A Multi-Layer Distributed Comprehensive On-line Monitoring System for GIS

GENG Yaming^{1,a}, Chai Yu^{1,b}, ZUO Fan^{2,c}, WAN Jiefeng^{2,d}, ZHAO Guodong^{2,e}, ZHU Meng^{2,f}

¹Operating&Maintenance Station, Taizhou Maintenance Branch, Jiangsu Electric Power Co, Taizhou 225300;

²School of Electrical Engineering, Southeast University, Nanjing 210096, China.

^a6736639@qq.com, ^bchajy@163.com, ^c850527240@qq.com, ^d983082574@qq.com, ^e281636528@qq.com, ^f472881284@qq.com

Keywords: GIS, Distributed structure, IEC61850, On-line monitoring, ARM

Abstract. Gas Insulated Switchgear (GIS), as important equipment of power system, provides primary guarantee for its security and stability. Therefore it is significant to monitor the operating status and working performance of GIS. In this paper, a comprehensive online monitoring system of GIS with a multi-layer distributed structure is proposed. The design realizes the monitoring of many important parameters of GIS, including the temperature of gas, the pressure of gas, operating status, three-phase mechanical properties, the characteristics of control loop, etc. The system has lots of functions such as the collection of data, the storage and management of data, the calculation of parameters and remote communication. Field experiments verify that the system is accurate and effective enough to meet the requirements of online monitoring.

Introduction

GIS (Gas Insulated Switchgear) is important electrical equipment which is widely used in transmission, distribution and substation fields^[1]. After the optimum design, the primary equipment of a substation is integrated a whole except the transformer. GIS has lots of advantages such as smaller occupied area, higher reliability, stronger security and less maintenance work. However, Due to its feature of seal, it's more difficult to find its early failures are than traditional circuit breakers and those failures often cause more losses. To keep abreast of the equipment's operating conditions and find potential faults, online monitoring of GIS becomes a must^[2]. At present, periodic maintenance is still widely used for most electrical equipment in China. But the traditional planned maintenance costs a lot of material and financial resources and will result in the decrease of reliability of power supply. Therefore, condition-based maintenance is an inevitable trend of development. Condition-based maintenance has more advantages than regular maintenance^[3]. Real-time dynamic online monitoring can provide early fault warning effectively and accurately. It can also provide the basis for the diagnosis and condition-based maintenance. In this paper, characteristic of main variables of 220kV GIS and corresponding monitoring methods are analyzed to realize the multi-tier distributed design of GIS online monitoring system which is based on IEC61850. The system features high synthesis, excellent expansibility and stability by monitoring multi-variables.

Main variables monitored by the system

In this paper, the proposed online monitoring system is used to monitor ZF40-126 GIS. Due to the sealed nature of GIS and its complex internal structure, parameters must be monitored to reflect both the status of GIS and the important factors which may cause the fault. With the requirements of the monitoring system and the current monitoring methods taken into consideration, the parameters including circuit current of SF6 circuit breakers, grounding switch status, SF6 gas temperature and pressure are monitored in the paper^[4]. Specific monitoring parameters are as follows:

- 1) The circuit breaker closing state and cumulative breaking times. The cumulative breaking times can be used to determine the electrical endurance of circuit breakers.
- 2) The state of ground knife. During the maintenance, grounding switch must be closed unless the door of switchgear cannot be opened. It is necessary to grasp the state of ground knife for safety.
- 3) The travel of three-phase breaker moving contact. By calculating the three-phase circuit breaker moving contact stroke, some valuable mechanical parameters can be gained such as the speed of opening and closing, the times of opening and closing, open distance, three-phase different period, etc.
- 4) The current signal of closing coil. Monitoring the changes of DC coil current signal in the process of opening and closing can reflect secondary operations coil condition, operating status of solenoids and other mechanical components.
- 5) The current signal of charging motor. Through the current signal of the circuit breaker charging motor, the operation of electrical energy storage can be observed.
- 6) Mechanical vibration signal. The signal includes a number of circuit breaker operation status and internal mechanical structure information^[5].
- 7) The temperature and pressure signals of SF₆ gas. Temperature and pressure are usually monitored by sensors and then converted into corresponding purity and density.

