REQUIREMENTS FOR AUTOMATED ANALYSIS OF SUBSTATION DATA

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Abstract

Goal of the paper is to discuss future requirements for data integration and processing in substations for the purpose of extracting information for monitoring applications. The following requirements for the Automated Substation Analysis (ASA) System are discussed: database integration, new real time data processing applications, communication infrastructure and operator interfaces.

Introduction

Future trend in substation monitoring, control and protection is to install Intelligent Electronic Devices (IEDs) that have very flexible ways of recording field data. As a result, a large amount of detailed data may be acquired during major disturbances. Processing such data in a timely fashion, storing it for future use and presenting the results to the operators is a major challenge. Many vendors are providing partial solutions that will include handling of data from their own IEDs, or from selected IEDs from other vendors, but there is no comprehensive substation handling and analysis solution that meets the requirements for data integration and information extraction to meet the needs of different utility groups. Acquired data are not verified and errors accumulated during data acquisition and transmission, are affecting monitored measurements.

This paper discusses future requirements for data integration and processing for the purpose of extracting information for monitoring applications. The IEDs of interest are digital protective relays, digital fault recorders and circuit breaker monitors. The paper outlines the following requirements: database integration, real-time data processing, communication infrastructure, and operator interfaces. The processing software should allow a full automation of data analysis. The analysis should be enhanced through correlation among data recorded by different IEDs. Customized interfaces are to be developed for different utility groups: operators, protection engineers, maintenance crews, etc.

The final outcome of the discussion is to list the benefits that the new solution may help create. The main benefit is the automated substation data handling, archiving and viewing. The other benefits are: System-wide analysis of disturbances, improvements in EMS functions that came about as a result of the use of better substation data, new applications that were not conceived earlier and yet provide major operating improvement for substation operation. The paper ends with a discussion of future solutions giving details of a few demo software solutions that were implemented using actual field scenarios.

Background

Multiple benefits can potentially be achieved by substation data analysis applications, as a result of utilizing data from Intelligent Electronic Devices (IEDs). Newest development in the IED market and advanced processing and communication capabilities of the state-of-the-art IEDs raised several research and development issues. The main questions are:

- Can these devices be used to address broader needs in the utilities today allowing for further leveraging of the investment?
- Can these devices be used in a more cost-effective way to justify an extensive use in the future?

The answer to the first question is to develop new algorithms and concepts for automated on-line monitoring of the power system conditions where data can be shared amongst various groups of utility staff. The answer to the second question is to make the data recorded by IEDs readily accessible to the users in a more efficient way.

A new approach of substation data integration and information exchange (DIIE) is introduced to enhance the existing substation automation practices and enable introduction of new applications [1]. The list of new applications made possible by utilizing the DIIE concept is given as follows:

- Automated digital fault recorder data analysis (DFRA) [2]
- Automated circuit breaker monitor data analysis (CBMA) [3]
- Automated digital protective relay data analysis (DPRA) [4]
- Automated data correlation analysis (DCA)

Three main characteristics of substation data processing systems based on DIIE and new applications are given bellow:

- *Serving local functions*. Substation data processing will substantially improve local substation operations by automating existing functions and implementing additional ones.
- *Local pre-processing for control center functions*. By pre-processing data locally in substation, amount of data to be transmitted to the control center will be significantly reduced enabling faster operator responses.
- *Redistributing centralized functions*. Redistributing portions of centralized functions from the control center to the substation level will improve existing functions such as state estimation and maintenance functions resulting in more efficient power system operation.

The architecture of the ASA system featuring all mentioned functions is displayed in Figure 1. The system consists of a database, web portal and four new applications performing advanced automated analysis of IED data. The ASA features the scheduler software module enabling flexible configuration of the system structure and operation. It has centralized graphical user interface providing customized detailed information about IED measurements and substation events to different groups of users.

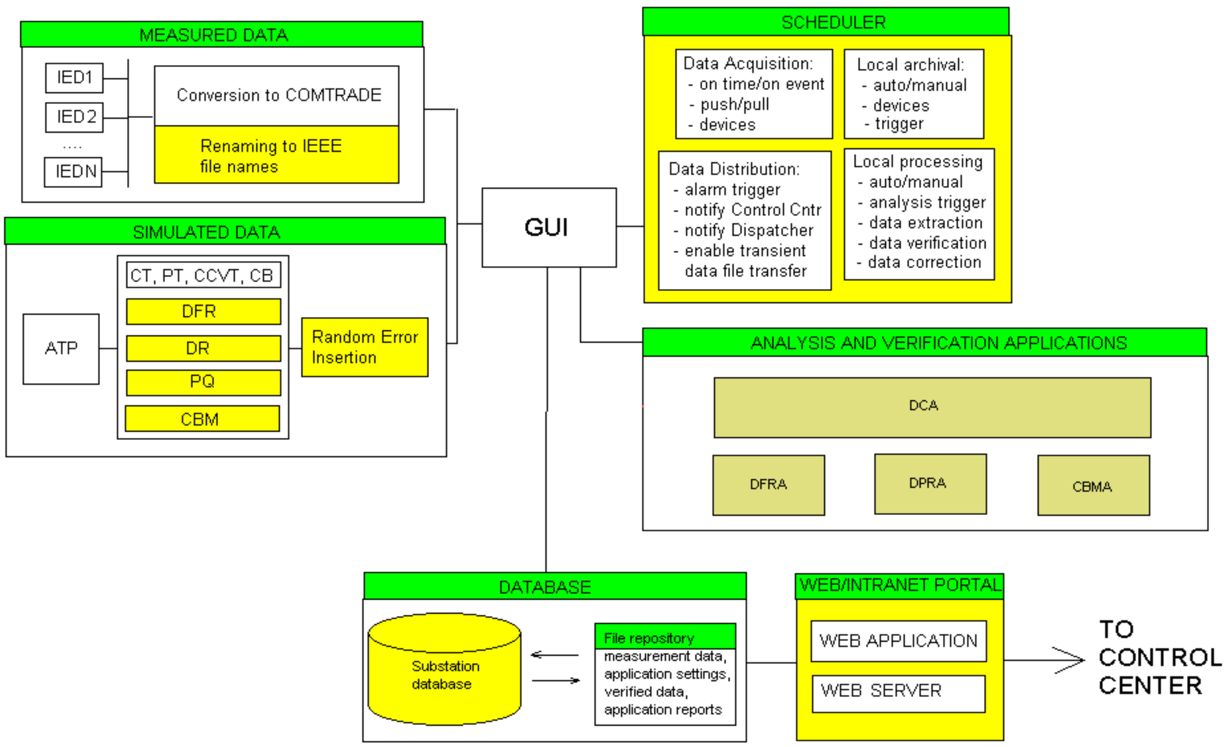

Figure 1 Architecture of ASA

One of the main advantages of the system is that it can operate in real time. The ASA software can analyze both the acquired data from the field and the simulated data by using embedded third party software simulation package. Elaborate substation data models are designed and implemented to create the data that resembles actual measurements acquired from substations. By analyzing the simulated data, evaluation of applications algorithms and parameters is enabled.

