AUTOMATED ANALYSIS OF CIRCUIT BREAKER OPERATION

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INTRODUCTION

In this paper a new approach to the analysis of test results for circuit breakers is discussed. It is implemented through new software called Automated Circuit Breaker Monitoring system - ACBM. The circuit breaker performance is evaluated based on the analysis of Digital Fault Recorder (DFR) recordings taken from circuit breaker control circuitry. This paper describes the testing procedure and usage of the software from the user's standpoint. It also explains the software architecture and analysis scenarios for the DFR recordings.

BACKGROUND

The circuit breaker (CB) is one of the most critical and important components of the power system. In the event of faults, it is used to isolate parts of the faulted system. In normal mode of operation, it is used to change system topology to accommodate the load flow needs. Therefore, maintaining the reliability and performance of the CB operation is of utmost importance in the utilities.

In existing practice, recording of results is performed using a portable custom recording device, which is moved from one breaker to another and reconnected each time when testing is performed on a different breaker. The recording device should be appropriately configured using customized software, to enable correct recording of important signals from circuit breaker control circuitry.

Circuit breaker is manually operated (tripped or closed), and the device automatically records the samples of predefined signals. Operators usually perform at least two tests on the circuit breaker – one for open and one for close operation, which gives them at least two records per tested breaker.

When testing of a particular breaker is completed, collected records are downloaded to the laptop over serial connection, using custom communication software. Waveforms reconstructed from the samples of monitored signals are printed on the paper or displayed on the laptop screen. Operator in the substation visually inspects the signals and looks for possible faults by overlaying them with the waveforms of the reference test cases. If any discrepancies are detected, operator will judge upon its personal experience about the gravity of defects and decide how to handle them.

Current testing procedure described above has several shortcomings. Firstly, analysis and interpretation of the test results is solely visual. Signal characteristics are not evaluated by numerical means, which can cause wrong evaluation conclusions. Secondly, archiving of the records is manual and not centralized. Finally, no results of the analysis are electronically saved for future reference.

Use of a typical portable Digital Fault Recorder (DFR) and new software solution called automated circuit breaker monitoring system – ACBM, enables improved approach to the process of assessing the circuit breaker operation. Main requirements that have to be met by the ACBM are:

- Automated interpretation and analysis of Digital Fault Recorder (DFR) recordings
- Automated archiving of DFR records and associated reports
- Web based retrieving of the DFR records and analysis reports

In the following sections of the paper, system architecture, procedures for the on-site as well as off-site analysis are described. Last section covers issue of data dissemination over corporate intranet.

SYSTEM ARCHITECTURE

Figure 1 displays the system architecture and basic software modules of the ACBM. The system architecture is split between two locations: the substation where data are recorded during breaker testing and the central repository where data from all tested breakers are gathered.

Figure 1 System architecture

In part of the figure showing the substation, CB denotes tested circuit breaker to which Digital Fault Recorder device (DFR) is connected. There are two software modules installed on the laptop: conversion software and analysis software. The server is shown on the right side of the figure. Several software modules reside on the server: conversion software, analysis software, database and web application. DFR recordings are transferred from the substation to the server either on diskettes or by modem. Server computer is connected to the corporate intranet. There is an option to upload DFR files to the server from any computer connected to the company intranet. Figure 2 gives the functional description and emphasizes the difference between on-site and off-site processing of the ACBM software.

Figure 2. Functional description of the analysis software

In the figure, SP indicates signal processing module. This module extracts pertinent signal parameters from recorded signals using advanced processing methods such as: wavelet analysis, Fourier analysis and digital filtering. ES indicates Expert System module, which is a decision making system emulating reasoning of a human expert. It is implemented using CLIPS expert system, developed by NASA [1][2]. In the following section, detailed description of the analysis procedures will be given.

ON-SITE ANALYSIS

Software residing on the laptop used in a substation is utilized for on-site analysis. It gives instant results about tested circuit breaker performances and directions how to address detected problems. To perform testing of the breaker on the field, several steps have to be done.

Pre Analysis Steps

In the new approach, DFR is connected to the circuit breaker using specially wired cable and DB-25 connector. Thereafter, DFR is configured to record important signals using appropriate resolution and sampling frequency. Duration of the recording, record number, date and time of recording and other significant identification information should be downloaded to the DFR as well. Choice of the software used for configuring depends on type of the DFR. The most common types of the DFR used by CenterPoint Energy are RTR-84 from Hathaway and TR-2000 made by Rochester Instrument Systems, Inc [3]. In the rest of the paper, testing procedure for TR-2000 DFR is described. For configuration and communication between DFR and laptop, Display Station software from Leading Edge Research, Ltd has been used [4]. After configuring DFR, circuit breaker is manually operated. Upon detection of the rising edge of the Trip Initiate or Close

Initiate signals, DFR automatically starts recording predefined set of signals and stores collected samples to the DFR files in the Rochester format. List of the monitored signals is given in Table 1.

