Facilitating Restoration After System-Wide Disturbances Using Automated Analysis

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***Abstract* — The paper focuses on new concepts in automating analysis of all the IED data recorded in substations. It addresses the main requirements for enabling integration of existing and deployment of new analysis functions. New concept also enables combining the use of integrated IED data with other useful tools for system troubleshooting such as advanced digital simulators.**

Automated analysis of integrated data collected from different types of IEDs is a first step towards new solutions that will dramatically reduce the time needed for restoration after system-wide disturbances. Importance of a transparent system configuration database and ability to match measured data collected from IEDs to their corresponding system components is discussed through example requirements for new functions.

Several utilities are taking steps to automating the process of data collection and analysis and integrating both measurements and system configuration data. The paper introduces some of the existing solutions as well as the solutions that are currently being developed.

***Index Terms* — electromagnetic transient analysis, power system data integration, power system faults, power system measurements, power system monitoring, power system restoration, power system testing, substation measurements**

I. Introduction

SYSTEM-WIDE disturbances such as a recent blackout in the Northeast, USA, on August 14, 2003, where fifty million people experienced loss of power and over $65 billion in economic activity was lost, may have devastating impacts. Although such disturbances cannot be fully predicted and prevented, it is important to provide means for speeding up the system restoration after such an event. The analysis of the monitored and recorded data is essential for correct identification of the causes, classification of the impacts, and management of the restoration actions leading to selection of the best strategy for system restoration.

Automating the processing and analysis of monitored and recorded data is the key for speeding up the restoration after system-wide disturbances. There are several functions that can be automated: a.) Collecting the disturbance data and making it readily available for the analysis; b.) Identifying the main disturbance features; c.) Performing the analysis; d.) Disseminating the analysis results.

This paper specifies requirements and solutions aimed at a.) Automating the analysis of the recorded fault and disturbance data leading to faster identification of the problem and b.) Automating commissioning test of relaying systems to facilitate restoration after system-wide disturbances. The requirements are addressing variety of hardware and software issues as well as design and implementation decisions. The topics to be specifically addressed are: what is the relevant data that should be recorded, how the data analysis should be performed, what are the data sources (IEDs) needed for the analysis, what is the role of sampling synchronization and how it may be done, how the substation and system topology should be represented for the analysis purposes, etc. In addition, the paper addresses how the integrated data and results of the automated analysis can be used to dramatically expedite troubleshooting, in this case through the use of advanced simulators.

Several utilities are taking steps to automate the process of data collection and analysis while making choices regarding variety of options. Possible solutions are demonstrated through examples of automated analysis applications as they are currently installed in several utilities. This paper gives a discussion of the trade offs involved in making different solutions. The unique experience in using automated systems for data analysis at various utilities is shared through specifying requirements for future solutions.

II. Background

Major steps towards fully automating and enabling faster system restoration are being done through current developments in substation automation, especially in the field of communication and data integration [1]. IED vendors are improving existing and making new devices with features that enable better interoperability and connectivity. Substation automation further enables completely new applications running at both the substation and centralized level. Several new standards are aimed at resolving the communication issues and making the information available [2,3,4].

Substation automation addresses the following important issues:

- Handling of redundant data collected by IEDs connected to the same switchyard to improve consistency and accuracy of substation data.
- Utilizing the processing power of an industrial PC located in a substation to perform pre-processing for some EMS functions thus making them more robust and

accurate.

- Automatically processing disturbance data to reduce time and inconsistency in comparison with this analysis being done manually.
- Utilizing the variety of data from different IEDs to perform better overall system-wide analysis of the given events and/or equipment operations by specifying new functions.

The following sections discuss the requirements for data integration as well as the description and requirements for the new functions. Advanced simulator solutions that facilitate use of the data integration and automated analysis are described as an example how troubleshooting of miss-operations can be expedited thus providing faster restoration.

III. Data Integration and Information Exchange

The main requirement for enabling integration of functions is providing effective data integration and enabling smooth information exchange. This requirement must be satisfied at all levels of data processing (switchyard, substation, system-wide).

