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Development of an Overall Condition Monitoring System of High Voltage SF_6 Circuit Breaker

YUE DONG, DENGMING XIAO
Electronic Information and Electric Engineering
Shanghai Jiao Tong University
1954 Road Huashan, Shanghai
CHINA

Abstract: - ***With the rapid development of arts of sensors and IT, on-line monitoring of circuit breaker is now desirable and practical for electric power utilities. This paper describes a set of overall on-line monitoring systems that was developed to control and monitor the condition of SF_6 circuit breaker with different type of sensors and microcomputer based controller. The aim of the developed system is to provide overall information about the conditions of each part of SF_6 circuit breaker as much as possible to diagnosis the incipient faults and potential defects in circuit breakers.***

Key-Words: - SF_6,, circuit breaker, on-line, sensor, fault, condition monitoring

1 Introduction

Maintenance of circuit breakers in power substations has been traditionally based on the time schedule (at fixed intervals). That criterion, aside from having significant costs for the concessionaries, often does not provide the answer to an immediate need of maintenance and availability requirements in the circuit breakers, the maintenance schedule established were based on fault history, number of operations, age, etc. In case a circuit breaker malfunction is detected or there exists an imminent fault, an off-line maintenance is usually done.

It is known that for the routine time-based maintenance of circuit breakers, in between maintenance outages, it is never clear if the circuit breaker functions exactly as desired, so this kind of maintenance is expensive, inefficient, and may be delayed. However, with increasing awareness of the benefits of condition-based maintenance, it can be expected that there will be advantages to be obtained from monitoring the condition of the circuit breaker in order to ensure that maintenance is carried out only when it is really needed.

On-line condition monitoring systems offer the opportunity for utilities to move towards a condition based maintenance philosophy. It has been shown that time based maintenance has little effect in detecting the defects that may cause future failures. Moreover, it has also been proven that intrusive maintenance can introduce failures. There have been many papers on the benefits of on-line condition monitoring and the arguments put forward range from an increase in operating and maintenance efficiency to the forecasting of equipment failures. Moreover, apart from being economically feasible, it is essential that these monitoring systems measure the appropriate parameters and do not affect the reliability of the circuit breaker.

In our countries utility, there exist some circuit breakers that have served for years and should be replaced by new type circuit breaker according to utility procedures. However, many of them do not wear so much that should not be expired because of relatively few fault currents occur on them during their service careers. Thus, there exist necessities to diagnose the real endurance of that circuit breaker for possible continuous service and economical saving.

In this paper, a set of overall on-line monitoring systems are constructed to control and monitor the condition of SF_6 circuit breaker with advanced sensors and microcomputer based data acquisition and procession system. The aim of the developed system is to provide overall information about the conditions of each part of SF_6 circuit breaker as possibly as it can, to diagnosis the incoming faults and potential defects on circuit breaker in time.

2 Description of Monitoring System

The system is a diagnostic and monitoring system for SF_6 single-pressure, spring-operated power circuit breakers rated 220kV and above. It consists of a modular microcomputer units and sensors. The units here are composed of two parts: one is the unit that functions the measuring the conditions of circuit breaker, such as contacts wear, integrity of the SF_6

gas system, the circuit breaker mechanical system, the electrical control system and auxiliaries etc., another is the unit that functions the data acquisition and processing with a microcomputer based system.
his system is designed and tested to operate under a wide range of temperatures, from -40°C to +70°C, and to survive electromagnetic interference conditions in a substation environment. The unit that functions measuring housed in a metal enclosure contains several dedicated electronic board assemblies, which is installed inside the circuit breaker control cabinet or in an additional enclosure mounted on the side of the control cabinet. Its sensors were used for the monitoring system detect necessary parameters to determine the condition of the circuit breaker, such as gas density, temperature, current, etc. The unit that functions data collection and procession has a local monitoring PC unit and remote controlled PC unit. The former continuously collect data from those sensors transfer the data to the remote controlled PC. The latter receive and store data in memory, perform calculations and compare data against established limits or set points for each parameter. The user-interface software allows the user to access and download information and change the set-point values. The functions performed by the system are: determine the wear of the interrupter arcing contacts, monitor the mechanical vibration waveform, monitor the integrity of the SF_6 gas system, record circuit breaker phase currents, moving contact travel characteristics, operating times and number of operations, record the status of the close/open windings and auxiliary switches, monitor the operation of air compressor system.