Group	Signal name		
Digital signals	Trip Initiate		
	Close Initiate		
			X Coil signal
			Y Coil signal
Contacts	"A" Contact		
	"B" Contact		
DC Voltages	Control DC Voltage		
	Yard DC Voltage		
Coil Currents	Trip Coil (TC) Current 1		
	Trip Coil (TC) Current 2		
	Closing Coil (CC) Current		
Phase Currents	Phase Current A		
	Phase Current B		
	Phase Current C		

Table 1 Monitored signals of the circuit breaker control circuitry

After signals have reached steady state (approximately 300ms since the beginning of breaker operation – depending on the configured recording time), recording stops without interference from the user.

Data are imported from DFR to the laptop over serial connection, using Auto-Poll command from Display Station software. Upon downloading all collected DFR recordings, operator enters additional identification information for every single record. Table 2 contains an example of a list of the information that user has to supply.

Substation ID (SSPID)	B r e a k e r Device ID	Breaker Manufacturer	B r e a k e r Type	Breaker ID
TO1-	26A0	SIEMENS	SDV	10103105

Table 2 Additional data describing single DFR record

Information is entered using the dialog of Display Station software, and saved to the appropriate section of the record. Up to this point, DFR recordings are stored in the Rochester file format. Every breaker manufacturer supports its own DFR file format. In order to enable analysis of recordings from DFRs made by different manufacturers, ACBM software is designed to process recordings in standardized COMTRADE file format [5]. Conversion from Rochester to COMTRADE file format is done using Export Comtrade feature of the Display Station software. Converted files are randomly named and saved to the predefined folder RIS OUTGOING, where ACBM expects all incoming files to be stored. From this point, analysis of the DFR records can be performed using ACBM software.

Analysis of selected files

There are two analysis modes using the ACBM software: "Selected Files" and "All Files" analysis. First mode of analysis enables users to select manually files to be analyzed from the RIS OUTGOING folder. DFR recordings are processed sequentially one by one. In this mode, after each record is processed, waveforms and the analysis results can be examined and compared. Results of analysis are not kept for future reference.

In "All Files" analysis mode, all files from the RIS OUTGOING folder are processed without user interference. After each record is processed, results of the analysis are saved in ASCII textual file, and next record is processed. User cannot examine results of the analysis until all files are processed. When processing is finished, user can view saved results in a form of the expert system report.

Main goal of automated analysis in substation is to discover potential flaws in circuit breaker operation. In this specific part of analysis process, results have to be received instantly, although they are not intended to be saved for future reference. Therefore, preferred mode of analysis in the substation is "Selected Files".

In this mode of analysis, user selects one or multiple files in the common File selection dialog. After that, analysis software starts processing of the first file. During analysis, the status window displays current status of the processing. When processing of one record is completed, analysis is stopped, until user examines the results and decides whether to continue with a new record or abort. Operator can use several different types of information in order to interpret received results. Figure 3 displays screenshot of the analysis software main window after processing of a single DFR record.

Figure 3. Screenshot of the analysis software main window

Window labeled with (1) displays waveforms of the signals from analyzed DFR record. Label (2) indicates signal names and corresponding extracted parameters. When the processing of a single DFR record is finished, analysis report is shown in a modeless, scrollable window labeled with (3).

Analysis report contains three sections. First section contains unique identification information of a DFR record: IEEE file name [6], and fields with date, time, substation ID, device ID, company name, breaker manufacturer, breaker type, SAP ID.

Second section, titled "Expert System Log", contains list of expert system rules fired during the record analysis. For every rule, there is a serial number and short description of the rule meaning. Expert system rules contain conclusions about analyzed signal waveforms: how do they differ from the reference signal waveforms and whether signal parameters extracted from tested DFR record fit in a given interval. They also check for a correct sequence of events.

Last section is titled "Maintenance & Repair Information". It contains short information about possible causes of detected problems and directions how to repair them.

Because the report can be compared against waveforms and extracted signal parameters, every asserted expert system rule can be examined visually. Feature that is very helpful in that case is capability to overlay multiple records. By selecting option "Action" from the main menu and command "Overlay Waveforms", "Overlay Dialog" shown on Figure 4 is invoked.

Figure 4. Screenshot of the analysis software Overlay Dialog

In the left hand list, with double click or by selecting appropriate button, user can select up to five DFR records to be overlaid on a single screen. There is an option to select a different color for each record from custom color selection dialog. By simple checking appropriate checkbox, user can select to overlay with reference waveforms for "close" or "open" breaker operation.

