TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 10, October 2014, pp. 7176 ~ 7185
DOI: 10.11591/telkomnika.v12i8.5320

Research on the Web-based On-line Monitoring Technology of the Smart Substation Primary Equipments

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Abstract

Smart substation primary equipment on-line monitoring technology is an important part of the realization of substation intelligentizes monitoring. In order to meet the requirements of smart substation on high-speed, efficient, steady on-line monitoring system, the sharing of online monitoring data of the power station and to improve interoperability of on-line monitoring device, the primary equipment on-line monitoring technology of smart substation based on the network is proposed by this paper. Based on the analysis of the substation primary equipment monitoring parameters, according to the three levels and two network structure, the author designed primary equipment monitoring terminal (process level), primary equipment on-line monitoring IED (bay level), the monitoring center (station level) respectively, and between each level there are communication network structures. The scene practical operation analysis shows that, on-line monitoring system for substation which based on the network is stable and reliable, and the change of the equipment running status can be monitored accurately and timely.

Keywords: *on-line monitoring, smart substation, primary equipment*

1. Introduction

Intelligence of the substation equipments is the key technology of the smart grid. The smart substation online monitoring system is an important technical method of conducting the overhaul and management of the power transmission and transformation equipment operation status and enhancing the lean level of substation primary equipment production and operation management. The web-based primary equipment on-line monitoring technology of the smart substation will become a growing trend for future development of the smart substation.

The development and application of on-line monitoring technology in China began in 1980s. Due to the limitation of the overall technical level at that time, the first upsurge has appeared in China until 1980s. But in the mid 1990s, it entered a low tide period. However, some manufacturers and research institutes did not give up their efforts to make continuous research on that technology; and around the world the power supply departments began to introduce on-line monitoring technology in succession. With the development of condition assessment and the state overhaul, especially with the establishment of the digital network and the smart power grid, the on-line monitoring technology has received increasing attention from the domestic enterprises. In particular, the field of power transmission and transformation, highlighted in the smart grid construction, brought the more vast development space for the on-line monitoring technology.

In western countries, the emphasis of the monitoring work has been placed on key equipments such as transformers, SF6 switches and GIS equipments, power cables, MOA and so on. And most of the monitoring tasks aim to acquire the system operation parameters, even for the insulation monitoring, which is mainly due to the fact that the foreign grid is comparatively fully developed, and the network is widely spread and widely used. Therefore, there are fewer requirements for the single equipment monitoring.

In China, real-time perception, monitoring and early warning, analysis diagnosis and assessment prediction of the smart substation on-line primary equipment operation status can be achieved by the smart substation on-line monitoring system through various sensor technologies, wide-area communication technology and information processing technology.

Received December 15, 2013; Revised June 28, 2014; Accepted July 18, 2014

Thereby, its construction and promotion work can upgrade the level of smart grid and realize smart substation primary equipment working state management. But with the construction of smart substations, there are some problems existing in the condition monitoring devices and the intelligence of electric power system: (1) Device functions and interfaces of different online monitoring manufacturers are not compatible and poor in interoperability, costing the users more money for follow-up preventive maintenance; (2) The state data needs to be sent from the substation status monitoring system to the information system to improve information sharing ; (3) Problems of under-standardization in the information model, analysis model and the data interface still exist, which brings difficulty in the proper use of the data.

According to the modern communication network technology and IEC61850 standard, the web-based on-line monitoring system of the substation is put forward by this paper, which is mainly composed of the on-line monitoring equipment, intelligent electronic device (IED) and the information integration platform, respectively arranged at the substation process level, the bay level and the station level. RS485/CAN/Zigbee/GPRS is adopted by the process level and the bay level to communicate; the bay level and the station level make use of the optical fiber to transmit data in accordance with IEC61850 standard.