2.1 Sensors of monitoring system

The system has sensors for SF_6 gas pressure, temperature, humidity, current, contact travel and vibration. The SF6 gas pressure sensor provides a direct voltage signal to the data acquisition board, which is proportional to the SF6 gas pressure inside the circuit breaker. The pressure sensor is mounted on the wall of special-made gas container, which is directly connected to the gas piping of the circuit breaker. The sensor has a measurement range of 150 psig with an accuracy of ± 0.5%.
The temperature sensor is platinum resistance temperature device that change their resistance by a known value depending on temperature. The sensor has a positive temperature coefficient of 38.5 every 100ºC. The sensor is mounted in the gas container (mentioned above) to measure the SF_6 gas temperature.
The humidity sensor used here is a capacitive humidity device for low humidity measurement with good stability, strong corrosion resistance ability and fast responsibility. The humid-sensitive medium of the sensor is macromolecule membrane material. The sensor has a humidity probe integrated with three pin-out terminals, which translate the change of the value of two capacitors (one varies with the humidity of environment whereas another is a reference one that does not vary with environment) into frequency. The frequency difference is translated into a voltage signal indicated as relative humidity with a range of 5 volt by frequency-voltage transferring, filtering and amplifying circuits.
To measure phase currents, miniature clip-on current transformer is used. The CT (current transformer) has a split core design and is mounted on the wires that carry the signal from the circuit breaker bushing. The CT includes an integral shunt resistor to provide a voltage drop as input to the data acquisition board.
To measure the currents of the open/close coil, Hall Effect type current sensor is used with simple structure, fast responsibility and wide frequency range. The sensor based on the Hall Effect principle has a hollow core design and is mounted on the open/close windings, which pass through the hollow core of the sensor and do not affect the operation of the circuit breaker. The sensor has a measuring resistor that provides a voltage drop as input to the data acquisition system.

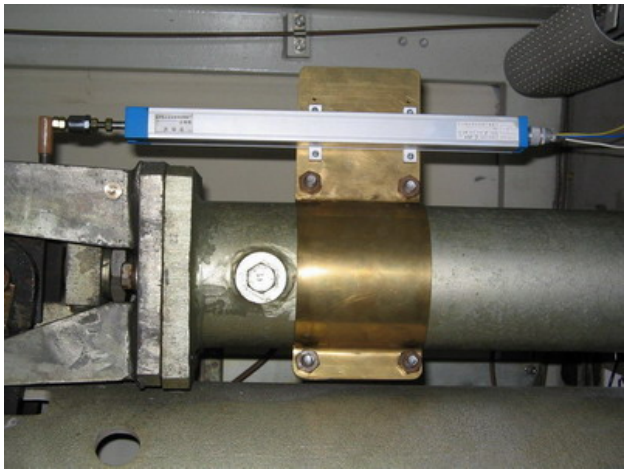

Fig.1. Installation of resistive sensor on circuit breaker operation mechanism

Resistance-slip type travel sensor is used to measure contact travel. The sensor comprises anodic-processing aluminum crust body; signal translation circuit with an input resistance 5KΩ and solid stainless steel bearing that provides smooth and tight linear movement. Plastic conductor rail in the

sensor surface and thulium metal pin guarantee the stability of output signal, low noise, long live actions. The sensor shown in figure 1 is usually installed inside the mechanism. The end of the moving pole of the sensor is fastened on the insulated parts of the mechanism, which moves in the same direction as moving contact does, while the crust body of the sensor is fixed on a reference part that is machined specially to link the parts of the operation mechanism. The fixed kickstand manufacturer provides makes a fast and firm installation in any place of aluminum slot. The linear movement is translated into a direct voltage signal with a measurement rang of 12 volt and accuracy of 0.1%.

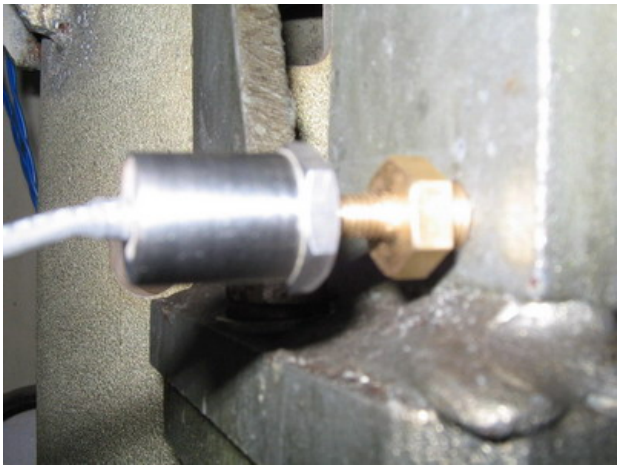

Fig.2. Installation of IC type accelerator on circuit breaker operation mechanism

The piezoelectric accelerator shown in figure 2 is usually used to measure the circuit breaker vibration when the circuit breaker operates. Depending on the characteristic of the HV circuit breaker vibration, high sensitivity of used piezoelectric material of the sensor fits well for acquisition of high frequency part of vibration signal. Meanwhile the sensor has ability of surviving high impact force caused by the circuit breaker operation.