After report is examined, it can be saved to the ASCII textual file or printed, by selecting corresponding buttons from CB Analysis Report Dialog. Individual report can be retrieved from CB RESULTS folder and reviewed using any ASCII editor.

Collected DFR records in Rochester file format can be exported to other locations (central repository server e.g.) using Display Station user environment and commands "System->Directory Maintenance". Files can be transferred on floppy disks or using modems.

Signal processing and expert system analysis depends on the parameters whose values cannot be easily determined just by studying the algorithms and equations. Because of complex relationships between different parameters and dificculties to model them, values of the intelligent system parameters are reached by experience, using probabalistic methods and procedures. Analysis software has to provide functionality to the users which will enable them to view, edit and save signal processing and expert system settings. Users should be able to observe influence of those changes on the final analyses report.

For on-site analysis, users are not involved in defining or changing values of the signal processing and expert system settings. They can view them and compare with results of the analysis. Settings can only be changed on the server, where off-site analysis is performed, and those changes can be saved to the database. Therefore, operators using ACBM for on-site analysis have to be able to import already defined signal processing and expert system settings and to use them during the processing. Figure 5 displays dialog for viewing expert system settings as part of the analysis application in the substation.

Users of the ACBM software for on-site testing can perform additional tasks using available commands:
- Launch external applications from the ACBM application shell, that can be used during circuit breaker testing (e.g. ASCII text editor, spreadsheet program or Display Station)
- Delete data from predefined folders

ACBM software includes elaborate help containing description of all the options and procedures that can be performed during on-site or off-site circuit breaker testing

Figure 5. Screenshot of the Expert System settings dialog

OFF-SITE ANALYSIS AND ARCHIVAL

Software residing on the server in the central repository is used for off-site analysis. During off-site analysis, several data processing steps are performed. Collected DFR records are analyzed again. Records and results are archived to the database and prepared for company-wide distribution. In this section, all the steps will be described in more details.

Pre analysis steps

Upon arrival to the server, DFR recordings are in the Rochester file format. Therefore, they have to be converted to the COMTRADE using the same software that was used during on-site analysis – Display Station [4].

DFR recordings are converted to the COMTRADE file format using Export Comtrade feature of the Display Station software. Converted files are randomly named and saved to the predefined folder RIS OUTGOING. Converted DFR recordings can be analyzed using two modes of the analysis: "Selected Files" and "All Files".

Analysis of selected files

Server is usually maintained by an administrator, which does not have to be directly involved in the process of circuit breakers maintenance. Therefore, he or she might not be necessary interested in performing the "Selected Files" analysis, which gives immediate results about performances of a particular breaker. But it is a good additional feature that might be useful as a complementary solution for processing DFR recordings on the server. It can also help to resolve if a record is correct, by checking whether it contains samples from all necessary signals. In case of any problems, DFR record is discarded.

Analysis of all files

"All Files" analysis is very useful feature of the server part of the analysis software. It enables fast processing of huge amount of data. It also minimizes required administrator time in the whole process of the off-site analysis.

After "All Files" analysis is started, software analyses all DFR recordings found in the RIS OUTGOING software.

User can abort analysis of the DFR recordings at any time.

Event reports are automatically saved to the ASCII textual files. When all available records are processed, ACBM software asks operator to store data to the database. If affirmative answer is selected, the process of archiving the data to the database is initiated.

Storing data to the database

Data can be stored to the database using "Store Records to the Database" command form the "Action" menu of the Analysis software. DFR recordings in COMTRADE file format, as well as analysis reports in ASCII text files are stored to the database.

Each DFR record and corresponding analysis report are uniquely identified with the IEEE file name [6]. It is important to prevent identical data to be stored to the database more than once. Therefore, before each record is loaded, software automatically searches for the corresponding record IEEE file name in the database. If identical name is found, DFR record already exists in the database and software skips to the next record. During process of loading the database, user is required to provide additional information about substations and breaker manufacturers that does not exists in the database. Information is entered through the custom designed dialogs.

Functions for changing the settings

In addition to the functions implemented for on-site version of the analysis software, the server version can also change Signal Processing and Expert System settings, as well to store those settings to the database.

CORPORATE LEVEL DATA DISSEMINATION

Using web application, users connected to the company intranet can access data stored in the database, using widely available internet browser software. Web application is implemented using new ASP.NET [7] Microsoft technology based on the server processing. Web application backed with Web server enables creation of dynamic Web pages. Contents of the Web pages changes based on user inputs and data retrieved from the database. Each time when user asks for a specific web page, data are fetched from the database and embedded into the predefined web page template. Dynamically created web page is then returned over the network to the user that asked for it.

