# Autonomous Tele-Information Network for Power Systems Switchgear Equipment e-Diagnostics

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## Abstract

The network enables automated and on-line diagnostics of switchgear equipment, especially low and medium voltage circuit breakers (CB). The communication in the network, within each substation, conforms to IEC 61850. The controlling devices connected with each CB collect sampled data of all electrical signals available at the CB and send them to the CONCENTRATOR that parameterizes them and carries out an analysis based on the rules contained in an expert system.

Methods of CB diagnostics, based on optical technology have also been implemented. The first consists of the detection and conversion to temperature of the infrared emission from the contact bulk. For contact evaluation it is necessary to have an a priori determined heat distribution pattern during normal operation with healthy contact for comparison.

The second of the new CB diagnostic methods uses spectral emission analysis and detection of special spectral lines during contact breaking. The contact is composed of two layers made from different materials, one for the contact itself and one for the contact base. The wear of the contact caused by subsequent closures and openings exposes its base layer so that emission lines that characterize the material in the base layer appear in the emission spectrum.

**Keywords:** circuit breaker diagnosis, IEC 61850, protection relay

## 1. Introduction

The purpose of the network is to integrate protection and control functions with e-testing of switchgear secondary voltage equipment and e-diagnosis of Circuits Breakers during normal operation.

Circuit Breakers (CB) are very important elements in the power system. They need to be reliable since their incorrect operation can cause major issues with power system protection and control. Due to large overloads that Circuit Breakers have to sustain when switching out shorted lines they are more susceptible to damage than other equipment and because of their cost they are expensive to replace. New methods of CB diagnosis have to be developed to increase the reliability of CB operation and to lower the power substation maintenance costs.

## 2. Architecture of the system

The architecture of the system, with implementation shown in a greater detail in one of the power substation, is presented in Fig. 1. Within each substation all communication is carried out according to IEC 61850 [1].

The controlling devices associated with each CB collect digitalized data from every possible electrical node of CB. The IEC 61850 wrapped data are then sent via SUBSTATION ETHERNET BUS to a CONCENTRATOR (CONC). The only processing of the data carried out at controlling devices is connected with protection functions implemented in it. It consists in determination of the Fourier spectrum of current and voltage signals, RMS values calculation and precise line frequency determination.

The main software processing of diagnostic data coming from CBs is localized at the CONCENTRATOR. It consists first of all of procedures for parameterization of the waveforms obtained at various nodes of CB. Various features of signals are extracted like transition time, pulse duration, spectrum content, contacts bouncing times etc. The second part of the software installed at the CONCENTRATOR is an Expert System that makes conclusions concerning the conditions of individual CB based on a system of rules collected in a database. These rules represent the knowledge about each CB and they have been formed as generalizations of long time testing of CB.

