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# Customized Monitoring and Assessment of Circuit Breaker Operations in Different Applications

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***Abstract:*** *This paper addresses two important issues: a) how improved CB monitoring may be implemented in real-time, and b) what would be the benefits of such an implementation. The paper is devoted to description of a prototype implementation of a real-time CB monitoring system. The system consists of a new CB monitoring data acquisition IED that is located at circuit breaker and captures detailed information about its operation in real-time. The CB files are transferred to the concentrator PC where the application software performs automated analysis and makes an assessment about the operational status of the breaker. The software is based on signal processing and expert system processing. Application example using actual field data is discussed.*

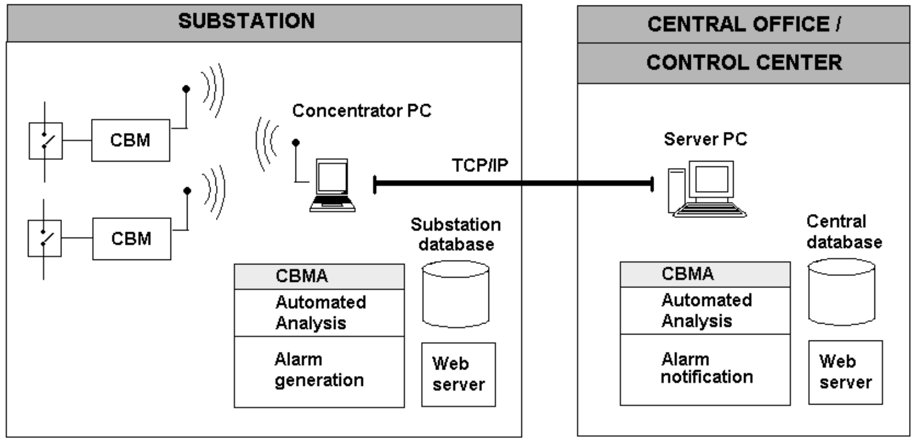
## I. Introduction

The system for real-time monitoring and analysis of circuit breaker operations described in this paper is an extension of widely used portable circuit breaker testing device concept [1, 2]. The traditional testing devices are temporally connected to the circuit breakers control circuit to record analog and digital signals. The operator opens and closes the circuit breaker each time the test is performed and data are recorded. The traditional analysis is done manually by overlaying traces from a "good" case recorded earlier and making a judgment of how different the new case is.The new solution is based on a new CB monitoring data acquisition IED called Circuit Breaker Monitor (CBM) which would be permanently connected to the substation CBs. CBM captures detailed information about each CB operation in real-time, regardless of whether the operation is initiated manually by the operator or automatically by the protection and control equipment and stores them in COMTRADE file format [3], [4]. As soon as the relevant CB control circuit signals are recorded and transmitted by wireless link to the concentrator PC, analysis software automatically performs the analysis.

CBMA provides better understanding of the condition and operating performance of each individual breaker by monitoring and analyzing expanded set of analog and digital signals from circuit breaker control circuitry. The advanced signal processing algorithms and knowledge base of the expert system implemented in the analysis software, significantly improve the reliability and consistency of the analysis results. Thanks to the fast and low cost CBM devices, new monitoring and control system described in this paper, enables permanent, real time monitoring of status and performance of circuit breakers for the entire network.

## II. Architecture of CBMA system

The CBMA system supports client/server architecture. The client part resides in substation. It consists of the CBM devices attached to the CBs and a software running on concentrator PC, both permanently installed in the substation, as shown in Figure 1. When breaker operates, recorded files are wirelessly transmitted to the concentrator PC. The client application automatically performs the analysis of recorded signals from the circuit breaker control circuit. For more efficient data manipulation, IEEE file naming convention is used for naming the recordings files [5]. The signal processing module of the analysis software extracts various parameters from recorded signal samples and expert system evaluate them against empirically obtained values and tolerances selected for specific type of circuit breaker.The resulting report describes detected abnormalities and possible causes of the problem. If discovered problem presents serious threat to the reliability of future circuit breaker operation, programmable notification is sent to the server located in the central office. The notification is then processed and a warning is sent via email or pager to the maintenance and protection personal.




Reporting is provided for both local and geographically dislocated users through implementation of local database and web server supporting information exchange through dynamic HTML pages. Recorded files and reports can be downloaded to the server via Ethernet network relying on standard, fast and reliable TCP/IP protocol. In the central office or control center, the server part of CBMA consisting of the analysis module, a central database and master web server is running. The central database allows for easy archiving and retrieving of the records and analysis reports from all system substations. Master web application allows remote users to search for the records and/or analysis reports from anywhere on the corporate network.