The overall structure of the monitoring system

Conventional monitoring systems typically use a two-layer structure—upper and lower computer. The upper and lower computer communicate through CAN bus and RS232 serial ports^[6]. This structure has many shortcomings such as the high cost of the lower computer, the lack of the capacity of sampling rate and overall treatment, and less overall practicability. The communication mode using CAN bus and RS232 serial port leads to obvious deficiency of data transmission speed and interoperability. According to the basic requirements for GIS on-line monitoring, combined with GIS's own characteristics, in order to adapt to the development trend of intelligent substation and meet the interoperability requirements, this system uses a multi-tier distributed structure in tree form based on IEC61850 standard.

IEC61850 standard divides the substation automation systems into substation layer, the spacer layer and process layer. This stratification is not only logical, but also is physical. It makes both the logical interface and the physical structure of the entire system clear. Process layer mainly conducts the functions related to the primary equipment such as sending the order of action command and the collection of the switching value and the analog quantity. It communicates with the spacer layer via Ethernet. Spacer layer uses the data of the layer to operate the primary equipment in that layer. Individual devices in the spacer layer may also communicate with each other via a logical interface. Substation layer communicates with spacer layer via Ethernet based on TCP / IP, which replaces the traditional way of CAN bus and increases the speed of communication and interoperability.

The entire system consists of multiple-sensors, data receiving and communication unit, distributed on-site monitoring and control unit, back-end server and other components. Each layer can communicate with each other rapidly through embedded Ethernet. Data receiving and communication unit consists of ARM module and FPGA module, which is responsible for monitoring the collection of data and remote communication. Distributed on-site monitoring and control unit, which is made up of the IPC with a touch screen, is responsible for the monitor of human-machine interface display data, historical data query and fault warning. Back-end server is used to monitor all devices, and implement remote operation. The multi-tier distributed structure can not only give full play to each part's superiority, but also make rational use of IPC's powerful calculating and analyzing capability and advantages of embedded processors such as fast communication and small volume. Based on IEC61850 standards, the design meets the modularization development and features good expansibility, interoperability as well as stability.

Fig.1 The monitoring system structure as a whole

The hardware design of GIS online monitoring system

As shown in Fig.1, GIS on-line monitoring device belongs to spacer layer, including the unit of data receiving and communication, the unit of distributed on-site monitoring and control, which is an important component of the system. It is supposed to not only receive the status information of primary equipment and send it to backstage server, but also communicate the commands of server to primary equipment.

Main structure of the system hardware design is shown in Fig. 2. SF6 sensor signal is converted by the RS485 / 232 directly, then the signal is connected to the RS232 serial of IPC. Switch signal is sent to the ARM chip on the core board via I/O board. The remaining analog signals need pretreatment through acquisition board before the core board completes the A/D conversion and sends the signals to ARM chip. Finally, ARM packages all switch signals and analog signals, and sends them to the IPC for processing via Ethernet. IPC can call the relevant algorithm to deal with those data and display them on man-machine interface. By analyzing the data, IPC can warn faults early and control operations of GIS.

Fig.2 Hardware structure

Hardware design of signal conditioning modules

Signal conditioning modules consist of sampling board and I/O board. The channel output of the I/O board is connected to the corresponding I/O pins of the ARM chip on the core board directly. I/O channels are isolated by optocoupler to achieve the isolation of internal and external signal of input and output. It can enhance electromagnetic compatibility and interference immunity besides protecting the internal circuit. The output channel adds monostable trigger circuit to the front end of optocoupler to filter the impulse wave of shorter pulse width at the power-on moment in cooperation with NAND gate logic circuit so that the relay malfunction caused by powering on and other interference can be avoided. Sampling board mainly acts as the low-pass filter and pressure

regulator of the analog signals. According to Shannon sampling theorem, if the signal bandwidth is less than half of the sampling frequency, these discrete sampling points could be fully representative of the original signal. If it is higher or same as the sampling frequency, it will result in aliasing. The sampling frequency of the design is 25kHz. Therefore, a low-pass filter is applied to filter out the signal whose frequency is higher than 12.5kHz. Because the transition process first-order RC filter operates slowly, a passive second-order RC filter is used.