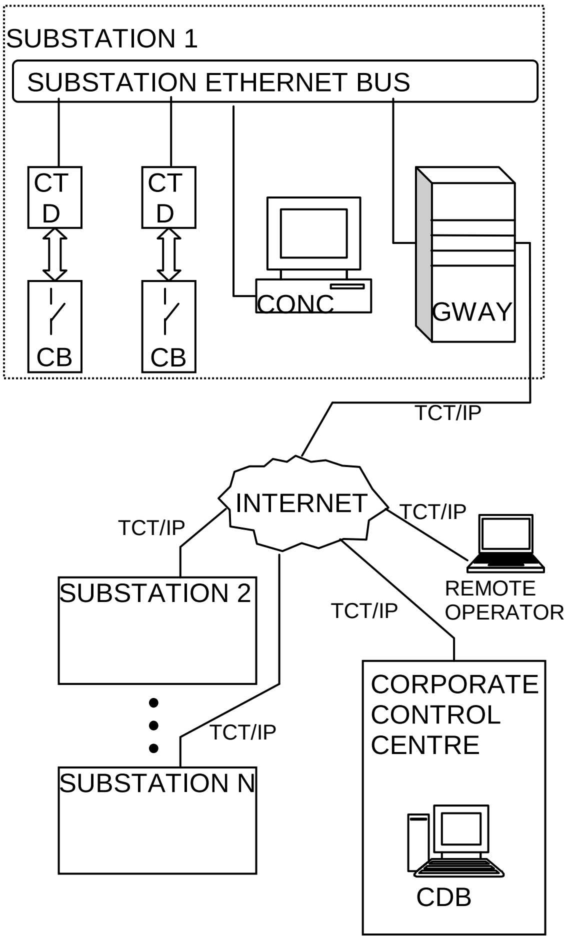


Fig. 1 e-Diagnostic Network System Architecture

The individual SUBSTATIONS are connected via GATEWAY (GWAY) to INTERNET. This enables the geographically dislocated classified operator (REMOTE OPERATOR) to access each SUBSTATION CONCENTRATOR or a CENTRAL DATABASE (CDB) and facilitates easy access to the historical data, making reports and their dissemination across the company.

## 3. Conventional methods of CB monitoring

*A. Signals that are acquired from the CB*

The main signals that are acquired from the CB are:

- phase voltages and currents,
- currents and voltages of closing and opening coils,
- motion monitoring signals,
- digital signals, mainly from auxiliary contacts, also triggering signals,
- sensor output signals.

The sampling frequency of all the signals – analog as well as digital – is the same in order to facilitate the determination of simultaneity of various phenomena taking place at the CB under test. The value of the sampling frequency has been chosen so as to provide adequate time resolution in the analysis of CB signals.

Samples of voltage and current signals, after resampling procedure are used for spectrum determination by FFT. The components of the spectrum are then used for RMS values calculation. The RMS values are the input to the protection functions.

In the case of CB tripping, buffered samples from all measurement channels taken over appropriate time period are transmitted to the CONCENTRATOR. The time period includes the moment before issuing a tripping command and extends to the moment when all the signals have stopped changing. This time period is one of the parameters that can be set by the operator.

*B. Analysis of the voltage and current signals*

Analysis of voltage and current signals during CB tripping and closing has the purpose of determination of the following CB parameters:

- contact bouncing time,
- opening time and its dependence on the load,
- closing time and its dependence on the load,
- opening time averaged over the last 10 measurements,
- closing time averaged over the last 10 measurements,
- closing as well as opening simultaneity between the poles for different load in the phases

The above parameters are determined for three phases. Usually, if one of the phase currents is switched off when crossing zero, the timing of this event cannot be determined very precisely. To accurately determine such parameter as simultaneity, several open-close cycles have to be analyzed. In any way, the analysis of the phase currents samples can give most precise value of CB opening and closing times.

*C. Analysis of opening and closing coils signals*

The analysis of opening and closing coils currents can tell a lot about the condition of CB. A typical waveform of the tripping coil current is presented in fig. 2.

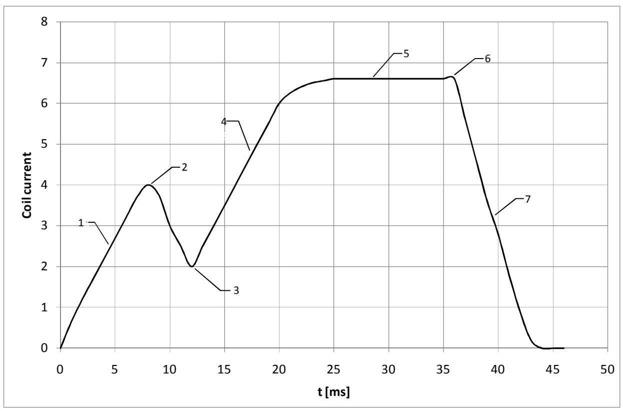


Fig. 2 CB coil current

This test indicates first of all if the coil has been short circuited or broke. During the first phase after a voltage has been applied to the coil (1), the current rises with the rate proportional to the coil inductance. After reaching a certain value (2), the armature starts to move and the coil current drops. After the armature has reached the end position (3), the current rises again (4) and achieves a steady value proportional to the coil resistance (5). At time (6) the auxiliary contact opens the coil and the coil current drops to zero (7). Fig. 2 shows a waveform of a healthy coil, which means that it is performing its function with sufficient margin (voltage at point (5) minus voltage at point (2)) to actuate the contact mechanism.