The requirements for the database, user interfaces and communication infrastructure will be discussed first, while the introduction of new applications, their categorization and development status will be given after.

Requirements for data integration and information exchange

Substation database

The design requirements for substation database are based on several factors. In order to define the required size and structure of the database, one must determine who are the users of the substation automation data, what is the nature of their application, what type of data they need, how often the data is required and what is the frequency of the update by each user. Since different users have different requirements, database will have to accommodate needs of all users - substation design engineers, protective relay engineers, dispatchers in the control center, maintenance staff, etc.

Substation database must perform several important tasks:

- Store and organize, in a logical manner, data collected and analyzed in the substation
- Allow users to have fast and efficient retrieval of data using customized queries based on multiple search criteria, such as types of events, time and location of measurement and event occurrence, specific IED type or ID etc.
- Provide reports containing detailed information on events in the substation, such as fault type and location, power quality disturbance, operations of protective relays, and circuit breaker operations and switching sequences
- Make the information available for the local/substation and system-wide use
- Enforce referential integrity preventing problems with database data redundancy
- Request additional information, not readily available from IED recordings or application reports, from the users
- Support data validation by establishing data entry rules, verifying individual fields in database tables and using lookup tables

In Figure 2, basic structure of the ASA database is displayed. The largest group of data in the substation is IED related data. The substation database for ASA is organized as follows:

- Raw IED recordings. These are samples of data collected in the field. There can be two types of data: “logged” – recorded continuously during certain period of time, or “event” – the beginning of their recording is usually triggered by predefined conditions. Both “logged” and “event” data could be in made available in different IED specific file formats.
- Simulated IED recordings. They are generated by the ASA system and kept for the reference and comparison with the field measurements.
- Verified IED recordings. These recordings contain corrected data, verified by the ASA applications.
- IED configurations and settings. This is IED device specific data, such as relay settings, DFR channel assignments etc.

The simulated and verified recordings are stored in COMTRADE [5] or ASCII files and renamed according to the IEEE file naming convention [6] enabling more efficient retrieval and manipulation.

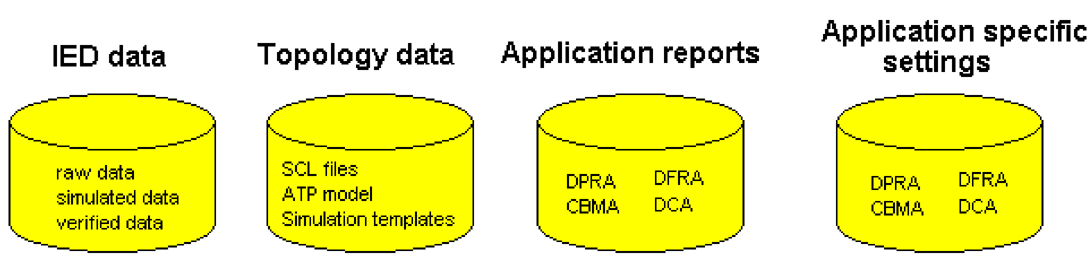

Figure 2 Database structure of the ASA

Apart from mentioned data, substation database contains substation topology files, in substation configuration language (SCL). The language is defined as part of the IEC61850 standard enabling standardized way for describing the substation topology, communication interfaces and descriptions of available data [7]. Together with the topology files, related ATP substation models and the simulation templates are kept in the database.

Reports from the analysis and verification applications are stored into the database and organized in a way that enables their efficient retrieval for particular event of interest, based on the type, time and location of the occurrence. Each application produces its own report containing different information, which could be redundant in some cases.

Last large group of data are application specific settings. Since the outcomes of analysis and verification application algorithms are dependent on the various parameters which are derived empirically, keeping them stored in the database enables users to compare and establish the relationships between various settings and measurements data.

Communication infrastructure

The communication infrastructure consists of several layers displayed in Figure 3. Layers are defined by their building objects and interfaces towards other layers. Building objects of each layer can generally be divided into following categories: physical network (wires, cables, optical fibers), protocols (serial, SCADA, Ethernet, MMS) and data formats (COMTRADE, XML, ASCII).

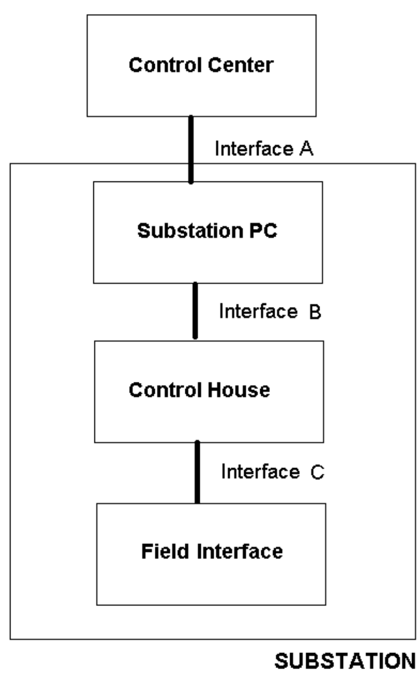

Figure 3 IED Layers and interfaces of communication infrastructure in the substation

The IEDs of interest for the ASA system - Digital Protective Relays (DPRs) and Digital Fault Recorders (DFRs) are usually located in the Control House and connected with the field equipment by wires. Samples of monitored analog and digital signals are transferred by vendor specific protocols and data formats (Interface C in Figure 3). The Circuit Breaker Monitors (CBMs) are installed next to the circuit breakers and are connected to the concentrator PC installed in the Control House via wireless modem.

In the Control House, DPRs and DFRs are connected to the concentrator PC by a serial or an Ethernet connection. For practical implementation, the required format for their data should be the standardized COMTRADE file format. The CBM files should also be in the COMTRADE file format.

Substation PC is a connection point between the substation and the Control Centre. The interface between these two layers (Interface A) should be based on IEC 61970 [8], [9] which is an already adopted common communication standard for data interchange between substations and control centers.