Several IED devices can be involved in collecting measurements from the substations: digital fault recorders (DFRs), digital protective relays (DPRs), power quality meters (PQMs), remote terminal units (RTUs), sequence of events recorders (SERs), programmable logic controllers (PLCs), circuit breaker monitors (CBMs) etc. (Fig. 1.). All the data made available through IEDs has to be collected and imported into a database. The database should contain both raw and pre-processed IED data. Besides the IED data, the database has to integrate all the system configuration data with description of substation components as well as their relationship and mapping to IED signals. The database with integrated data (IED pre-processed and processed data, system configuration) is a backbone for creating an analysis system that consists of several automated functions.

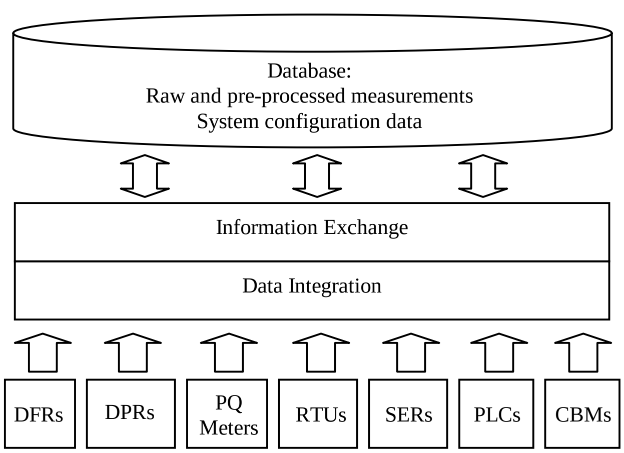

Fig. 1. Data integration and information exchange

General requirements for data integration and information exchange concept are:

- **Selecting IEDs for monitoring**. Each substation needs to be equipped with one or more IEDs that will provide monitoring of important signals. For each circuit, it is recommended to monitor all three phases as well as the residual for all voltages and currents. For digital signals, it is recommended to monitor the signals related to protection actions and statuses of all the breakers and switches defining the substation topology. Communication signals involved in protection schemes are of interest, too.
- **Utilizing Redundancy**. It is expected and recommended that there is some redundancy in measurements and that the most critical signals are monitored by different IEDs either of the same or different type. This will allow better measurement data verification and provide backup for situations when some of the IEDs fail.
- **Providing communication interfaces**. Communication infrastructure and channels for collecting data from all the IEDs installed in the substation need to be provided. Reliable communication channel towards central offices are also needed thus enabling system-wide data and function integration. Utilizing existing communication protocols is an option as long as the data can be collected in an automated manner and made promptly available for automated data format conversion.
- **Collecting IED data using some standardized means**. Typically, IED vendors provide device specific software for this function. New IEC 61850 approach opens the door for easier data integration at the IED level and transparent data collection regardless of the IED vendor. Until fully standardized, IED data collection will involve use of vendor specific software tools.
- **Time stamping with GPS**. It is highly desirable that all the sampled data is time stamped and synchronized utilizing GPS clock and that the IEDs keep track of time stamps at all times. Special care should be taken when handling the time in different time zones. All the IEDs in a system should use the same time zone (for example Greenwich Mean Time, GMT). Having precise time information, and being able to determine a correct time stamp for each sample is critical not only for aligning all the records and going back in history during the recovery, but also for enabling some advanced automated solutions such as the two-end fault location calculation, etc.
- **Unifying IED data formats**. All slow sampled measurements (i.e. power quality log data) should be kept in a log-type structure inside the measurement database. Those measurements should be updated in real time. All the event-like IED data should be converted to COMTRADE file format prior to any further processing [5-6]. All the other data (i.e. digital relay reports) should be collected automatically and stored in the database’s file repository. System should

provide support for more advanced file naming convention [7].