2. The Architecture of the Substation Primary Equipment On-line Monitoring System [2, 8]

In China, the web-based on-line monitoring system for substation equipment is composed of three levels and two networks [2] , in which three levels refer to the process level, the bay level and the station level, and two networks refer to the station level network and the process level network. This is a service-oriented architecture, in which different structural application functional units of the program (called services) can be linked up with protocols through these well-defined service interfaces. All the substation equipment running status parameters can be collected by the station level, and then the data, in accordance with IEC61850 agreement, will be uploaded to the province network side (PMS).The system diagram is shown in Figure 1.

The process level mainly consists of a variety of sensors, the primary equipment on-line monitoring terminals and so on. The primary equipment running status values can be acquired directly by the on-line monitoring device or indirectly by the sensors of the on-line monitoring device; and then through digital processing and calculation of the status values, the status monitoring data will be obtained. Finally, the status monitoring data will be transmitted from the process level network to the IED of the bay level so as to get configuration and control information.

The bay level, mainly including the transformer on-line monitoring IED, arrester on-line monitoring IED, circuit breaker on-line monitoring IED, capacitive equipment on-line monitoring IED, switch cabinet on-line monitoring IED etc., is responsible for data acquisition of the process level. Then through relevant data operation processing, the data, in accordance with IEC61850 standard, will be sent out from the station level network to the control level monitoring center, I order to obtain sampling commands and configuration information.

The station level is mainly composed of the station field control, remote communication, synchronization, the monitoring center, assistant decision-making subsystem and the information integration platform. Data communication and control commands can be completed through the IEC61850 protocol between the platform and various subsystems. In the future the subsystem functions can be directly integrated in the information integration platform.

There are five technical features of the station level network: owning data interaction interfaces between the station level and the bay level, data interaction interfaces within the station levels and data interaction interfaces within the bay level; possessing such functions as fault monitoring, fault self-recovery and data verification etc.; conducting convenient maintenance via software and hardware to reduce side-effect on the whole system to the minimum degree; supporting the transmission of the MMS (support message specification) information and joint locking information; and sharing the unified IP address in the station level to avoid the conflicts of IP address in the whole network.

The process level network also displays four technical features. First, the amount of information in GOOSE network and SV network can satisfy the requirements for real-time transmission and reliability, though the information in the network can be transmitted through no more than 4 level switch cascade. Second, as the topological structure of the star network is adopted by the process level network, the substation VLAN (virtual local area network) can be categorized according to the data traffic and data flow to realize the data isolation. Third, the VLAN domain data interaction performance and even the whole process level network performance will not be affected by the failure of any single point in the entire network. Lastly, as double configuration is employed in the network, the dual network is physically independent and dual network redundant configuration will ensure normal operation of one network regardless of the other network failure or paralysis.

3. Analysis of the Primary Equipment On-line Monitoring Technology

3.1. Monitoring Parameters [7]

At present, among the 220kV and above 220kV voltage level, the online monitoring objects mainly include the main transformer, high voltage parallel reactor, GIS, lightning arrester, circuit breaker, etc. As for the 110kV and below 110kV voltage level, the main transformer and arrester, will be the online monitoring targets, involving dissolved gas of the main transformer oil and arrester leakage current and arrester action times, etc.

(1) Transformer on-line monitoring

In substation, the transformer is the most important electrical equipment, in which the main monitoring items include the transformer oil dissolved gas and micro-water on-line monitoring, winding deformation on-line monitoring, temperature on-line monitoring, partial discharge on-line monitoring, iron core earth current on-line monitoring, casing insulating properties on-line monitoring etc.

(2) Circuit breaker mechanical properties and electrical performance online monitoring

The high-voltage circuit breaker is the most crucial switchgear in the power system, of which the on-line monitoring items involve the insulating gas (SF6 circuit breaker), breaking times, the breaking current waveform, the contact stroke, the vibration waveform, the open/close coil current, the operating mechanism oil pressure, and the energy storage motor current etc. For the 750 kV SF6 circuit breaker, the on-line monitoring items also comprise SF6 gas status monitoring and circuit breaker partial discharge on-line monitoring. The principle and methods of the circuit breaker on-line monitoring are basically the same as the GIS on-line monitoring.