Customized user interfaces

The user interface of the ASA system will be divided into two parts. The first part will be accessible from the concentrator PC (Client Graphical User Interface - CGUI), while the second one will be available online, to the LAN/WAN users and will be referenced as a Web application user interface.

The client GUI will serve several important functions aimed at displaying: the real-time IED data, analysis reports, substation topology, the layouts of the buses and feeders, equipment interconnections and the statuses of circuit breakers and IEDs . The client GUI also provides support for data simulation

One of the most important functional requirements of the centralized GUI is to enable seamless integration with the substation database. The GUI will provide the forms and customized dialogs with options allowing the users to manually or automatically store the data into the database according to the established business rules.

The main requirement of the Web application interface in current implementation of the ASA is to enable online access to the substation data and reports stored in the substation database. Some of the functions are supporting the authorization and authentication of the users, advanced searches of data based on multiple criteria, graphical displays of the signal waveforms and analysis reports, remote classification of the reports and data based on the levels of priority, file transfer between the substations and the control centers etc.

Different users of the data and reports provided by ASA will be interested in different information, as illustrated in Figure 4. Consequently, the software will feature customized interfaces which will fit specific requirements of each users group.

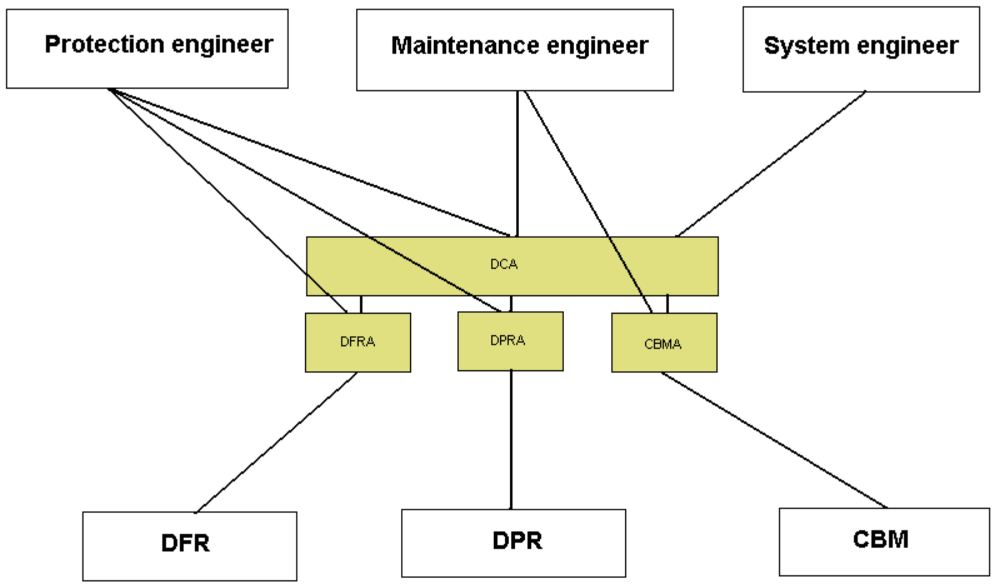

Figure 4 Data and information requirements of different users

Requirements for new applications

As an example of the applications made possible by the new DIIE concept, it may be noted that IEDs of interest for the ASA system solution are:

- Digital Fault Recorders (DFRs)
- Digital protective Relays (DPRs)
- Circuit Breaker Monitors (CBMs)

The data analysis applications listed in Table 1 will significantly improve existing practices related to substation monitoring and analysis. Circuit breaker monitor data analysis and DFR data analysis applications are already implemented. The implementation of Digital protective relay data analysis (DPRA) application is currently in progress, while Data Correlation Analysis (DCA) application is yet to be implemented. Detailed descriptions of these applications are given in the following sections.

Every data analysis application will provide comprehensive report regarding events monitored by corresponding IEDs (DFR, DR, CBM) of a particular substation as well as an estimate on how those IEDs behaved while responding to these events. The DCA application will provide additional level of information by correlating reports and inputs of three IED specific applications. Redundant and interrelated results of different analysis applications will provide better understanding of relationships between various substation events and their causes. Consequently, operators and engineers in the field and control centers will have better overall picture of the substation state and behavior of their IEDs before, during and after particular event in the substation and transmission/distribution network.

Device specific applications (DFRA, CBMA, DPRA) will automatically perform the data analysis and store the information in the database. Their reports will be available locally and in the central control office for both the users and other applications. DCA application will draw the data and results from the database and provide more detailed analysis and relations between various data sets and events.

It is important to note that the automated mode of operation of all the mentioned applications gives a new dimension to the substation automation. Besides the data measured by IEDs, new substation database will contain consistent, verified, pre-processed data and reports that will be readily available for local and system-wide users or other applications that may be connected to the database.

Table 1 New Automated Analysis Functions

Function name	Inputs	Outputs	Description
Circuit breaker monitor data analysis (CBMA) [3]	Digital samples of signals from circuit breaker control circuitry in COMTRADE 0 file format	Report in an ASCII text file format containing list of circuit breaker operating problems as well as recommendations how the detected problems can be solved	Evaluates performance of the circuit breaker based on the analysis of data taken from the control circuitry
DFR data analysis (DFRA)] 0	DFR records in COMTRADE file format	Report in an ASCII text file format containing results of detection and classification of faults and disturbances, verification of the correctness of the protection system operation and fault location calculation	Conducts automated analysis of fault records captured by digital fault recorders (DFRs) and disseminates event reports
Digital Protective Relay (DPRA) [4]	Digital Relay files in COMTRADE file format	Report in an ASCII text file format containing estimation of relay performances	Consistency checking of the data of various relay files. Correctness verification of the data of various relay files
Data Correlation Analysis (DCA)	CBMA, DFRA, DPRA reports and input files	Report in an ASCII text file format describing correlations between reports of CBMA, DFRA and DPRA applications	Detects the correlations between input data and reports of three previously mentioned applications. Provides comprehensive understanding of substation events and measurements.