- **Specifying system configuration and component information**. Handling of the system configuration data may be the biggest issue to solve. Some steps towards standardization in system configuration data are taken with SCL, 61850-6 [2]. Additional problem is handling the changes in the system as well as being able to track back in history to determine what was the system configuration and parameters at the time certain events took place. This problem is also present when the IED specific configuration data are considered.
- **Automating the analysis**. All the analysis functions need to be fully automated. Input data should consist of the raw or pre-processed data recorded by IEDs as well as the power system component information, both accessed through the database. Analysis reports and calculated results should be stored back to the database. Each analysis module should be executed depending on its trigger conditions. For example, the analysis of DFR data should be triggered by an occurrence of a new event, which creates a COMTRADE file in the database. Event related analysis reports should utilize the same file naming convention thus enabling easy mapping and relating the reports to the original event data.
- **Broadcasting the results**. Analysis modules need to provide means for automated dissemination of both the analysis reports and additional relevant information such as IED raw data or configuration data. Broadcasting should support sending notifications using emailing, faxing, paging, printing services, and file copying over Internet and Intranet.
- **Centralizing the database**. Combining database engines and file repository is recommended for keeping all the collected IED data in a raw and pre-processed form, system configuration data and component description, analysis reports, and processed data.
- **Maintaining a database of history and valid test cases**. All the good test cases that were either recorded by IEDs or simulated using system model should be kept together with the corresponding system configuration parameters. This data can be used during the troubleshooting sessions and can dramatically reduce the time of restoration. The history data for the system configuration description and IED settings should be available as well. The system configuration information should be restorable for any given time stamp from the past.
- **Pre-processing for EMS and upper level functions**. Some of the automated functions perform extracting of features and information from the monitored signals for the use in the upper level functions such as EMS. Pre-processing the data and making it available for the upper level functions should increase the efficiency and improve the accuracy and robustness of the analysis.
- **Enhancing user interfaces**. System needs to provide tools for searching, accessing, and viewing IED data, analysis reports, and system configuration data and component descriptions. User interface tools need to be universal and preferably web-based allowing use of standard web browsers significantly simplifying the maintenance (no need for installing software on each workstation).
- **Assuming technology compatibility**. Automated analysis modules should be used on PC systems running Windows as well as be compatible with the centralized database, communication and networking resources to facilitate intensive data exchange. Web-based technologies such as ASP, HTML, and XML [8-9] should be used for designing user interfaces as well as for data exchange.

IV. New Functions

The use of new IEDs together with the concept of data integration and information exchange enables implementation of several new functions. This section focuses on new generation of applications primarily aimed at automating the analysis of substation data by utilizing data integration.

New functions that will be described can be represented in three levels (Fig. 2.):

- Monitoring/tracking (switchyard, substation level)
- Substation level analysis
- System-wide analysis

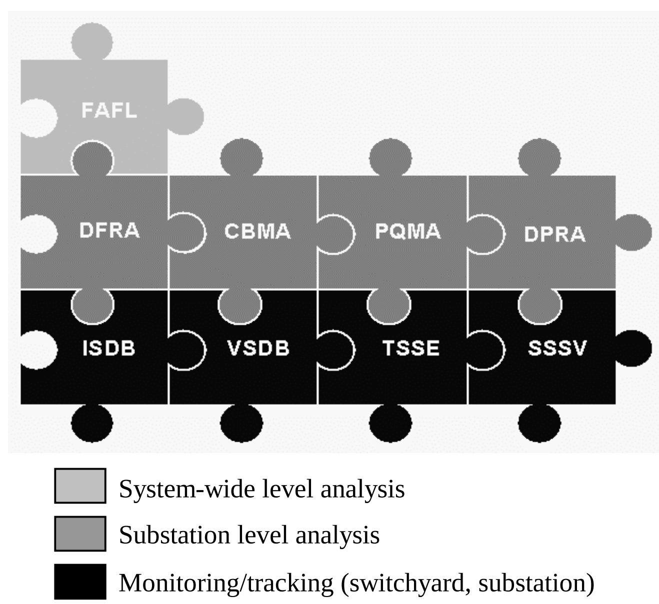

Fig. 2. Modular approach to new automation applications

All the functions should be implemented as software modules that together with data integration are creating a system for automated analysis of recordings and disturbances. Modular approach allows new functions to be added at all levels. Some functions rely purely on device specific data while others can use data from several IEDs as well as the processed data (calculated data and/or analysis reports from other applications). The description of the functional modules is given in the following sections.