The design of core board

There are two programmable embedded chips on the core board. The one is Cyclone 2-generation FPGA of Altera and the other is AT91RM9200 ARM9 series of Atmel. The main task of FPGA is to control the A/D conversion of the A/D chips at the fixed sampling rate and FIFO sort of data. FPGA also sends data to ARM through bus. The main task of ARM is to receive the data from FPGA and send to IPC in the form of Ethernet packets.

The core board uses dual-core design and controls the cooperation between FPGA and ARM by the interrupt signal. Software flow chart is shown in Fig.4. FPGA sends configuration signal to set the A/D chip to start A/D conversion. When ARM receives an interrupt signal from the FPGA, it begins to accept signals from the A/D sampling chip and detects switch status at the same time. When ARM receives ten groups of interrupt signal, it starts to pack them and send them via Ethernet.

Fig.4 The flowchart of Core board software

Experimental data and analysis

The entire system is mounted on ZF40-126 GIS and the ABC three-phase displacement of SF6 circuit breaker in GIS is tested to prove the accuracy and reliability of the on-line monitoring device. IPC invokes corresponding algorithm to eliminate noise and calculate the mechanical parameters. Results of travel data in the experiment are shown in Table 1. Errors between online monitoring data and pre-delivery test results are shown in Table 2.

Tab.1 experiment data of GIS's mechanical parameters

Measurement parameters	Travel data of online monitoring system			Factory data
	A phase	B phase	C phase	Three Phase
Contact travel(cm)	12.148	12.252	11.85	12.000
The contact trip(cm)	2.8457	3.1152	2.939	3.0000
Closing sequence		BAC		BAC
Closing speed(m/s)	2.283	2.331	2.167	2.200
Opening sequence		CAB		CAB
Opening speed(m/s)	4.981	4.952	5.046	5.000

Tab.2 errors of GIS on-line monitoring system

Measurement parameters	Error		
	A phase(%)	B phase (%)	C phase (%)
Contace travel	1.23	2.10	1.24
The contact trip	5.14	3.84	6.13
Closing speed	3.78	5.95	1.50
Opening speed	0.38	0.96	0.92

The result of Tab.2 shows that the system is suitable for on-line monitoring of GIS. It also shows that test data is close to the pre-delivery data as travel, the order of switching, the speed of switching and other mechanical parameters are relatively accurate. Therefore the system can conduct the task of on-line monitoring successfully.

Conclusion

According with the development tendency of intelligent substation, the proposed system makes a huge change to the online-monitoring of the primary devices on the process layer of traditional substation. The multi-tier distributed GIS online monitoring system can monitor various parameters, which meets IEC61850 standards. Its reasonable structure of the hardware layout can achieve a clear division and coordination between layers. It also meets the instantaneity, reliability, interoperability requirements. Obtaining online monitoring data is the basis for condition-based maintenance and fault diagnosis. With the development of smart grid, the on-line monitoring system proposed in this paper will have wide application.

REFERENCES

- [1] Dale Rogerson. Inside Com. Redmond[M]. Washington, U.S.A: Microsoft Press, 1997.
- [2] Loeb L B. Electrical Coronas. University of California Press, 1965.
- [3] M • Landry et al Benefit Case studies of On-line Condition Monitoring System for HV CBISH.97 Canada 1997.
- [4] Breg D, works G N. Effect of space charge on electric breakdown of sulfur hexafluoride in non uniform fields. AIEE Trans, 1958, Vol.77:p820~823.
- [5] Charbkeaw N, Sunwanasri Thanapong, Bunyagul Teratam. Mechanical defect detection of SF6 high voltage circuit breaker using wavelet based vibration signal analysis[J]. Telecommunications and Information Technology, 2008, ECTICON, 2008, (2): 901-904.
- [6] IEC62063 , High-voltage Switchgear and Control Gear-the Use of Electronic and Associated Technologies in Auxiliary Equipment of Switchgear and Control gear[S].