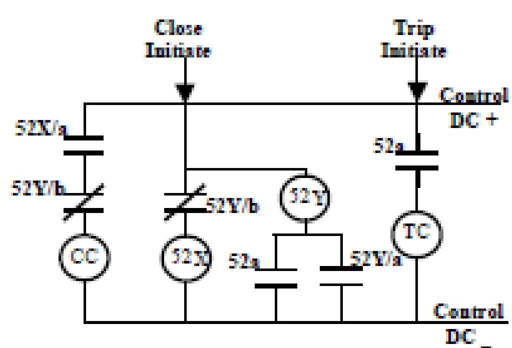
## III. Description of CBMA hardware

The system hardware in substation consists of circuit breaker monitors located on each breaker in the switch yard and a concentrator PC, used for gathering data, placed in the control room.

### *3.1 Circuit Breaker Monitor IED*

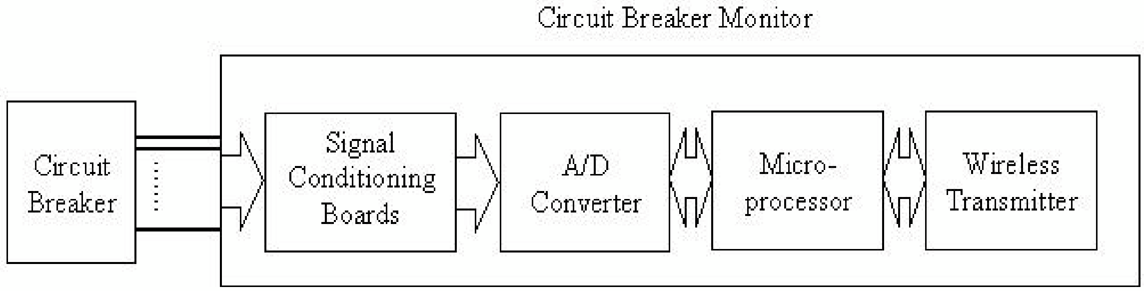
The circuit breaker monitor IED (CBM) has three main tasks:

- Perform data acquisition of signals from the Circuit Breaker control circuit and record sequences of tripping and closing
- Convert captured signals into files according to COMTRADE file specifications
- Transmit files wirelessly to the concentrator device.




The CBM IED monitors 15 electrical signals from the circuit breaker control circuit shown in Figure 1. The signals are generated during either tripping or closing of the breaker. Of these 15 signals, 11 are analog and 4 are status signals.

The most important signals are Trip Initiate and Close Initiate. These signals, initiated by the relay or the operator, cause generation of some other signals, as a result of the circuit breaker tripping or closing. All of the monitored signals are voltage signals. The signals representing currents are taken from shunts, thus converting them to appropriate voltage signals. In the worst case scenario time between the fault occurrence and the breaker lockout is about 1 (one) minute. The monitoring device is designed to record and store recorded data for this duration.




A block diagram of the Circuit Breaker Monitor IED is shown in Figure 3. The system consists of following modules:

1. Signal conditioning boards: The Signal conditioning and isolation module Provides appropriate voltage levels for data acquisition. The voltage levels of signals at circuit breaker are either 130VDC or 1 VDC. The signal conditioning module conditions the input signals to be in the [-5, +5] V range as required at the input of the A/D converter module. The module has adjustable gain for all 15 channels. A user determines suitable gain values for the hardware to be used with input signals during set up. The gain can be adjusted by software within a certain range for precise calibration in case of drift over time. The module also provides galvanic isolation of the signals at the input to prevent faults at the input of the module from damaging the rest of the system.
2. Analog to digital converter: The A/D converter employed has 16 channels and a 16 bit resolution. It takes the input from signal conditioning board and converts it to digital form. The sampling on the 15 channels utilized is synchronous. The sampling rate used is 5760 Hz but can be modified by software depending on the capability of the A/D converter.
3. Microprocessor: A microprocessor belonging to the x86 family is used for controlling the data acquisition and running the communication protocols. The microprocessor is equipped with 32 MB of memory to store 1 minute of data in case of offline monitoring.
4. Wireless Transmitter : A wireless system capable of transmitting data to distances over 200m is used for transmitting the recorded data to the concentrator PC. A transfer protocol for data transfer is established and the receiving software is set up appropriately. The transmission bandwidth of the transmitter for real time monitoring is chosen to be larger than 1.4Mbps (5760Hz x 15 channels x 16 bits).