*D. Analysis of motion monitoring signals*

The motion of the CB contacts can be measured and analyzed if the CB contains transducers for measuring velocity or acceleration.

The contact mechanism of a CB is constructed in such a way that the contacts open or close as fast as possible to prevent the re-strike of the arc. Because of the acceleration and speed of the CB mechanism, damping devices have to be used, otherwise powerful mechanical strains that develop can shorten CB service life and cause serious damage.

*E. Analysis of digital and sensor signals*

Digital signals at CB are usually the signals from auxiliary contacts. These can also be used for CB mechanism motion analyzing. Other digital signals are triggering signals and control signals.

The sensor signals come from various pressure sensors and their analysis is relatively straightforward.

Each signal describing the event such as contact opening or closure is analyzed based on the rules of the expert system knowledge base. The purpose of this is to verify that the values of extracted signal features conform to the expected values within given tolerances. The possibility to analyze many signals with precisely time coordinated samples give almost 100% certainty that the CB most crucial parameters such as opening and closing times as well as simultaneity are determined properly.

## 4. New methods of CB monitoring

Normal procedures of CB servicing consist basically of counting the number of activations and then carrying out a detailed examination of the CB in off line mode. As has been described in previous paragraphs, methods have been developed to assess the condition of CB during normal operation by monitoring the electrical signals at CB nodes – switched currents and voltages, currents of activation coils and voltages at various auxiliary location contacts that measure the time it takes for the main contact to close or open. The behavior of electrical signals, however, cannot give precise information about the condition of CB contacts which are crucial to CB proper operation. So it is not possible to confirm if the CB is able to perform successfully the next open-close cycle.

*A. Temperature distribution monitoring*

One of the new methods of CB monitoring that is able to give the condition of the CB contacts is based on optical technology. It requires an optical fiber and special detector. The diagram of such a solution is presented in Fig. 3.

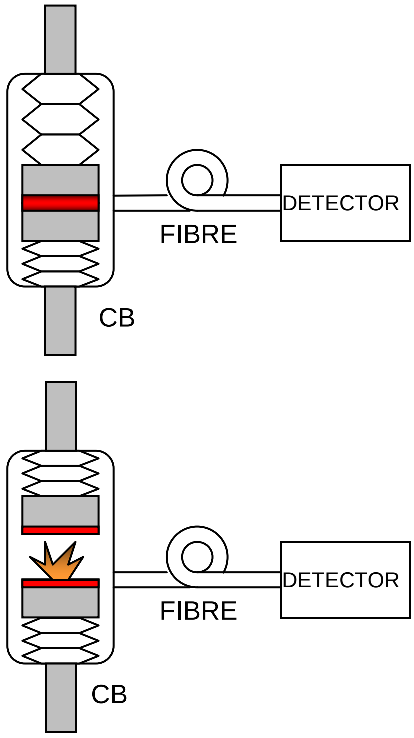


Fig. 3 Schematic of diagnostic circuit during CB closure and during contact opening

The heat generated within contact area with given values of clenching force and the material of the contact depends directly on the contact resistance and changes mainly with the value of the current flowing through the circuit. Simulations of the contact heating have been carried out and the result of one such simulation is presented in fig. 4 during one half period of sinusoidal current of 10 kA and 50 Hz.