(3) Lighting arrester on-line monitoring

When suffering impulse voltage, the lightning arrester will release energy in the form of electric current, and finally conduct it into the earth. As soon as impulse voltage disappears, the lightning arrester will return to the system power frequency voltage, under whose control the micro leakage current will come out of the lightning arrester internally and externally and flow through the earth. Arrester insulation performance can be directly displayed by the lightning arrester leakage current, especially the resistive current.

(4) Capacitive equipment on-line monitoring

The capacitive equipment, the electrical equipment with the capacitive screen employed in its insulation structure, accounts for about 40% of the substation electrical equipments. As the capacitive equipment is composed of the current transformer, capacitor voltage transformer, capacitor, insulating porcelain column, high voltage casing and capacitive lightning arrester, the major monitoring characteristic quantity include the dielectric loss, leakage current, equivalent capacitance (some can also monitor partial discharge) etc. This kind of on-line monitoring can be realized by the leak current sensors installed on the capacitive equipments such as the porcelain column, casing or lightning arrester. Its dielectric loss value can be calculated through the phase difference between the leakage current and the system voltage.

(5) SF6 gas on-line monitoring

Owing to its efficient insulation performance, SF6 gas, as the arc quenching and insulating gas, has been widely used in the power system, including the high-voltage circuit breaker, the mutual inductor and GIS. SF6 gas could maintain equipment insulation level and possess excellent arc quenching capability, for indoor gas insulation strength depends on the density value of SF6 gas, namely, SF6 gas molecule numbers per unit volume, which has nothing to do with the temperature. Density value is represented by the 20□charging pressure.

The decreased SF6 gas density caused by leakage of equipments may bring about serious consequences such as the reduction of the switchgear applied voltage strength and the reduction of the circuit breaker breaking capacity etc., which would result in the poor electrical performance of devices. When the environment temperature changes, the leak position will give rise to the "breathing" phenomenon; and when the external moisture enter the interior of the high-pressure devices and lead to the increase of SF6 gas humidity, the poor electrical performance and even safety accidents would take place. Thus, in order to ensure safe and reliable operation of the insulation equipments, the density of the SF6 gas, gas leak, gas micro water content etc. must receive the real-time monitoring.

(6) High-voltage switch cabinet on-line monitoring

High-voltage switch cabinet contains high-voltage switch equipment components, bus, support insulator etc. Its safe operation would be threatened by the defects or deterioration of the internal insulation parts and the poor contact of the electric conduction linking parts. Discharge fault defects of the high-voltage switch cabinet mainly includes the following aspects: metal protrusions of the conductor and the coat internal surface, defects and aging of the insulation parts; surface filth of the support insulator; the linking points of high-voltage bus, poor contact of main circuit contacts of the high-voltage switch and the circuit breaker contacts, internal discharge defects of the switch elements etc. As the discharge phenomena are likely to occur in the accident latency period, more information about the operation of the high-voltage switch cabinet would be acquired by monitoring of partial discharge.

3.2. Design of the Monitoring Center Software [5, 10]

In general, the monitoring center software, shown in Figure 2, can be divided into the substation network, city bureau network, and the provincial network.

In substations, the substation layer is responsible for collecting operation status data of the whole substation equipments and the health information. Various kinds of substation equipments monitoring information will be visually displayed by station level monitoring center. As the source of data, the substation system will start to deploy from the substation layer, which is mainly employed for the station monitoring, involving data sampling, access control, monitoring data display and so on. In accordance with the IEC61850 protocol, the substation layer, taking the optical fiber as transmission medium, carry out data or command interactions with all intelligent logic equipments. The sampled data will be stored in the local network. And with IEC61850 protocol as the communication agreement, the substation layer will get ready for the external data communication. On the one hand, data sharing can be realized between the substation and the other external systems; on the other hand, the monitoring data can be uploaded level by level. Substation data will first be uploaded to the upper level, namely the city bureau network.