V. Monitoring and Tracking

The following functional modules have been identified and developed for monitoring and tracking the substation data coming from IEDs:

- **Integrating the IED data into substation database (ISDB)** assumes collecting of all analog and digital measurements in a substation. All other non-operational data gathered from IEDs should be added to this set of measurements as well. This function should include data format conversion if needed. In today's solutions, this function is partially implemented and supported by the hardware and software of individual IEDs.
- **Verification of Substation Database (VSDB)** performs collecting, processing and data consistency checking at the substation level. Redundant data is eliminated and redundancy is used to create an improved set of measurements. All detected measurement errors are filtered out. Output data are more concise, reliable and consistent. Several processing and consistency checking algorithms are used, some are handling analog measurements (i.e. redundant branch current measurements and Kirchhoff's current law) while others are handling topology measurements such as branch status determination, branch current and status consistency [10-11]. Additional algorithms examine changes in analog and digital measurements from snapshot to snapshot and report transitions in the transmission line and load connectivity.
- **Two-Stage State Estimation (TSSE)** function detects the topology errors [12]. This function normally includes three steps: 1) The first stage state estimation is nothing but a conventional one, which is based on the bus/branch model. Most of the conventional state estimation methods capable of bad data processing are used directly. A Weighted Least Absolute Values (WLAV) method is used due to its ability to exclude bad data; 2) After the first stage state estimation, we need to detect and identify any existing topology errors. This detection/identification procedure is based on the normalized residual analysis. This step is called Suspect Substations Identification; 3). The detailed models of suspect substations are incorporated into the bus/branch model at this stage. The generalized state estimation, which can consider zero-impedance branch, runs based on this expanded model.
- **Substation Switching Sequence Verification (SSSV)** is used to verify if all the switching sequences are performed correctly. It consists of the following processing steps: 1) Determination of optimal switching sequence for each type of fault condition or load transfer operation; 2) Analysis of the executed switching sequences; 3) Comparison whether the executed switching sequence is an optimal one. This function uses data from several IED specific applications such as digital fault recorder data analysis (DFRA), circuit breaker monitoring analysis (CBMA) and digital protective relay data analysis (DPRA).

VI. Automated Analysis

Automated analysis functions provide analysis of the data collected by digital fault recorders, circuit breaker monitors, power quality meters and digital protective relays. Other functions may be identified as substation-wide or even system-wide. As an example, four device-specific and one system-wide automated data analysis applications are briefly discussed next:

- **Digital Fault Recorder Data Analysis (DFRA)** is an application that conducts automated analysis of fault records captured by digital fault recorders (DFRs) and disseminates event reports. Event analysis has the following goals [13]: 1) Detection and classification of faults and disturbances; 2) Verification of the protection system operation; 3) Verification of circuit breaker operation; 4) Calculation of fault location. This function automatically provides fault and disturbance data and analysis reports dramatically reducing the time needed for understanding the fault and expediting power system restoration.
- **Circuit Breaker Monitor Data Analysis (CBMA)** evaluates performance of the circuit breaker operation based on the analysis of data taken from the control circuitry [14]. It requires input data in COMTRADE file format. At the end of processing, it gives a report in an ASCII text file format that contains list of circuit breaker operating problems as well as recommendations how the detected problems can be solved. It helps in CB maintenance as well as in predicting possible CB failures. The function provides lots of details related to CB operations that can be used in the upper level functions.
- **Power Quality Monitor Data Analysis (PQMA)** is a powerful software tool which can be used for power quality analysis and modeling. It integrates the following functions [15]: 1) Converting, retrieving and managing PQ meter files; 2) Modeling of power quality events; 3) Online replaying of recorded events or created signals; 4) Implementing event detection and classification; 5) Enabling waveform characterization; 6) Providing data file compression. In addition, PQ data can be used for verifying the data collected by other IEDs or in situations where other IED data is not available.
- **Digital Protection Relay Data Analysis (DPRA)** has several applications such as: 1) Consistency checking of the data in various relay files. Checking is performed by comparison among osillography file, fault report and event report; 2) Verification of correctness of the data obtained from various relay files, which is done by comparing the reference data contained in the osillography file and the fault report; 3) Providing results to some higher-level applications, such as Fault analysis including fault location (FAFL), as described next.