The sensor used here is a miniature IC type accelerator that integrates the typical accelerator with a charge amplifier, which make the measurement easy and increase the accuracy and reliability. The sensor is mounted with M5 screw thread installation, which is easy for installing on different places of the operation mechanism. Small impedance output, good disturbance resistive ability and low noise make the measuring signal distortion-immune. The mechanic vibration is translated into a voltage signal as input to the signal procession module.

2.2 Hardware

The monitoring system hardware shown in figure 4 and 5 includes sensors, electric board assemblies, local monitoring unit, and remote monitoring unit. The local monitoring unit shown in figure 3 is an industrial computer controller that collects variety of data from the different signals of sensors, and transmits data to the remote monitoring unit (usually be a high performance PC). The PC store the data received from local monitoring unit, process the data with software composed of several modules, and create database. The results from software modules are stored in computer, displayed on LCD, or printed whenever needed.

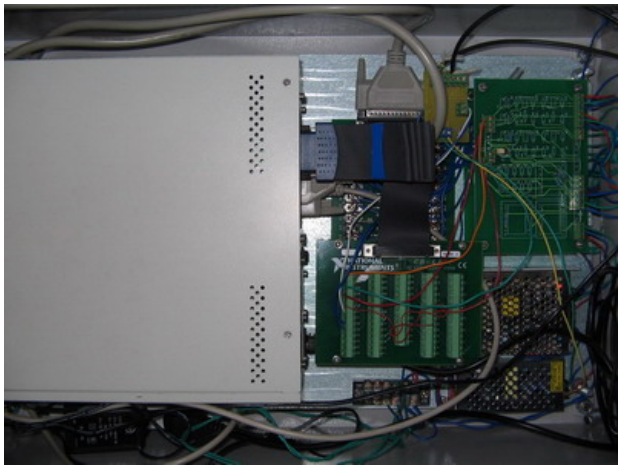

Fig.3. Local motoring unit and terminal boards installed in cubicle

The system has four electric board assemblies. Each of them has an additional circuit on its purpose of the board. The Auxiliary board interfaces with heaters CT's, temperature sensors monitoring temperature of the operating cabinet and gas pressure sensor measuring the air pressure of charging compressor.

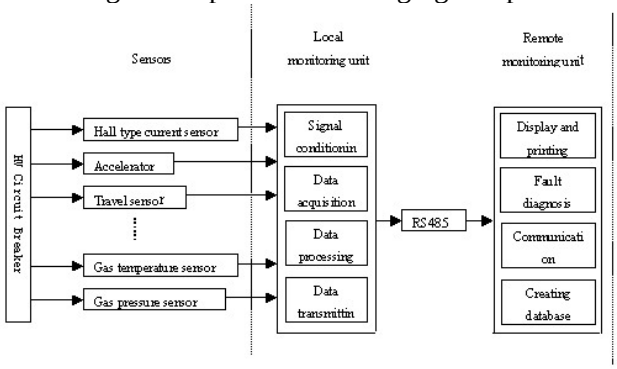

Fig.4. Structure diagram of monitoring system of single circuit breaker

The pole board has a constant power module that supplies power to piezoelectric accelerator that measure the vibration caused by the circuit breaker operation. The Pole Board also interfaces with one travel sensor and up to three clamp-on phases current

CT's. It detects when control coils are energized and can read the state of two auxiliary switches.

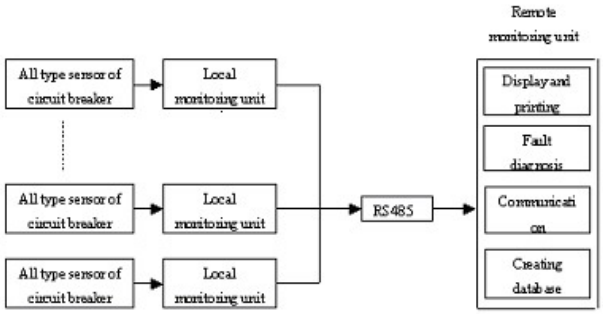

Fig.5. Structure diagram of monitoring system of multi-circuit breakers

The gas board interface with SF_6 pressure sensor, temperature sensor, and humidity sensor, which monitor the relative humidity of SF_6 gas in arc chamber. The sensors are installed in a good sealed container filled with SF_6 gas and connected with the pipe of SF_6 circuit breaker.

The alarm board controls a liquid crystal display, red, yellow and green indicator lights and two relays that indicate alarm conditions. The CPU Board has a port for communication with remote monitoring computer either via direct cable or modem connection.

The wires lead from these boards is connected with a universal screw terminal board, which is provided with flat cable connector and signal conditioning circuits functioning smoothing, filtering, restraining noise, increasing signal-to-noise, etc. The signals from terminal board are inputted into the data acquisition board assembled in industrial computer controller. The local monitoring units connect the remote monitoring unit with a RS-485 bus for data communication.