### *3.2 Concentrator*

The concentrator device consists of a high capacity wireless receiver connected to a PC which stores and processes data. The concentrator can be set in one of the two modes using the software.

1. Continuous monitoring : In this mode the concentrator continuously receives recorded data from each IED simultaneously. The transmission bandwidth required for this application is quite high , n x 1.4 Mbps, where n is the number of circuit breaker monitors in the system.
2. Event monitoring: In this mode the concentrator continuously polls the IEDs for their status and if any trip or close event has occurred the recorded data is uploaded. The transmission bandwidth for this application can be quite low as the data is transmitted offline.

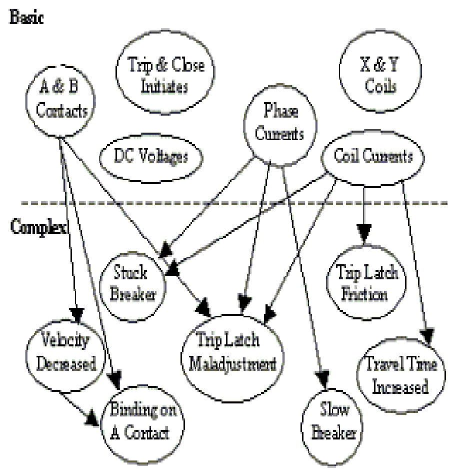
## IV. Signal Processing

Signal processing module analyzes the data from CBM recordings using empirically obtained values of signal processing settings and extracts the signal features characterizing the transitions of the analyzed signal waveforms and describing them quantitatively. For example, some of the features extracted are time instances at which the coil current picks up or when the phase current breaks, a measure of voltage drop for the supply DC voltage, magnitude of the noise on the contact signal etc. The signal processing consists of several steps, performed using advanced signal processing techniques. Fourier analysis is used for obtaining the information on frequency spectrum of the signal. For elimination of measurement noise, removal and extraction of unnecessary signal components of the frequency spectrum, digital filtering is being used. Wavelet composition and reconstruction algorithm is used for denoising and separation of signal features.

## V. Expert system

Rule based expert system is implemented in CLIPS [6]. Purpose of the expert system in analysis application is to emulate reasoning of a human expert maintaining the circuit breakers. It compares the extracted signal features against the empirically obtained values. Each type of circuit breaker has particularly customized set of rules used for the analysis of the expert system. A rule represents a fragment of knowledge that is used in the decision-making process. One of the advantages of rule-based expert systems is that they may be formed in hierarchal structure where some rules are simply intermediate steps to a final conclusion. When the expert system first begins to execute, all of the extracted features and settings (facts) are loaded into the short term memory. Once the facts are loaded, the inference engine uses the rules stored in long-term memory to analyze the information given in the facts. The rules were designed to enable the inference engine to perform two layers of analysis on the given data.

The following **Figure** shows a graphical representation of the two layers of analysis.




The first layer uses a set of basic rules to make sure that all the extracted parameters are within their corresponding tolerances. If a parameter is outside a tolerance, then the rule that checks the parameter becomes activated. The activated rules from the first layer of analysis provide some preliminary results about the circuit breaker condition. The second layer uses a set of complex rules to analyze the interrelationship between all of the activated rules from the first stage. Based on which rules were activated, the expert system tries to come to a conclusion about the overall performance of the breaker. A certain combination of basic rules may indicate a particular problem whereas a different combination would indicate another problem.

The expert system was designed to only analyze a single event or operation at a time. In the case of multiple operations, the data is divided up into a group of single operations and fed into the expert system separately. The results from each layer of the analysis are logged to an analysis report. The report provides useful information about the circuit breaker operation to enable maintenance personnel to fix the problems that are discovered.

## VI. Conclusions

The new CBMA system for real-time monitoring and assessment of circuit breaker operations provides for better understanding of condition and operating performance of each individual breaker by monitoring and analyzing expanded set of analog and digital signals from circuit breaker control circuitry. Permanently monitoring the circuit breaker data recorded for each operation enable of integrity and topology of the entire power network. This solution facilitates the analysis process by providing timely results that are consistent, irrespective of who runs the analysis. Enhanced reasoning, consistency and speed are achieved by using advanced signal processing and expert system techniques. Wireless link for communication and transfer of data from CBM to the concentrator PC increases the flexibility of the system which provides important advantage over hardwired solutions.

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