DFRA application requirements

The ultimate fault analysis system should provide a detailed system-wide analysis of an event to the interested users within seconds after the event occurred. Logically, the main goals of the DFRA solution are:

- Reduce time spent on handling and analyzing the DFR records.
- Integrate archival and viewing of DFR data coming from different types of DFRs.
- Disseminate recorded data and results of the analysis over the utility corporate Intranet

The architecture of the DFRA application is displayed in Figure 5. The modules work together enabling the main function: classification of DFR event files. The following typical scenario describes the functions of individual modules:

- Client constantly monitors incoming folders or attached DFRs files for new events
- When a new DFR file is detected, Client reads it and prepares for the analysis
- Client uses embedded file format filters to extract event data from DFR files

- Client module performs signal processing to extract representative parameters of an event
- Expert system uses calculated event parameters to classify/analyze the event
- If the event is classified as a fault, Fault Locator calculates fault location
- Expert system report and the event file are passed to Data Management Layer

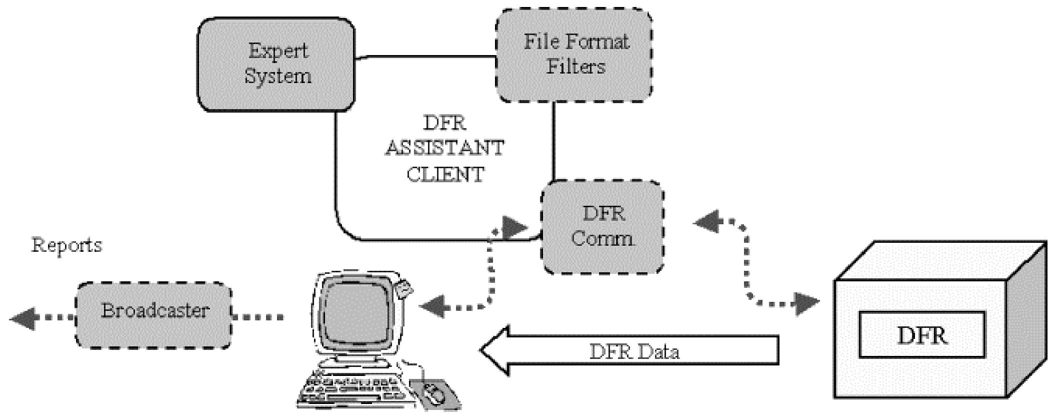

Figure 5 DFRA software architecture

The event analysis is triggered as soon as a new DFR file is detected in a designated folder on the hard disk of the substation PC. The system does the processing of each of detected DFR files individually. For one DFR file, the analysis is conducted for each circuit being monitored by that particular DFR.

The objectives of the event analysis are detection and classification of the fault/disturbance and verification of the correctness of the protection system operation. The analysis is conducted by a rule-based expert system and is based on two sets of the signals: analog signals and digital signals. Analog signals are generally used for fault detection and classification, while digital signals are used for the analysis of the protection system operation List of input signals for DFRA application is given in Table 2

Table 2 Input signals for DFR Analysis application

Symbol	Description	Type
I	Line currents: 3 phases or 2 phases & zero seq.	Analog
V	Bus voltage (3 phases or 2 phases & neutral)	Analog
CBP	Bus (primary) breaker contact status	Digital
CBS	Middle (secondary) breaker contact status	Digital
PRT	Primary relay trip status	Digital
BRT	Backup relay trip status	Digital
TCR	Blocking signal received status	Digital
TCT	Blocking signal transmitted status	Digital
TCFR	Breaker failure signal received status	Digital
TCFT	Breaker failure signal transmitted status	Digital

Prior to being passed to the expert system, analog signals must be processed to extract a set of parameters used by the expert system's rules. List of Expert system input parameters is given in Table 3.

Table 3 Expert System Input Parameters

Symbol	Description	Type
IAp	Current, phase A	Pre-fault
I0p	Zero-sequence current	Pre-fault
IA	Current, phase A	Post-fault
I0	Zero-sequence current	Post-fault

CBMA application requirements

CBMA application automatically evaluates performances of the circuit breaker based on the analysis of signal waveforms recorded from the circuit breaker control circuitry. The automated analysis process starts with the CBM data and ends with a concise event reports, containing information about circuit breaker failures and repair recommendations. Figure 6 displays CBMA software architecture with an example where Rochester DFR was used to collect field data.

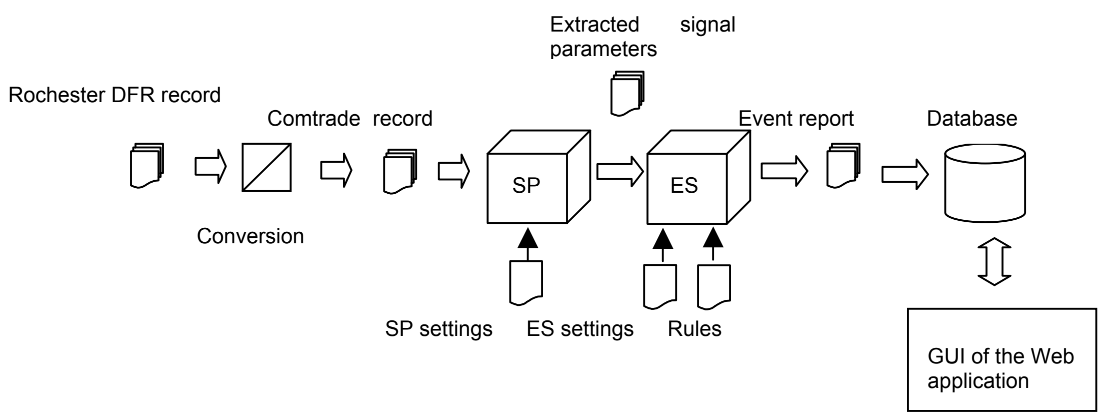

Figure 6 CBMA software architecture

Signal processing block performs data pre-processing. The analysis of the circuit breaker operation is performed based on some characteristic parameters (features) of the recorded signals. For examples, a feature could be a location of change in the recorded signals where the coil current picks up or where the phase current breaks. Signal parameters are used to describe the signal features quantitatively. Some of the processing tools used for parameter extraction are Wavelet analysis, Fourier analysis and digital filtering.

The core of the analysis is performed by an expert system emulating the reasoning of a human expert. This process is similar to the process of overlaying a given record over a reference record to establish or verify the existence of a discrepancy. It consists of the following steps:

- Classification: the event needs to be classified i.e. recognized either as a closing or opening of a breaker
- Characterization: each signal describing the event needs to be characterized by finding its pertaining temporal information
- Verifying signals: each signal describing the event needs to be analyzed based on the rules defined by the system designer and/or by the user. The purpose of this analysis is to verify that the features of each signal correspond to the ones normally expected. Common features will be recognized and reported.
- Verifying the cause-effect relationship among signals: the relationships involving multiple parameters and possible multiple signals need to be analyzed to determine the causes of observed signal features.
- Verifying operation: overall correctness of the breaker operation needs to be verified by comparing actual breaker operation against stored pattern(s) specified by the user. The patterns are stored as settings. Settings vary for different breaker types.
- Creating event reports: At the end of the analysis, the system needs to create an event report in a form of a text file. Event report needs to clearly describe the object (circuit breaker), the event (operation), and the conclusions (performance).

