relatively long distance, short delay, high capacity, and strong anti-interference ability. The vacuum degree detection in the project is to transmit data at a relatively close distance. The circuit breaker works in a complex electromagnetic environment. ZigBee communication does not require routing and additional power supply, and is not affected by environmental interference. ZigBee communication module consists of CC253X, CC2591 and circuit components.

In order to adapt to the intelligentization of substation equipment, circuit breakers intelligent terminal that fully supports substation digitalization is configured. The entire substation is uniformly modeled under the IEC61850 communication system to improve the intelligent level of power system equipment condition monitoring, data maintenance, fault diagnosis and system integration. In this design, the circuit breaker status monitoring function is classified to construct the intelligent circuit breaker communication model under the IEC61850 standard. The SWM61850 is installed to provide
an Ethernet interface for the IEC61850-8-1 communication protocol. The communication module can communicate with the digital substation local monitoring interface and supports remote services such as Telnet and FTP. The vacuum degree message data transmission between the data model and the substation communication server discriminates the vacuum state in real time. The substation communication model based on the IEC61850 is shown in Figure 2.

In the experimental system, the vacuum pressure is measured in an indirect manner to characterize the state of the insulating gas. We can also monitor other state parameters. In order to meet the substation communication requirements, the intelligent circuit breaker state monitoring IED model is written in Structured Control Language (SCL). The model function structure is shown in Figure 3. The model configures various protection functions of the circuit breaker in logic device PROT. Logic device MEAS performs parameter measurement and state judgment on voltage parameters, current parameters, power factor, arc state, contact wear, gas insulation and other factors in circuit breaker operation. Logic device CTRL configures the interlock function of the circuit breaker, the switch control, the phase selection operation, the fixed point closing and closing functions. Logical device PIGO summarizes the alarm information, the operation command.
4. Data communication analysis

The built-in protocol conversion SWM61850 can be directly embedded into the terminal intelligent device in the form of a module, and the IEC61850 protocol service can be directly provided externally. In this design, the module will complete the message communication between the IED and the system server. For the vacuum degree monitoring data, the sampled measured value (SMV) message is used to send the data to the IEDSout software circuit breaker state monitoring IED logic node SIMG to determine the current circuit breaker vacuum state. The communication process of data transmission can be analyzed by Ethereal software. For voltage data, SMV is used for sampled data transmission. SMV messages are continuously sent with real-time data collection. According to the range of communication transmission data values, the switch selection control flow will be triggered under the current communication model, and the corresponding mode command is executed to change the switch operation mode. The switch selection mode operation flow and the signal of the detection signal voltage sampling according to IEC61850-9-2 is shown in Figure 5. The signal voltage data is sent in accordance with the protocol IEC6SMV. According to the contents of the data packet, 0x88ba is the message type of the SMV. According to the IEC 61850-9-2 protocol data format specification, the packet sampling rate is 200 and the number of Application Service Data Unit (ASDU) is 5. The voltage sample value is 2.7V.
The switch selection mode operation flow is shown in Figure 6 in the data information in node data transmission process as provided.

According to the range of communication transmission data values, the switch selection control flow will be triggered under the current communication model, and the corresponding mode command is executed to change the switch operation mode. The switch selection mode operation flow is shown in Figure 6.

In addition to monitoring the pressure of the insulating gas, we can also comprehensively analyze the current insulation properties of the gas based on information such as density and temperature. According to the range of communication transmission data values, the switch selection control flow will be triggered under the current communication model, and the corresponding mode command is executed to change the switch operation mode. The switch selection mode operation flow is shown in Figure 6.

The SMV packet is a periodic fast packet, which is generally a sampling message sent by the server to the IED client for use. The switch selection control flow is divided into four operation modes, mode 1 is safe operation state, mode 2 is critical operation and alarm, mode 3 is lock operation and alarm, and mode 4 is device isolation trip. The SIMG vacuum monitoring node obtains the data information in node data transmission process as shown in Table 1.

### Table 1. SIMG node data information

| LN: SIMG | Mod | ChBeh1 | ChBeh2 | ChBeh3 | ChBeh4 | Pres | Tmp | Den | InsAlm | InsBlk | InsTr | PresAlm |
|----------|-----|--------|--------|--------|--------|------|-----|-----|--------|--------|-------|---------|
| CF       |     |        |        |        |        |      |     |     |        |        |       |         |
|          | {0,1} | {0,1.33e-02, 9.9e-02} | {1.33e-02, 6.6e-02} | {6.6e-02, 9.9e-02, 9.9e-02} | {19.9e-02, 1.01e+05} | {9.16e-04, 2.1426e-03, 3.4268e-02, 6.4785e-2} | {20.12} | {1.18e-31} | {1.33e-02} | {6.6e-02} | {9.9e-02} | {6.6e-02} |
| MX       |     |        |        |        |        |      |     |     |        |        |       |         |
| FC       |     |        |        |        |        |      |     |     |        |        |       |         |
| ST       |     |        |        |        |        |      |     |     |        |        |       |         |
According to the function node data information, it can be known from Tab. 1 that when the vacuum pressure is in the interval (0, 1.33e-02), the system executes mode 1; when the vacuum pressure is in the interval (1.33e-02, 6.6e-02), the system executes mode 2; when the vacuum pressure is in the interval (6.6e-02, 9.9e-02), the system executes mode 3; when the vacuum pressure is in the interval (9.9e-02, 1.01e+05), the system executes mode 4. In addition to monitoring the pressure of the insulating gas, we can also comprehensively analyze the current insulation properties of the gas based on information such as density and temperature. The node data pointed to by DATA-SET will update the function node data according to the reporting period to meet the requirements of real-time monitoring and be associated with the relevant protection function nodes.

5. Conclusion
This paper designs and applies ZigBee+SWM61850 intelligent communication system in the condition monitoring of vacuum circuit breakers. The message transmission between vacuum pressure data and condition monitoring IED monitoring node SIMG is completed. ZigBee+SWM61850 is a combination of IoT communication and intelligent substation communication system, which can shield complex electromagnetic environment interference and easily realize data sharing among multiple nodes. The intelligent communication system synergizes various functions such as state monitoring, control operation, protection coordination and data sharing, greatly improving the accuracy of data transmission and the stability of equipment operation.

This paper designs the intelligent circuit breaker IED model based on IEC61850, and divides it into six logical devices according to functional requirements. SMV message is used to periodically send sampling data. The device status information is periodically uploaded by using GOOSE message, and the operation control command is sent according to the evaluation. Combined with the vacuum pressure monitoring of vacuum circuit breakers, four protection action intervals are delineated according to the vacuum pressure, which has an important influence on the vacuum state monitoring, protection synergy and intelligent terminal function integration of vacuum circuit breakers.

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