The city bureau is in charge of such tasks as data collecting from subordinate substations, centralized displaying of the substation equipment running conditions, local backup implementing of the operation data, and subordinate substation data transmission by the standard data interfaces to province network side, so as to complete the timely upload of the regional electric transmission and transformation operating situation. In addition, substation related equipments can also be handled by expert system software. Hence, it is helpful and feasible for the city bureau to perform the monitoring management of any subordinate substation.

After collecting data uploaded by the city bureau about regional power transmission and transformation equipments status, the province network side will establish state monitoring database to unify the storage of the substation equipment status data of different regions. And then the collected data will be processed and shared in the production management system of the province network side, so as to fulfill advanced application of the monitoring data and provide reference of daily management work for province network side product technology departments. The auxiliary decision-making system of the province network side expert software can make prediction of all kinds of monitored device operating status at different levels and figure out the sequence of the equipments that need to make maintenance according to the different levels and scores, so as to improve the efficiency of maintenance work deployed by the province network side. The key information via data service center can be sent to the national grid headquarters to fulfill the upload about working conditions of regional power transmission and transformation. Another function of the status monitoring database is to achieve data sharing with other application systems through the enterprise service bus, so as to realize the potential of the on-line monitoring data and provide assistance in information integration for the province net side.

4. Design of the Substation Primary Equipment On-line Monitoring Network

China State grid company formulated the standard DL / T860 "Substations communication networks and systems" based on IEC 61850 to realize the automation and equipment interoperability among online monitoring equipment manufacturers. The hierarchical distribution design is adopted by the smart substation, namely, the station level, the bay level and the process level. Each level consists of different devices or different subsystems so as to fulfill different functions.

Seen from Figure 2, different communication media are employed by the communication network according to different levels of data transmission. In the process level, the communication between sensors and on-line monitoring devices can be achieved by the optical fibers, cables and wireless media (such as infrared, Bluetooth, ZigBee). To be specific, monitoring terminals of the on-line monitoring system, the important equipment of the process level, can provide the input / output interfaces etc. They can communicate with the bay level IED through the wired ways such as RS232, RS485 or CAN bus cable etc. or wireless ways like WiFi /ZigBee etc., and gather the sampled data from the monitoring terminals. The communication between the bay level IED and the station level could be realized through IEC61850 protocol. The station level consists of standing domain control, remote communication, synchronization subsystem and the information integration platform; and the communication of data and control instructions between information integration platform and each subsystem could be achieved by the agreement IEC61850. Finally, the communication within the station level could be realized through the I2 protocol (communication Protocol of on-line monitoring system of power transmission and transformation equipment in China State Grid Corp).

4.1. The Design of Network between the Sensor and the On-line Monitoring Device

At present, various ways of connection between the sensor and on-line monitoring equipments will be employed in on-line monitoring system, such as the point-to-point transmission connection, serial port and parallel port connection and the wireless network connection etc. Among them, the wireless sensor network composed of the field-bus connected sensor controller and the self-organizing wireless access network, compared with the traditional center processing, has the advantages of high robustness, high accuracy, strong flexibility and so on. The diagram of the field bus and the self-organizing wireless sensor network is shown in Figure 3. The primary equipment status values can be acquired by sensors, and then uploaded to the on-line monitoring device by bus or wireless network.

In the field bus network, as cable is used as the transmission medium, RS-485 communication mode can be employed to achieve the signal wired transmission. Adopting half-duplex working mode, RS-485, at any time, only has one point in the sending status. It is very convenient when RS-485 is used in the multipoint interconnections, for a lot of signal lines can be saved. In wireless sensor networks [9,11], most of the nodes are static, except a small number of mobile nodes. The wireless sensor network, compared with the wired sensor network, possesses the characteristics of small volume and low energy consumption etc.

4.2. The Design of Network between On-line Monitoring Device and IED

Nowadays, the smart substation is commonly designed as two parts, with one part concerning measurement and control system and protection system, and the other part concerning on-line monitoring network. The bay level network and the process level network are generally categorized as the star-like structure and the ring-like structure, or SMV network and GOOSE network. SMV network is mainly responsible for uploading data of the current and voltage alternating current, while GOOSE network is in charge of uploading the data of the switching value, break-brake/close-brake control and anti-mistake defense,etc. Among the present domestic and foreign pilot stations, SMV samples value networks of 220kV and above 220kV substations, with regard to such factors as safety and reliability etc., generally operate in the way of point to point and few sites employ part interval networking; SMV sampled value network of 110kV and below 110kV substations adopt networking modes and communicate with the IEC 61850-9-2LE.