- **Fault Analysis Including Fault Location (FAFL)** includes the following [16]: 1) A novel algorithm for fault location. This algorithm requires data from several IEDs as well as the correct switching state of each substation at the moment of the fault; 2) Fault analysis which is partially based on processing results obtained from device specific applications such as DFRA and CBMA; 3) Local as well as system wide analysis of the faults. This module is intended to work as a system-wide analysis module and it uses data gathered from several IED types as well as calculated data and/or reports from other functional modules. A report from this function enables user to instantly focus on possible causes of the fault and the means for their elimination.

VII. ADVANCED SIMULATORS FOR RELAY TESTING

Digital simulators for relay testing have been around for a quite a while and several utilities and vendors have been using them for evaluating and troubleshooting IEDs, primarily protection relays. Several advanced solutions are available on the market [17-20]. The test set vendors are adding digital simulator functions thus giving a new dimension to the use of test sets [21-23]. Also, several transient simulation tools became available and accessible through user groups [24-25].

Demands for the use of advanced digital simulators in facilitating the restoration are expanding. Three main scenarios and needs for use of digital simulators can be identified:

- Verifying IED settings.
- Troubleshooting the miss-operations.
- Evaluating IED operation for fast transmission line re-commissioning.

A. Lab Setup

Evaluation of IEDs before the purchase can be accomplished by the use of a lab setup. This is a traditional simulator function and is more and more used in the power industry. Use of the history data containing simulated and/or recorded waveforms of fault disturbances that are realistic for the power system of interest enables proper evaluation and selection of the most suitable protection equipment. Lab setup is also used for IED setting verification and commissioning as well as for troubleshooting miss-operations when field-testing is not possible. For example, there are situations when going to the substation and setting up the test tools may require more time than to simulate the whole scenario in the lab.

B. Portable Simulator Setup

Troubleshooting miss-operation of an existing IED in any given substation (on-site) can be done by utilizing a portable version of digital simulators using pre-defined test waveforms or waveforms that were captured during the actual disturbances (Fig. 3.). So far, portable test sets have been used primarily for phasor-based testing of protective relays. Keeping a history of valid test cases as well as restoring system configuration for any given time stamp is becoming a critical condition for enabling this function.

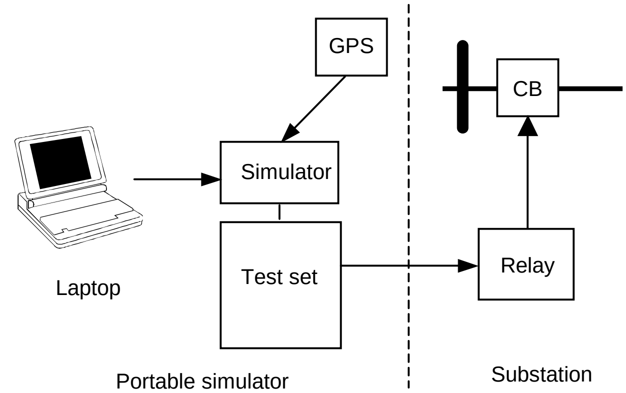

Fig.3. Portable simulator setup

C. Permanent Field Installation

The need to have an easy and quick way of evaluating IED operation before the critical transmission lines can be restored may be done using permanently installed digital simulators at the substations located at two (all) ends of the line(s) of highest interest (Fig. 4.). The current availability and pricing of the advanced digital simulators makes this approach attractive. Two main benefits would be: 1) Dramatically reducing the time needed for setting up and wiring of simulator equipment and tools in a substation 2) Insuring that enough power will be delivered through simulator amplifiers for the desired test application. In addition, current technology and developments in communication infrastructure can enable a remote use of permanently installed digital simulators where testing procedures can be conducted from a remote site.