CBMA software requires input data in COMTRADE file format, with reserved signal names and fixed signal order. List of signals is given in Table 4.

Table 4 Input signals for CBMA analysis application

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
	Close Coil (CC) Current
Phase Currents	Phase Current A
	Phase Current B
	Phase Current C

CBMA gives the report in ASCII textual file format, which contains list of circuit breaker defects, possible cause for each defect, as well as directions how detected problems can be solved. Lists of abnormal signal behaviors that can be detected during open and close breaker operations respectively are given in Table 5 and Table 6.

Table 5 "Open" breaker sequence signal abnormalities detected by CBMA

Signal Name	Signal Behavior
Trip Initiate	Signal resets prematurely
Trip Coil Current	Dip delayed
	Delayed drop-off or no drop-off
	Distorted waveform
	Trip current flat
	Trip current sustained value low
	Trip current pick-up delayed
A & B Contact	Abnormal noise on contacts
	Contacts bounce
	Response time is increased
	Response time is reduced
	Dropout during trip operation
Phase Currents	Currents fail to break within required time
DC Voltages	Voltage drops below threshold
	Oscillation on the waveform
	Noise (distortion)
	Spike

Table 6 "Close" Breaker sequence signal abnormalities detected by CBMA

Signal Name	Signal Behavior
Close Initiate	Signal resets prematurely
X Coil	Late or no activation
	Late or no deactivation
	Premature deactivation
Y Coil	Late or no activation
	Premature deactivation
	Late or no deactivation
Close Coil Current	Dip delayed
	Delayed drop-off or no drop-off
	Distorted waveform
	Close current flat
	Close current sustained value low
	Close current pick-up delayed
	Close current pick-up premature
A & B Contact	Abnormal noise on contacts
	Contacts bounce
	Response time is increased
	Response time is reduced
	Dropout during trip operation
Phase Curr	Currents fail to raise
DC Voltages	Voltage drops below threshold
	Oscillations on the waveform
	Noise (distortion)
	Spike

DPRA application requirements

The main goal of Digital Protective Relay Data Analysis (DPRA) application is to check data consistency and correctness of various files extracted from digital relays. The analysis results will provide protection and maintenance engineers with useful information about relay performance and detection of possible relay internal faults.

The architecture of the DPRA software is displayed in Figure 7. The automated analysis starts with relay input signal data extraction from an oscillography file. After that, based on the relay settings file, the reference set of data is generated by a Reference Data Generation Module. Next, the data extracted from event and fault reports, and oscillography file are verified against reference data in the Data Consistency and Correctness Checking Module. The analysis ends with a relay data analysis report.

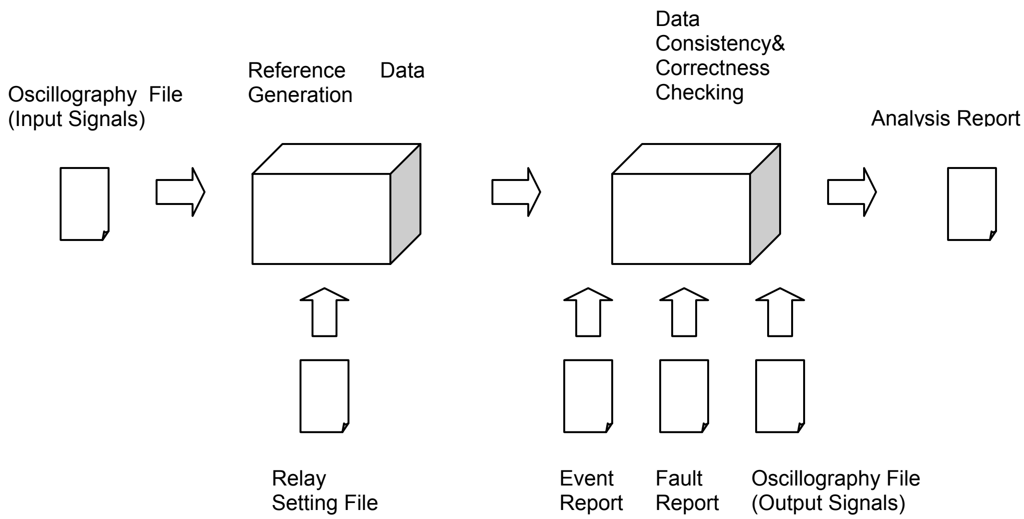

Figure 7 DPRA software architecture

Reference Data Generation Module is actually an abstract relay model that can be configured according to the relay setting file. In the relay setting file, protective elements, control elements, logic equations defining internal logic of the relay, oscillography file and fault report are configured. Based on the configuration, a customized relay model is generated. The analog current and voltage waveforms, input digital channel status, such as circuit breaker contact status and scheme communication signal status, are used as inputs to the relay model. Based on these inputs , the reference relay data are generated. The types of reference data are the same as those in the fault report and those user-defined output and internal digital channel status in the oscillography file.

Data Consistency and Correctness Checking Module sequentially performs data consistency and data correctness checking. Regarding data consistency checking, the relay event data in the event report are checked against those in the fault report and those in the oscillography file. If any discrepancy exists, a warning will be issued in the analysis report, indicating possible relay internal faults.

Regarding data correctness checks, the data in the fault report as well as the user-defined output and internal digital channel status in the oscillography file are checked against those generated in the Reference Data Generation Module. The data checked include:

- Fault inception time, fault type, fault location, auto-reclose shot count
- Pre-fault current & voltage phasors, fault current & voltage phasors
- User-defined external and internal digital channel status osillography data

The input data for DPRA application comes from four relay files: relay setting file, oscillography file, fault report and event report. Their contents and formats are summarized in Table 7.

Table 7 Input data for DPRA analysis

Relay Setting File
product setup
system setup
logic equations defining interaction of inputs, features and outputs
protective elements
control elements
input/output
Oscillography
oscillogram of analog data (Analog Actual Values)
oscillogram of digital data (FlexLogic operands)
Fault Report
date and time of trigger
name of trigger (specific operand)
active setting group
fault type
fault location
auto-reclose shot count
operated elements
pre-fault current and voltage phasors
fault current and voltage phasors
Event report
event cause
event date and time

The DPRA application reports consist of two parts. First one is the report from the Data Consistency check and the other one is the Report from the Data Correctness Verification. The Table 8 displays the content of both DPRA reports.