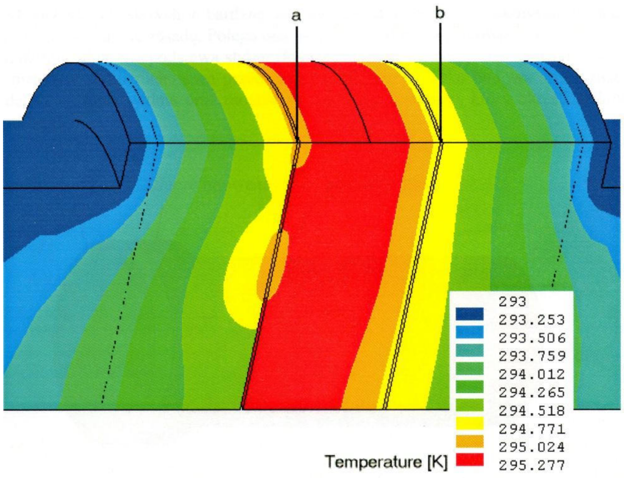


Fig. 4 Temperature distribution within the contact body

The evaluation of circuit breaker contact condition consists in measurement of the intensity of emission spectrum, mainly the intensity of infrared emission, within closed contacts.

The change in contact resistance can be caused mainly by the change in the actual surface through which the contacts come together. The open and close cycles during breaker operation, sometimes with great loading current cause substantial deformation of contact areas, thermal stresses. There is migration and segregation of contact material, which for DC loads can be one way and for AC contact two way, depending on the phase of electric arc. For contacts composed of inhomogeneous physico-structural material, the additional element influencing the structural changes are differences in physico-chemical properties and their change with temperature. The surface changes are connected with differences in boiling temperature values and propensities for oxidization of the compounds making the contact structure.

The heat generated within contact area depends directly on the contact resistance. The infrared emission is detected and converted to temperature. For proper contact evaluation it is necessary to have an a priori determined heat distribution pattern during normal operation with healthy contact for comparison. The advantage of this method is that it can be used without any interference into inner construction of the CB.

*B. Spectroscopic methods*

The arc phenomena accompanying electrical discharge in the contact slit are difficult to analyze. There is no simple mathematical model describing comprehensively the physical phenomena. During current interruption a lot of diverse physical processes can take place influencing the arc type – arc long, short, stable, unstable. Moreover, completely different discharge processes can take place – glow arcing, dark arcing and . Because of so many different factors influencing discharge process, it is almost impossible to diagnose correctly the contact system with existing methods.

The method that has been proposed for CB diagnostic uses spectral emission analysis and detection of special spectral lines during contact breaking. This solution demands from CB manufacturer a special construction of contact area. This construction is such that the contact is composed of two layers made from different materials, one for the contact coating and one for the contact base, fig. 5. Such a construction greatly facilitates the detection of spectral emission changes and the moment of complete degradation of the contact area.

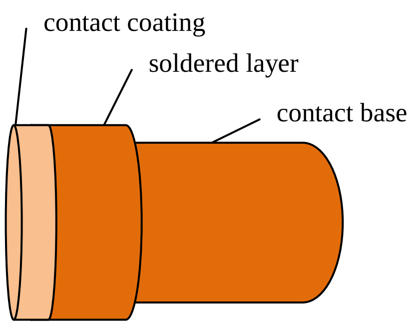


Fig. 5 An example of the moving part of the contact

The spectral analysis of closed as well as opening contact is based on the detection of radiation (of continuous spectrum) emitted by solid bodies heated to high temperature and electrical discharge in the contact slit. The emitted spectra are characteristic for a given material and are emitted by single, not interacting atoms of the elements, either in excited or gaseous state. The purpose of the detection system is to catch the difference in the discharge emission spectrum and determine structural changes taking place in the contact material.

The observation of molecular or atomic spectra enables the following types of analysis:

- qualitative – detection of a given element or compound,
- quantitative – determination of percentage of a given element or compound,
- structural – special configuration.

The equipment that is used for spectrum observation, analysis and recording can be very advanced, like spectrophotometers working in very broad electromagnetic spectrum, from microwaves to high energy X-rays, or laser spectrophotometers.