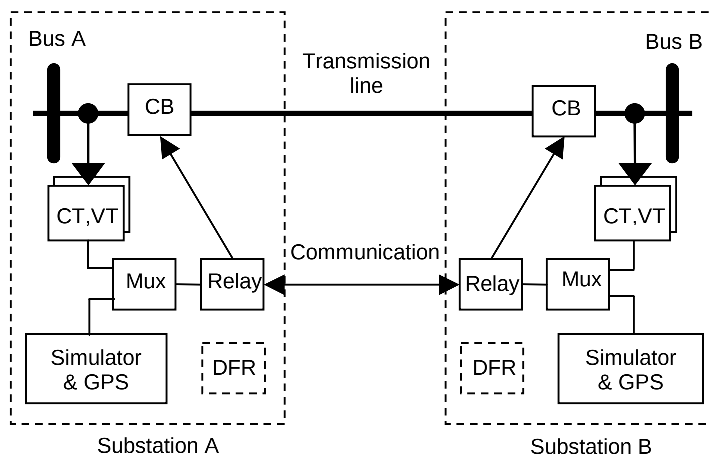

Fig.4. Digital simulator permanently installed in substations

VIII. SYSTEM CONFIGURATION DESCRIPTION

It is very important to distinguish between data integration and integration of functions. Data integration requirement has to include not only integration of all the IED data, but also system configuration data and component descriptions. The IED data collected in substations needs to be matched against the power system configuration and components. The system configuration has to be restorable for any given time-stamp (extracted from the IED data). Power utilities have their system data entered in different databases but they rarely have interchangeability of the system configuration data between different applications. Keeping all the configuration data properly matched to the power system model and updated in different databases and applications is a major challenge.

Current developments in new standards such as IEC 61850 do address these issues, but we may still be far from a comprehensive solution. Enabling the existing and new applications to provide support for standardized way of handling system configuration data is a challenging task.

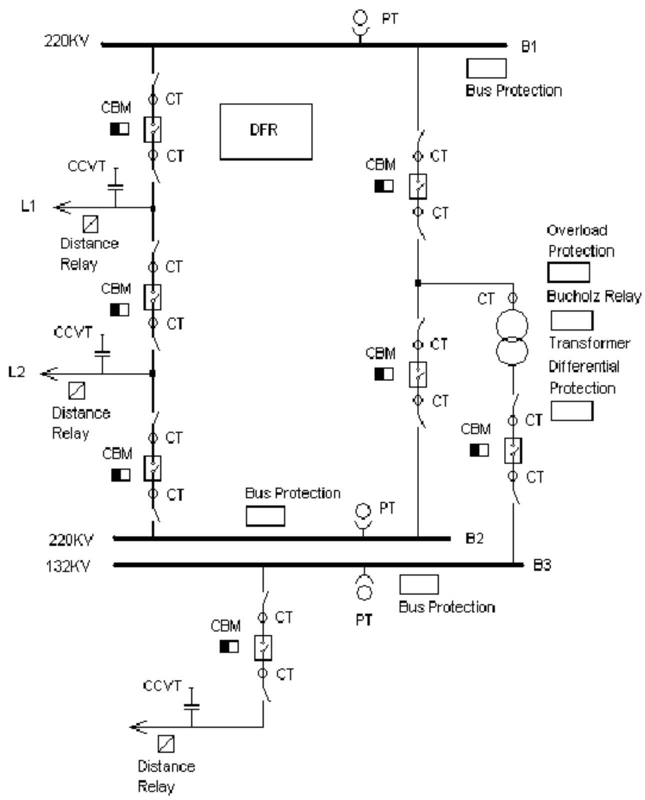

Fig. 5. Example substation configuration

An example of a simple substation one-line diagram is given in Fig. 5. In this example, one can identify several different substation components and different types of IEDs. Each component has to be fully described, placed in the system topology, and characterized with its parameters as well as its relationship to the IEDs that monitor its signals. For example, line L1 should be described as a line going from one substation to another (both ends of the line should be defined), with specified length, line impedances, related signals being monitored by the distance relay and DFR, rated bus voltage, other components attached to it such as CTs, VTs, circuit breakers and their CBMs, then corresponding description of the protection schema on this line, communication signals, etc.

Only a full description of substation and power system configuration will enable integration of data and applications. Power system configuration data is typically stored in different databases. For example, custom databases developed by IT groups in power utilities or configuration data for short circuit study programs [26-27].

As mentioned before, additional requirement for handling the system configuration data is to keep history of all the changes. System configuration do change over time and it is very important to be able to restore system configuration data for any given time stamp from past. Keeping IED data in a database without knowing corresponding configuration and IED settings may make such a database useless.

IX. Examples of Functions

This section will further details about two of the functions.

A. *Circuit Breaker Monitoring Analysis (CBMA)*

This function relies on extensive monitoring of circuit breaker operations by looking at the CB control circuit signals (Fig. 6.) [14].