The on-line monitoring device could communicate with the bay level IEDs through the wired way of RS232/RS485/CAN or the wireless way of WiFi/RFID/Zigbee. The data measured by the sensors of on-line monitoring device can be uploaded to IED through the communication network, and then it would be processed and calculated by IED, with the equipment failure information being stored and displayed locally [2, 6]. Figure 4 illustrates the communication network between IED and on-line monitoring equipment.

4.3. Design of Communication Network between IED and the Integration Platform of Information

The future smart substation communication network structure between the substation level and the bay level is generally built according to the design idea of the double-loop and double-network structure, which will make data communication of the whole substation communication network smoother and the communication network stronger. The network structure is shown in Figure 5.

Generally speaking, common network transmission of the double-loop and double-net network structure can be accomplished by MMS, GOOSE, SNTP and IEC 61850, among which MMS is responsible for the transmission and protection of the measurement and control action information, alarm information, primary device status information and background control command etc., GOOSE is employed to transmit the five-case united atresia information, SNTP is used to set time for the station level equipment, and IEC 61850 is the transmission protocol of the primary or secondary equipment on-line monitoring information.

The information integration platform is located in the station level. The functions such as data sampling and monitoring, operation atresia and fault recorder etc. can be fulfilled by station level, involving various kinds of application subsystems such as the automation system, communication system, synchronization system, online monitoring system and so on; the data are gathered from different kinds of merging units of the equipment level and IED, and then they are processed by IED and are transmitted to the information integration platform, so as to realize centralized management and information sharing of the subsystems of all levels. In order to ensure the system safety and reliable operation, double-network backup mechanism[2] is adopted by the network structure.

5. Design of the Key Technology [4]

5.1. Design of On-line Monitoring Terminals

The process level of the on-line monitoring system includes the substation primary equipments, sensors and field processing units, among which the sensors and field processing units are known as the monitoring terminals. At present, the sensor technology has been fully developed, and the function of the monitoring terminals is to collect data and make preliminary treatment, so as to make A/D conversion and classified storage of the non-digitalized sensor information.

The circuit breaker online monitoring terminal, designed by the author of the thesis, makes use of DSPTMS320F28335 as the core of circuit breaker intelligent monitoring unit and deploys in the modular structures, including the DSP28335 minimum system, communication module, signal conditioning module and power supply module etc. Figure 6 illustrates on-line monitoring unit core hardware structure. As the output signals sent by the sensor is much smaller and the voltage does not match with that of A/D sampling module, the signal conditioning circuits need to be adjusted. Then the signals would be sent to the A/D model to convert, and finally would be processed through DSP treatment. At the same time, FPGA is employed to detect B codes in this system and to realize synchronous sampling of multiple units.

5.2. The Design of On-line Monitoring IED

The English full name of IED is the Intelligent Electronic Device. In the IEC61850 protocol, IED is defined as a kind of device consisting of one or more processors, which possess the capacity to receive external resources or send data or control commands to external resources. IED, the key equipment in modern smart substation bay level, could carry out coordinate work and bidirectional data communication with the information integration platform and the process level (including intelligent devices, merging units and intelligent terminals). It plays an important role in the smart substation status monitoring system and auxiliary system.

In the substation, intelligent monitoring IEDs, according to the types of monitoring equipments and their different installation locations, can be categorized into transformer monitoring IED, circuit breaker monitoring IED, capacitive equipment monitoring IED, lightning arrester monitoring IED and SF6 gas monitoring IED etc. Although each IED has different functions, the main functions of IED include data extracting, data stipulating and data uploading etc. Apart from the transformer IED control of air-cooled control terminals (air-cooled control should realize congealer switching control function through remote control, local control and automatic control etc.), other IEDs are similar with each other in the hardware design and the software design.