For CB diagnostic it is not necessary to use very advanced methods, suitable for whole spectrum determination. The knowledge of contact material and the extinguishing medium enables to use suitably manufactured semiconductor diodes or other detectors with selective spectral characteristic.

The wear of the contact caused by subsequent closures and openings exposes its base layer so that emission lines that characterize the material in the base layer appear in the emission spectrum.

In the laboratory of The Institute of Electric Power Engineering of Wrocław University of Technology, spectrophotometric experiments have been carried out for various discharge types and different contact material. The spectral analysis has been carried out for arc and glow discharge for contacts made of pure materials like Ti, Ta, Ni, W Mo and for contacts made from sintering of different alloys [2,3]. The measurement results for contacts made of molybdenum, tantalum and nickel are presented in fig. 6, 7 and 8.

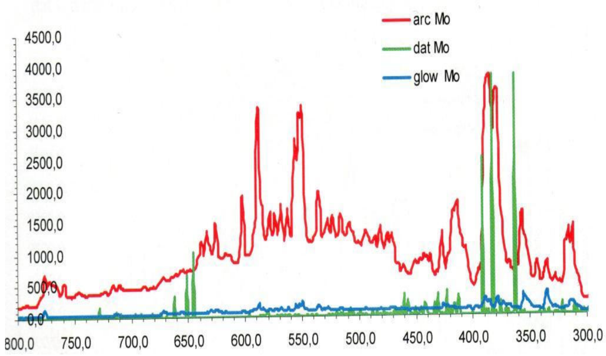


Fig. 6 Contact compound made of molybdenum (Mo): arc – arching discharge, glow – glowing discharge, dat – data from physico-chemical tables; abscissa – wavelength, ordinate – radiation intensity

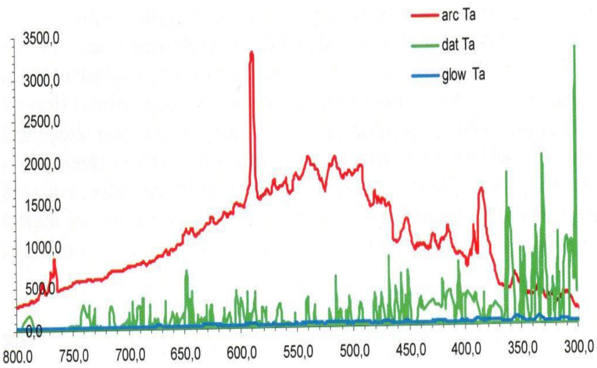

Fig. 7 Contact compound made of tantalum (Ta)

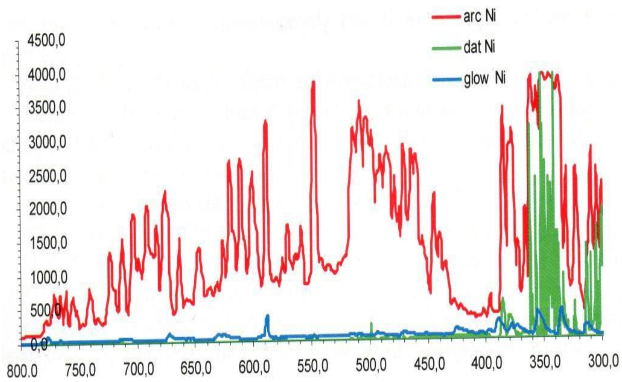

Fig. 8 Contact compound made of nickel (Ni)

The examples of measurement results presented in fig. 6, 7 and 8 show that it is possible to detect various metals included in the contact compound and on that base to infer about ongoing contact degradation.

## 5. Conclusion

It is expected, that new methods of CB diagnostic will considerably lower the maintenance cost of switchgear equipment.

The described methods of contact diagnostic together with experimental research done on the subject [4] show that it is possible to apply optoelectronic methods for CB contact degradation detection during normal CB operation.

The optoelectronic methods together with detailed analysis of electrical signals at all nodes available in CB provide for comprehensive diagnostic of CB.

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