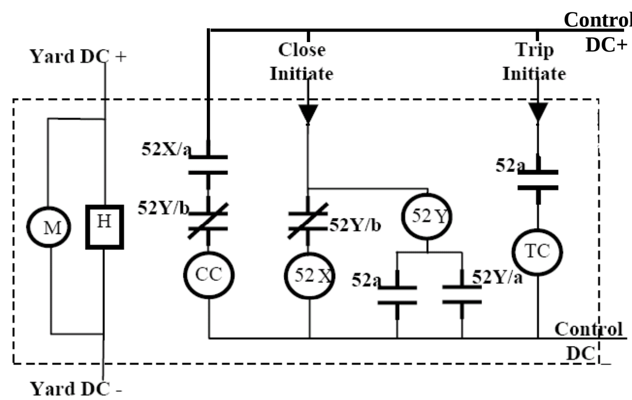

Fig. 6. Simplified diagram of a circuit breaker control circuit

Two sets of signals are being constantly monitored for both closing and opening operation of a circuit breaker (Table 1). These signals can be monitored with a classic DFR unit or a custom data unit called circuit breaker monitor (CBM). Several features related to the monitored signals have been identified and characterized [14].

Table I Monitored Signals from a CB control circuit

Open Operation	*Close Operation*
Trip initiate	Close initiate
Supply DC voltage	Supply DC voltage
Yard DC voltage	Yard DC voltage
A contact	A contact
B contact	B contact
Trip coil current	Close coil current
Phase currents	Phase currents
	X coil
	Y coil

The automated analysis performs feature extraction from recorded signals. Expert system evaluates around one hundred rules and provides a report in plain English. Example of the report is given in Fig. 7. As the example shows, several statements related to both the extracted features and expert system outcome can be a part of the report. The reports can further be automatically classified by priority and disseminated as needed.

This function can help identify possible causes of a problem during a blackout, which can improve decision-making related to system restoration. Features and parameters extracted at this level can be passed to the system-wide analysis functions enabling more detailed analysis at the system level.

Test Case # 13	
Feature	Control voltage spike 'A' contact noise 'A' contact delayed X Coil deactivation delayed Y Coil activation delayed Velocity decreased Effect of mechanism binding (bearing friction) on 'B' contact
Expert System Report	-------------Expert System Log-------------- The record indicates a closing operation! R2: Breaker closes! R10: Control voltage spike! R16: 'A' contact noise! R19: 'A' contact delayed! R55: X Coil deactivation delayed! R59: Y Coil activation delayed! R68: Velocity decreased! R71: Effect of mechanism binding (bearing friction) on 'B' contact! ------Maintenance & Repair Information------ Check substation battery, charging system, and control cables. Check auxiliary assembly, contacts, and linkage. Check close circuit connections. This breaker is slow. The auxiliary alignment needs to be checked. An auxiliary contact may be broken or the mechanism may be binding.

Fig. 7. Example report from CBMA function

B. Digital Fault Recorder Data Analysis (DFRA)

With a new concept of data integration there is a new dimension added to this function especially with respect to data verification [28]. By combining data from different IEDs and extracting features, the data can be used for a system-wide analysis. Monitored signals are the line(s) currents and voltages as well as the status channels such as relay trip, auxiliary breaker, communication signals related to protection schemas etc.

Several events can be recognized by DFRA function:

- Manual trigger – detecting change of status on the digital channel designating an external trigger.
- Relay trip – detecting change of trip output on the monitored relays (i.e. primary and backup).
- Relay slow – detecting if the relay trip and pick-up time is greater than the setting (e.g.4 cycles).
- Breaker open – detecting a change of status on auxiliary breaker channels by looking at both the current levels and digital status channels.
- Breaker slow – detecting if the breaker operation time is greater than the setting (e.g. 8 cycles).
- Restrike occurred – detecting if the breaker opens, and if the phase current through that breaker is not zero.
- Reclosing unsuccessful – detecting multiple relay trips in a record, and phase current levels at the sequence end.
- Possibility of ferroresonance – detecting breaker trip for all breakers, and/or detecting breaker failure contact change.
- Wrong carrier signaling – detecting if the relay trip and the carrier signal are in disagreement.