Table 8 DPRA reports

Report on Relay Data Consistency Checking
(1) Discrepancy warning on relay events
(2) Discrepancy warning on relay targets
Report on Data Correctness Verification
(1) Error warning on fault inception time, fault type and fault location
(2) Error warning on pre-fault, fault, post-fault voltage and current phasor values
(3) Error warning on user-defined output & internal digital channel status

Examples of the analysis

In this section, examples of analysis of two already developed applications of the ASA system are discussed. First, the signal waveforms of an analyzed DFR record and related analysis report of DFRA application are given for the A-G Fault event, when the breaker was too slow to operate [10]. Later, the waveforms of the CBM record signals and CBMA analysis report are presented for the event of closing the circuit breaker when the close assembly maladjustment occurred.

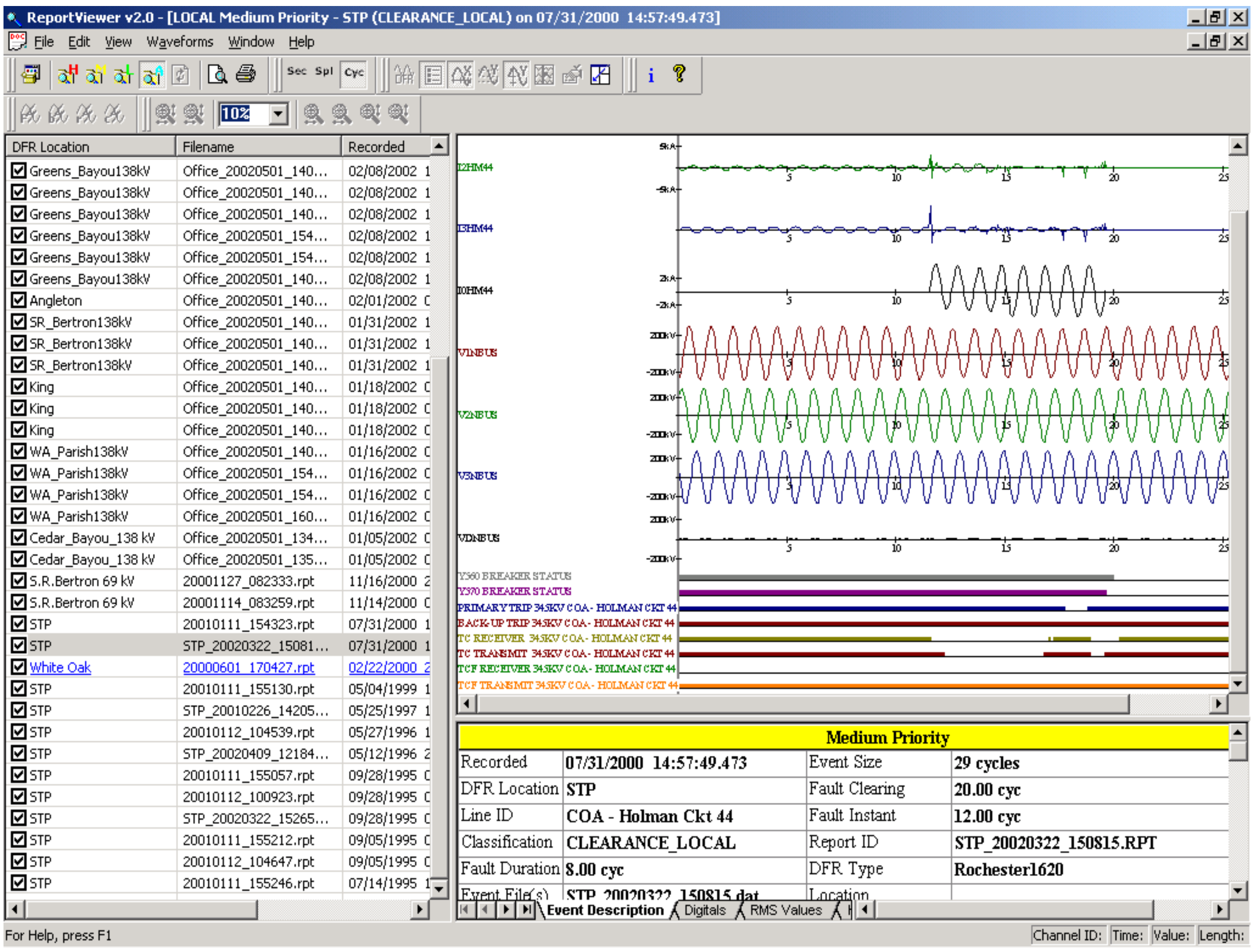

Figure 8 DFR signal waveforms displayed using DFRA Viewing software

Event Report

```
DFR Asistant - Expert System for Automated Analysis of DFR Recordings
Copyright: Test Laboratories International, Inc., 1996-1999

*** Expert System Log ***
The bus breaker opened in 21 cycle
The middle breaker opened in 20 cycle!
Line breaker(s) open after the disturbance!
The event is a ground fault!
The event is a phase A to ground fault!
The fault is cleared by the protection at this substation!
Primary relay tripped in 18 cycle!
The bus breaker opened in 3 cycle after the trip!
The bus breaker slow!
The middle breaker opened in 2 cycle after the trip!
The middle breaker OK!
Primary relay did trip correctly!
Backup relay did not trip, but primary relay did!

*** Event Origin ***
DFR Assistant Client :   STP
Substation :             STP
DFR Native File Name :   Event805.pre
Affected Circuit:        COA - Holman Ckt 44

*** Event Summary ***
Trigger Date and Time:   07-31-2000 14:57:49
Event Description    :   AGND_FAULT
Fault Location       :   68.889413 [miles]
Event Outcome        :   CLEARANCE_LOCAL
Breaker Operation    :   1st,  CB_SLOW
Breaker Operation    :   2nd,  CB_OK
Relay Operation      :   PRIM,  RL_TRIP_OK
Relay Operation      :   BACK,  RL_NOTRIP1_OK

*** Analog Signal Values ***
    Prefault Values:          Fault Values:          Postfault Values:
  I0  =   0.0173 [kA]      I0  =   3.5936 [kA]      I0  =   0.0047 [kA]
  Ia  =   0.5093 [kA]      Ia  =   3.3281 [kA]      Ia  =   0.0024 [kA]
  Ib  =   0.5205 [kA]      Ib  =   0.1909 [kA]      Ib  =   0.0015 [kA]
  Ic  =   0.5542 [kA]      Ic  =   0.1890 [kA]      Ic  =   0.0005 [kA]

  V0  =   0.7565 [kV]      V0  =   6.2733 [kV]      V0  =   0.7536 [kV]
  Va  = 282.3316 [kV]      Va  = 263.5340 [kV]      Va  = 282.2481 [kV]
  Vb  = 284.3163 [kV]      Vb  = 282.2139 [kV]      Vb  = 283.6281 [kV]
  Vc  = 284.2307 [kV]      Vc  = 281.3770 [kV]      Vc  = 282.7893 [kV]

  Vab = 490.3010 [kV]      Vab = 471.8386 [kV]      Vab = 490.2504 [kV]
  Vbc = 493.5354 [kV]      Vbc = 492.6034 [kV]      Vbc = 490.9177 [kV]
  Vca = 489.9282 [kV]      Vca = 468.4061 [kV]      Vca = 488.7642 [kV]

*** Digital Signal Status ***
                      Trips        Resets
  Primary Relay:     18 cycle     19 cycle
  Backup Relay:        N/A          N/A

                     Operates     Operates
  Main CB:           21 cycle        N/A
  Second CB:         20 cycle        N/A

                     Rel. Rng.   Dist. Rng.   Dist. Rng.
                                              (anytime)
  TCF (CBF X):           1           1           1
  RCF (CBF R):           1           1           1
  TC (Block X):          1           0           1
  RC (Block R):          1           0           1
```