IED, as the bay level equipment of the substation on-line monitoring system, is not only responsible for receiving accurate and real-time sampling commands from the station level, timely issuing commands to the process level sampling devices, and sending upload data of the process level back to the station level, but also responsible for recording abnormal incidents of the breaker to make early warnings or alarms as well as afterwards analyses. On the whole, coordination, transmission, data processing, and IEC61850 protocol embedding and other functions will be fulfilled with the help of IED.

Take the circuit breaker on-line monitoring IED [12] as an example, which is designed by the authors of the thesis. In order to satisfy the requirements of high-speed and real-time property, the structure of ARM+DSP is used in order to ensure a quick and efficient transmission ability and powerful real-time monitoring function. ARM9 chip S3C2440A of Samsung Corp. is used as the ARM chip. Together with other hardware equipments such as peripheral keyboard, LCD, Ethernet communication etc., ARM9 chip can conduct the entire system management and control, including sending the instructions to DSP, sending fed back data, further data processing, storage and display, and communicating between DSP and the station level server. 2000 series TMS320F28335 chip of Texas Instruments (TI) Company is used as DSP chip, which take advantage of DSP high-speed arithmetic and the characteristic of on-chip peripheral to complete circuit breaker status data sampling, calculating and analyzing, and at the same time in response to the ARM requirements, the data processing results are sent to ARM. The overall hardware architecture of the circuit breaker monitoring IED is shown in Figure 7.

As for software data communication of the circuit breaker monitoring IED, the data communication modules include the communication between ARM and DSP, the communication between DSP and monitoring terminals, and the communication between ARM and the station level.

In the operation process, the host computer ARM, in accordance with the configuration file, initiates the polling function, issues sampling commands to circuit breaker monitoring terminal equipments until it arrives at the polling time according to the pre-set communication protocol, and finally wait for the return value (The SPI interrupt request sent from DSP to the ARM). The flow diagram of the system software is shown in Figure 8.

5.3. Specifications of IED Embedment in IEC61850 Standard [3,13]

IEC61850 is object-oriented, with the development model to make dynamic and static design and with the method of object inheritance to contrive the classes of different levels. A uniform data object model can be built for the system by IEC61850. IED contains various logical devices (LD), which include the logical nodes (LN); and each logical node (LN) involves different data and data attributes. Detailed description of each class can be provided by IEC61850, including the corresponding attributes and services; and then the server of those IED could provide external access interfaces. In this way, it is clear to see the services provided by each IED; and the communication between IEDs is visible. Therefore, IED interoperability and design standardization can be realized via the embedded IEC61850 protocol. IED data model represents its data types, that is to say, IED data model decides which data needs communication and how the data communicate. IED hierarchical model is shown in Figure 9. In

IEC61850, the logical nodes are the basic data models, which include certain data objects composed of corresponding data attributes.

Embedded Ethernet is applied by IED, so that it can be directly connected with the substation automation system network without making use of the central processing units, communication units and protocol conversion units, gateway and other intermediate links. As IEC61850 is also adopted by the station level, it can save much time for the entire system design and maintenance.

5.4. The Design of the Backstage Software

In order to make it easier for updating and expanding, modular and hierarchical design should be adopted by the backstage software. Modules can be configured flexibly, owing to its high cohesion. The interfaces between different levels should be clear and concise, and possess strong compatibility and expansibility, so as to ensure that the technical transformation of certain level will not exert any influence on the other levels. The backstage software should display the functions such as information collection, remote communication, analysis and early warning, management and maintenance, security authentication, information display, data export and operation monitoring, etc.