An example of a DFRA report is given in Fig.8. Such a report is accompanied with the recorded data that have already been converted to COMTRADE file format.

```
D P R A   E V E N T   R E P O R T

*** Event Origin ***
DFR Assistant Client :     So_Hou_AutoPoll
Substation :               S.T.P.
DFR Native File Name :     ZQ1757
Affected Circuit:          D. Velasco Ckt #27

*** Event Description ***
D. Velasco Ckt #27 is the circuit with largest current disturbance.
The disturbance is a phase B to ground fault.
The fault is cleared by the protection system at this substation!

*** Fault Location ***
Fault is located 21.54 miles from this substation.

*** Protection System Operation Analysis ***
Backup relay operation starts at 0.0337 sec [2.0202 cycles]
                  and ends at 0.0487 sec [2.9202 cycles].
The middle 52B contacts operate at 0.0605 sec [3.63 cycles].
The bus 52B contacts operate at 0.0537 sec [3.2202 cycles].
The bus breaker status change after tri is applied is 1.2 [cycles].
The middle breaker status change after trip is applied is 1.6 [cycles].

*** Event Summary ***
Trigger Date and Time:   12-12-2003 15:36:30.923
Event Description    :   BGND_FAULT
Fault Location       :   24.54 [miles]
Fault Resistance     :   3.68 [Ohms]
Disturbance Duration :   24 [ms]
DC Offset            :   271.13 [%]
Event Outcome        :   LOCAL
Breaker Operation    :   1st,  CB_OK
Breaker Operation    :   2nd,  CB_OK
Relay Operation      :   PRIM,  RL_OK
Relay Operation      :   BACK,  RL_OK

*** Line Currents and Voltages ***
  Prefault Values:      Fault Values:       Postfault Values:
 I0 =  0.0087 [kA]    I0 =  24.19 [kA]    I0 =  0.001 [kA]
 Ia =  0.2076 [kA]    Ia =   0.801 [kA]   Ia =  0.000 [kA]
 Ib =  0.1868 [kA]    Ib =   22.83 [kA]   Ib =  0.000 [kA]
 Ic =  0.1672 [kA]    Ic =   0.272 [kA]   Ic =  0.000 [kA]

 V0 =   0.006 [kV]    V0 =  0.086 [kV]    V0 =  0.001 [kV]
 Va =  283.70 [kV]    Va =  272.6 [kV]    Va =  282.2 [kV]
 Vb =  284.90 [kV]    Vb = 106.4  [kV]    Vb =  282.8 [kV]
 Vc =  283.80 [kV]    Vc =  272.7 [kV]    Vc =  283.6 [kV]
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Fig. 8. Example report from DFRA function

The report contains information related to the line being identified as a circuit with the highest disturbance. Experiences in the field suggest that the analysis should be performed for all the lines/circuits being monitored by DFRs/IEDs. This approach would enable easier spotting of the faults located beyond the buses where the data have been collected and recognizing if several lines have been involved. Other field experiences suggest extraction of as many as possible of different disturbance and fault related parameters that can be forwarded to other applications: fault duration, DC offset at the moment of fault occurrence, fault resistance, etc.

DPRA function provides both the converted IED data and the analysis reports and makes them available in the database. Several broadcasting mechanisms are available: printing on network printer, automated emailing, paging, faxing or file copying. This function can be configured to do the pre-processing and extraction of several parameters that may be available for re-use by other analysis functions such as system-wide fault analysis, two-end fault location calculations, etc. Several tools for further analysis of the processed data, report viewing and database access via web-based user interface are available as well.

X. Conclusions

The paper outlines requirements for integrating data and functions for automated analysis. Description of analysis functions and their impact on the power system restoration is given next. Having both the IED data and analysis reports readily available is the key to dramatically reducing the time needed for the restoration. The integration of data and functions requires proper handling of the power system configuration and system component descriptions. The exact system configuration has to be restorable for any given time stamp from the past.

Data availability together with described ability to restore power system configuration at the time of faults enable efficient use of other tools such as advanced digital simulators. The paper describes some of the latest approaches in using digital simulators by combining the history of test cases and ability of simulation tools generate test cases automatically. Installing simulators in substations may dramatically reduce the time needed for troubleshooting the miss-operation.

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