The monitoring system hardware accommodates the specific requirements of a great variety of circuit breakers. For instance, some circuit breakers have a common gas system while others have three separate ones. Some circuit breakers are gang operated, some allow independent pole operations with a single mechanism and others have three separate mechanism. On some circuit breakers the three poles are mounted on a common frame, for others they are several feet apart. All these differences require a different combination and arrangement of sensor inputs, which need a flexible hardware design.

2.3 Software

The tasks of the software can be categorized as follows: accept and provide data for further analysis, check quantities with respect to their valid range, verify proper function, perform calculations and analysis, identify and output alarm information.

Fig.6. Main user interface of real-time condition of circuit breaker

The main user programe interface is shown in figure 6. The used software is Visual C++ 6.0 professional with operation system of Microsoft Windows XP. The design idea of software programming is based on multi-threading. The topology of the software function is shown in figure 7. Main program controls four modules: Database module, Communication and alarm module, Display and printing module, and Condition analysis module. Condition analysis module is of the most importance, which comprises Electric endurance module, Vibration analysis module, SF_6 moisture monitoring module, and Auxiliary monitoring module.

Database module carries out data receiving, processing, and storing. Data from local monitoring units is acquired in a time-controlled manner, such as every two seconds, and also in an event triggered manner. Data that is read once two seconds comprise the coil continuity, compressed air pressure, SF_6 gas pressure, temperatures, humidity, and heater currents. Event triggered data are acquired as a 10k Hz snap shot of breaker operation with contact travel, phase current, coil current and vibration signal.

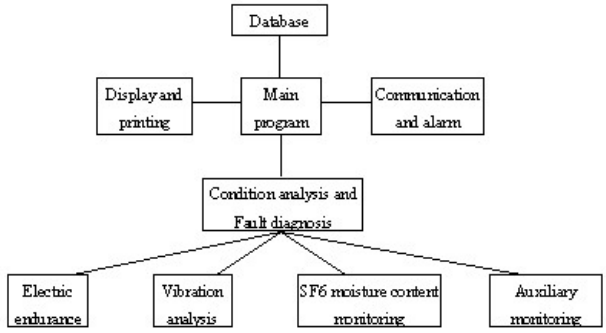

Fig.7. Structure diagram of software function module

With every operation of the circuit breaker, data from main program are transmitted to condition analysis module and calculate quantities. In electric endurance module, contact erosion, ablation of main nozzle and auxiliary nozzle are calculated with a special proprietary algorithm. These values, such as phase current, arcing time, reaction time and contact velocity, etc., are accumulated with every operation and are used to calculate a quantity that indicates interrupter wear in percent. If this quantity reaches 80% the interrupter has been seen as alarm and should be inspected and possibly replaced.

Vibration analysis is an indirect and noninvasive method, which examines the conditions of delivery and operating mechanism where mechanical faults occur most frequently. According to numbers of field tests, it is proven that the repetition of vibration signals of the same type of circuit breaker is very good. Thus, six vibration waveforms per type circuit breaker in normal case are recorded as 'fingerprint' after the firm installation of accelerator, which are compared as standard references with other signals in any case. With powerful mathematical tools, effective features extracted from vibration signals are used to diagnose the possible, potential faults.

SF_6 gas as good insulation medium is most critical monitoring item that should be paid more attention. Once the moisture content of SF_6 gas increases to a certain extent, the insulation performance of circuit breaker will be damaged greatly. SF_6 gas pressure and temperature readings are both used to calculate SF_6 gas density using the SF_6 gas density equations. The SF_6 gas density is then used to calculate a temperature compensated pressure. If the temperature corrected pressure is outside the specified range, an alarm will be generated.

Likewise an alarm condition is identified in Auxiliary monitoring module, if any other quantities, including compressed air pressure, coil continuity, total contact travel, operation cabinet temperature, which are calculated from the circuit breaker operation snap shot, are found outside their specified range. The acceptable limits can be set differently with and without operation.

3 Conclusion

With rapid development of IT and manufacturing, function of computer hardware and software increase greatly. Microprocessor based design is being replacing by combination of high performance PC, powerful software tool, advanced sensors, and corresponding apparatus. Software burdens more tasks hardware had ever done.

The monitoring module of this system is composed of Electric endurance module, Vibration analysis module, SF_6 moisture monitoring module, and Auxiliary monitoring module, which covers almost all the important parameters that reflect the overall and objective information to the user, and is helpful to diagnose the endurance of circuit breaker for economical saving.

There have been lots of diagnostic means of circuit breaker, but not any single means can give absolute and precise reflection on conditions of circuit breaker. Based on variety of information provided by the overall developed system described here, combination of different means not only can make up each own defect, but also can reflect the operation condition on different aspects and is helpful for power engineers to conclude more objectively and correctly.

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