Figure 9 DFRA analysis report

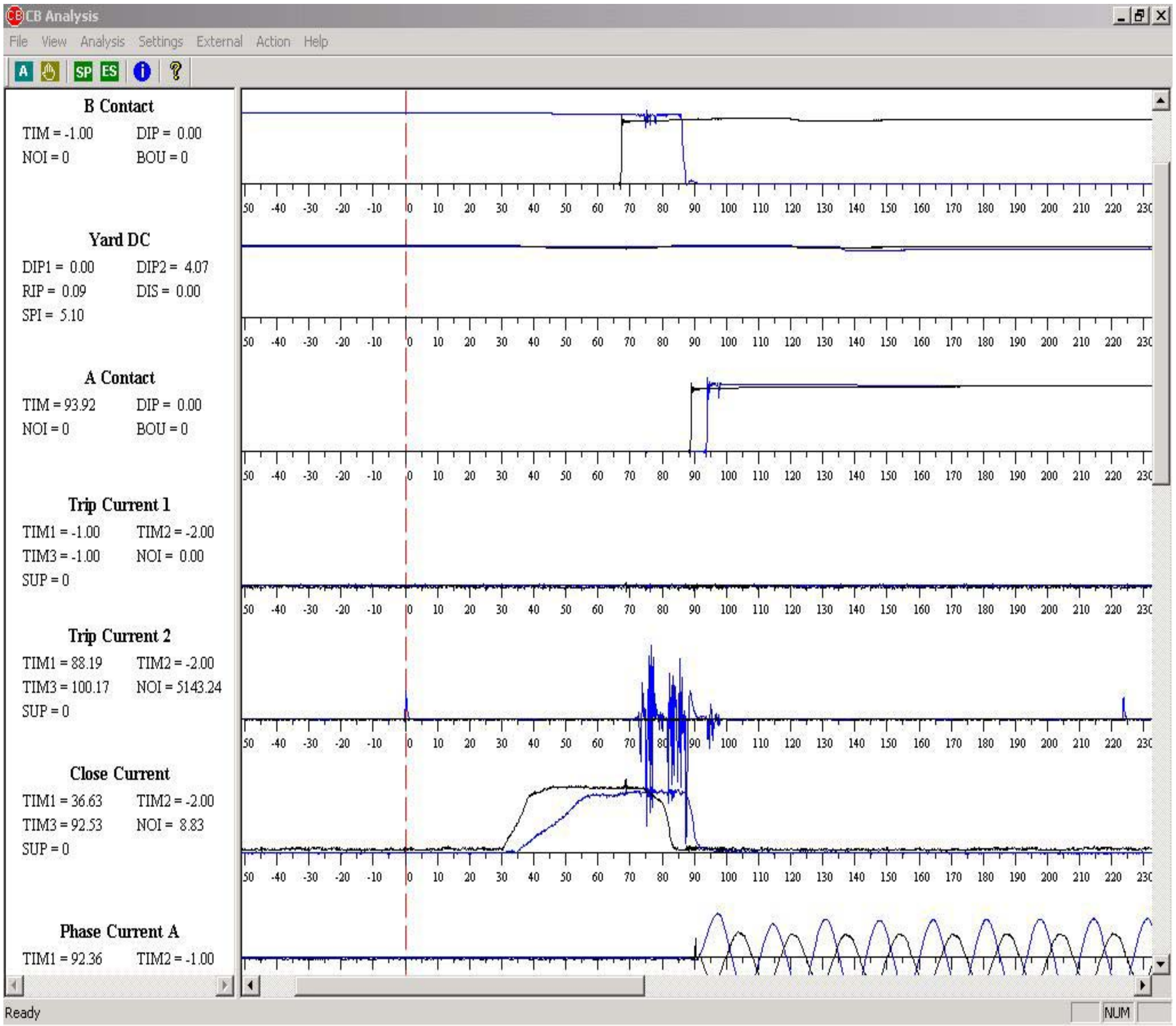

Figure 10 CBM signal waveforms displayed using CBMA Viewing software

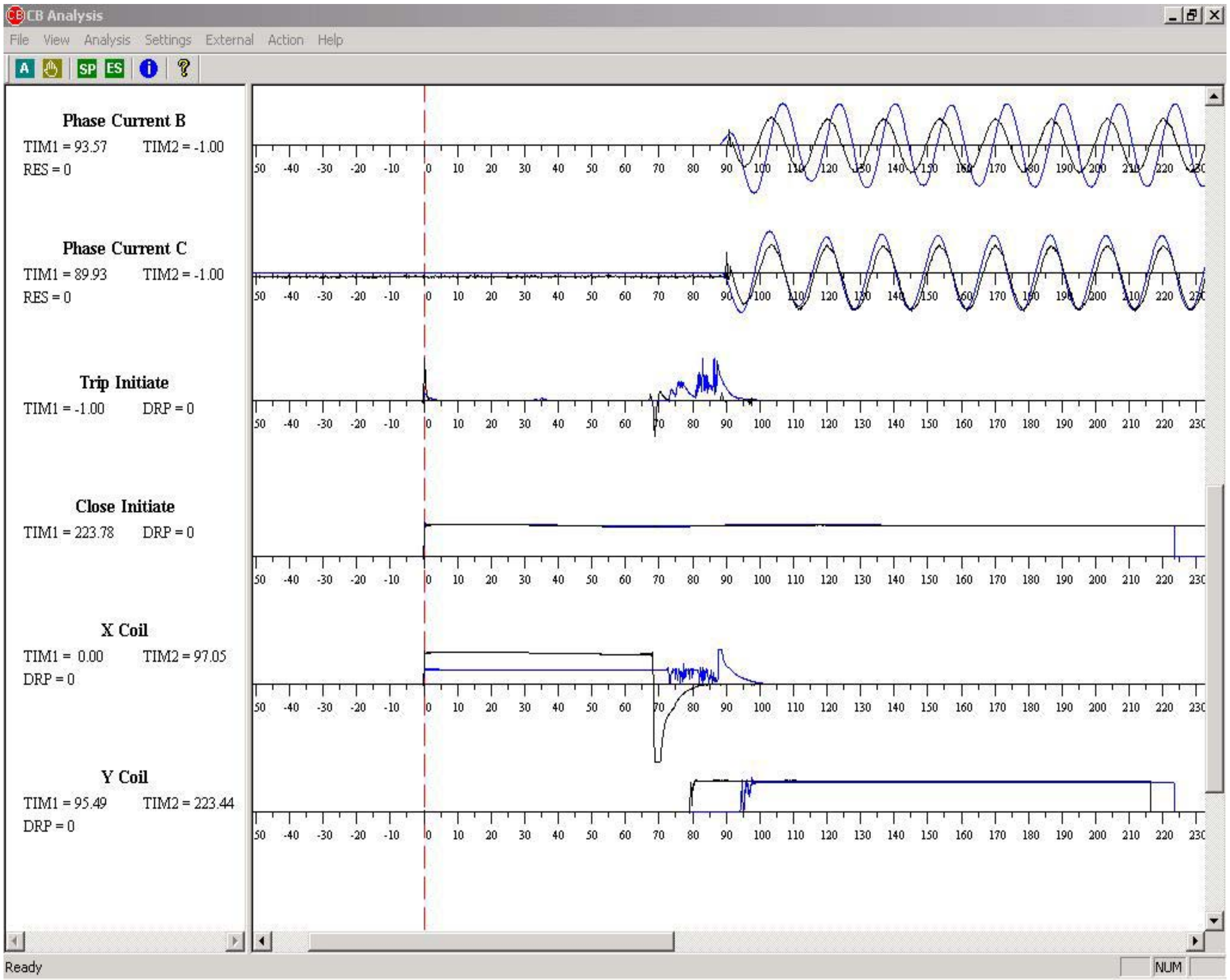

Figure 11 CBM signal waveforms displayed using CBMA Viewing software (continued)

REPORT ON EXPERT SYSTEM CB RECORDS AUTOMATED ANALYSIS
Copyright: Texas A&M University, 2001, 2002
Customized for: CenterPoint Energy
****
DFR record file name: 020827,134159817,
-5D,THW3,38B0,CNP,ABB,V,10077722,C Creation date: 27 Aug 2002
Creation time: 13:41:59.817 Station ID: THW3Device ID: 38B0
Company name: CNP Brkr manufacturer: ABB Brkr type: V
SAP ID: 10077722Comment: C

-------------Expert System Log--------------
The record indicates a closing operation!
R2: Breaker closes!
R26: 'B' contact flat!
R38: Close coil current pickup delayed!
R55: X Coil deactivation delayed!
R78: Close assembly maladjustment!

Figure 12 CBMA analysis report

Conclusion

In this paper, the requirements for automated analysis of substation data are elaborated. The Following requirements for the Automated Substation Analysis (ASA) system are discussed: database integration, new real time data processing applications, communication infrastructure and operator interfaces

The new approach of substation data integration and information exchange (DIIE) is introduced to enhance the existing substation automation practices. The concept enables more efficient use of data collected in substations as well as integration and automated operation of novel substation data analysis applications. Many different utility groups may benefit from this approach.

The main benefit is the ease of substation data handling, archiving and viewing. The other benefits are: system-wide analysis of disturbances, improvements in EMS functions and new applications that were not conceived earlier and yet provide major operating improvement for substation operation.