The specific functions of the software system include:

(1) High-voltage equipments status panoramic information collection and modeling: unified modeling of the different data types and data sources could provide complete panoramic information database for equipment diagnosis;
(2) Parameter management of the main equipments and monitoring equipments;
(3) Status monitoring data analysis and early warning;
(4) Equipment status evaluation, which could provide the device status reference for extension of the intelligent dispatching function;
(5) Calculating equipment risk value according to the power transmission and transformation equipment risk assessment models, processes and methods: identifying the potential external threats and internal defects of the equipments, analyzing the assets loss degree and threat probability after the equipment suffering inefficacy, and acquiring equipment risk grade in power grid through risk evaluation model;
(6) Providing threshold, so as to give alarms;
(7) Real-time receiving and analyzing the command messages.

Expert software is installed in the station level of the smart substation, and its working principles are as follows: the expert software distributes an IED for a set of the same type high voltage devices, and each IED collects the sampled data from different monitoring terminals through the connection between the process level network and the subordinate monitoring terminals; then accurate information, with analysis and encapsulation by the IEC61850, can be obtained to do data fault tolerance; and in the process of transmission the abnormal data will be marked and fed back to the IED for data extraction once again, until the normal data has been acquired; in the repeated operations, the monitoring of the IED working conditions and health status can be realized. IED can make a comprehensive analysis of the data from different monitoring projects, and eventually arrive at a conclusion of the comprehensive diagnosis results for the monitored equipments. The fault points and their detailed information will be stored in the local, and the control commands will be issued for the on-line monitoring devices so as to locate and correct errors or prevent the faults.

6. Analysis of System Running Examples [5]

The substation status monitoring system described in this paper has been successfully applied to one 220kV substation of the national grid. The transformer partial discharge monitoring sensor is shown in Figure 10 and the site installation of various transformer monitoring IEDs in the transformer intelligent component cabinet are displayed in Figure 11.

Transformer monitoring equipment consists of the following modules: transformer summary, transformer collecting, oil gas and micro water monitoring, partial discharge monitoring, transformer working condition monitoring, cooler unit monitoring, and under-load tap changing voltage monitoring. The transformer current running status and the monitoring remnant data and alarm threshold of the test items can be calculated and exhibited. This module contains current transformer oil chromatographic monitoring data, historical data, historical curves, and algorithm analysis, etc., which is shown in Figure 12(a), 12(b).

Figure 13 illustrates the field installation of high-voltage circuit breaker monitoring device and the intelligent component cabinet and various sensors installation. Parameters such as insulation gas (SF6 circuit breaker), breaking current waveform, break-brake/close brake coil current, the operating mechanism stroke, speed and mechanical vibration, contact temperature rise and other parameters can be displayed by the expert system, as is shown in Figure 14.

The main monitoring values of Zinc oxide lightning arrester include resistive current and total leakage current value. Zinc oxide lightning arrester insulation status can be reflected by the total leakage current value, and its resistance current value is a more sensitive indicator of the insulation performance. Lightning arrester on-site monitoring terminals and expert software interfaces are demonstrated in Figure 15 and Figure 16 respectively.

In order to display the real-time monitoring information and historical data, corresponding software modules are respectively configured for other substation equipments, as is shown in Figure 17.

Furthermore, in substation, the real-time status of the secondary smart components of on-line monitoring control cabinet can also be displayed by status monitoring expert software, which contains the faults, start and stop, and the current temperature of the control cabinet. On the basis of the realistic foundation running status, the control work of the intelligent component IED can be completed by status monitoring expert software, as is shown in Figure 18.

7. Conclusion

With the help of the network-based smart substation on-line monitoring system, the power companies, in a convenient and highly efficient way, are capable of acquiring the real-time substation primary device status information, understanding the operation condition of equipments, assessing system operation risks, timely and effectively making maintenance planning, and enhancing security and stability of the system. What's more, according to the production management system (PMS), the asset management can be optimized, device resources can be explored appropriately, operation costs can be reduced, and drastic benefits can be produced.

However, restricted by the current level of technology, much improvement should be made on the intelligence of the substation equipment status monitoring system, especially the improvement on reliability, accuracy and stability of the monitoring equipments and the standardization of IEC61850. In addition, further studies should be made to better integrate the real-time information and non real-time information and to upgrade online status diagnosis and intelligent prediction.

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