Web application provides several functions that can be used for accomplishing different tasks. Functions supported by the ACBM web application are:

- Authorization and authentication of the users
- Basic search (Default) of DFR records and reports
- Advanced search of DFR records and reports
- Displaying DFR signal waveforms and analysis reports
- Graphical presentation of the system and substations statistics

- Displaying signal processing and Expert system settings
- Remote manual classification of the DFR records and analysis reports
- File transfer of the DFR records between server and workstations connected to the company intranet and vice versa
- Remote user accounts maintenance
- Exporting search results to the spreadsheet

ACBM database contains confidential information, which needs to be protected from unauthorized users. In order to access the data, users have to be identified. The act of determining the identity of the requesting entity is called authentication. Users have to provide credentials (name/password pair) in a special form in order to be authenticated. Once the identity is authenticated, it must be determined whether that identity can access a given resource. This process is called authorization. Due to the restrictions that some users can have in accessing the data, two levels of the hierarchy are available. Users at the lower hierarchy level cannot access certain pages that are available to the others.

There are two ways of searching for the DFR recordings and corresponding reports using web application. First is called the basic and the other is called advanced. Basic search is a default way of accessing stored records. All records are assorted according to the substations in which they were taken. List of all existing substations in the system is provided in the form of a table with underlying hyperlinks, (see Figure 6). When user wants to access record taken in a particular substation, he/she will have to click on the substation name listed in the table.

Figure 6. List of the substations used for basic search of the DFR records

After that, user will be redirected to the page listing all records taken during testing in particular substation, as shown in Figure 7.

Figure 7. List of all DFR records taken in one substation

In order to view waveforms of the found DFR records, or their corresponding event reports, user will have to click on hyperlinks in the last right column – "Waveform" or "Report". For example, upon selection of the option "Waveform", user will be redirected to the page shown on Figure 8, which displays waveforms of the one DFR recording overlaid with reference case for a close breaker operation.
 DFR recordings can be classified by clicking on hyperlink in appropriate row of the column "Classified", and selecting one of two choices from the dropdown list box: good or bad. Selecting option "Update" in the column to the right can save the classification.

Figure 8. DFR signal waveforms page of the web application

Advanced search of the DFR records can be performed using the form shown on Figure 9. In this form, user can set one or more different criteria for searching the database. Records can be searched by: substation name, date, breaker manufacturer, breaker type, classification, breaker ID, breaker device ID, breaker operation or using exact IEEE file name of the DFR record. By clicking on button "Submit", SQL query is initiated which returns the list of records matching all given criteria in page similar to the one shown on Figure 7. If none of the stored records satisfies given criteria, appropriate message will be given to the user, which will then have to broaden the search, dropping some of the given criteria.

Figure 9. Advanced search page of the web application

Graphical presentation of the system and substations statistics provides useful information regarding current status of the analysis. >From the "system statistics" pages, users can find out the percent of the DFR records belonging to each substation, or the percent of the tested breaker manufacturers and types as well as the overall number of tested breakers in the system. Substation level statistics gives similar information for a particular substation.

CONCLUSION

Paper describes new approach in analyzing circuit breakers operation using Automated Circuit Breaker Monitoring system – ACBM. By describing overall analysis procedure, it is shown that new approach offers significant advantages over the existing way. It improves current solution by providing following benefits:

- Analysis consistency (Expert System)
- Time saving (Analysis Automation)
- Historical repository (Database)
- Retrieval (Web-based user interface)

Future steps will involve further automation of data collection process. In the future development, of the system, data acquisition unit will be permanently installed on the circuit breaker. It will enable automatically recording and analyzing the data, each time the breaker is operated.

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REFERENCES

[1] Artificial Intelligence Section, Lyndon B. Johnson Space Center, NASA, 1998, *"CLIPS Basic Programming Guide"*, version 6.10, Houston, USA

[2] R.A. Orchard, 1998, "FuzzyCLIPS Version 6.04A User's Guide", Integrated Reasoning, Institute for Information Technology, National Research Council Canada, Canada

[3] Rochester Instruments, Inc., 2000 *"TR-2000 Multi Function Recorder – Operation Manual",* Rochester, USA

[4] Leading Edge Research, Ltd, 2000, "*Display Station – online datasheet"* [available online] - http://www.lerltd.com/Documentation/DS/DS.pdf, Lisburn, Co. Antrim, Northern Ireland

[5] IEEE Inc., 1999 "IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems", IEEE Std. C37.111-1999

[6] Final Report of IEEE Power System Relaying Committee Working Group H8, 2001, "File Naming Convention for Time Sequence Data", *Fault Disturbance Analysis Conference*, Atlanta, Georgia; and the *Spring 2001 Meeting of the IEEE Power System Relay Committee*

[7] Anderson, R.,Francis, B.,Homer, A.,Howard, R., Sussman D., Watson K., 2002, "*Professional ASP.NET 1.0 – Special Edition*", Wrox Press Ltd., Birmingham, UK