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References

[1] M. Kezunovic, A. Abur, “Data Integration and Information Exchange: Impact on Future Substation and EMS Applications,” EPRI Technical Report # 1010898, May 2004

[2] M Kezunović, T. Popović, D.R. Sevcik, A. Chitambar, “Requirements for Automated Fault and Disturbance Data Analysis,” CIGRÉ Colloquium, SC B5 – Protection, Sydney, Australia, September 2003

[3] M. Kezunović, G. Latiško, Z. Ren, D. Sevcik, J. Lucey, E. Koch, W. Cook, “Automated Analysis of Circuit Breaker Operation,” *17th International Conference on Electricity Distribution – CIRED 2003*, Barcelona, Spain, May 2003.

[4] M. Kezunović, X Luo, “Automated Analysis of Protective Relay Data”, CIRED 2005, Turin, June 2005

[5] IEC Std. 60255-24, “Common format for transient data exchange (COMTRADE) for power systems”, First Edition 2001-05, *International Electrotechnical Commission, 2001*

[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] IEC Std. 61850, “Communication Networks and Systems in Substations”, work in progress, *International Electrotechnical Commission*, [Online]. Available: www.iec.ch.

[8] M. Kezunovic, T. Djokic, T. Kostic, "Automated Monitoring and Control Using New Data Integration Paradigm", *Hawaii Int’l. Conference on System Sciences, HICCS-38*, Waikoloa, Hawaii, January 2005

[9] IEC 61970: Energy Management System Application “Programming Interface (EMS-API), draft IEC Standard. Part 301: Common Information Model (CIM) Base, v.10.4”, May 2003. [Online] Available (model view): http://www.cimuser.com

[10] Test Laboratories International, Inc.: “DFR Assistant – Software for Automated Analysis and Archival of DFR Records with Integrated Fault Location Calculation” [Online]. Available: http://www.tli-inc.com