IED data utilization for operations, protection and maintenance

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Abstract--**To improve monitoring, control and protection of the power system new intelligent electronic devices (IEDs) have to be installed in substations. IED devices are capable of recording huge amount of data and providing much more information than earlier when only electromechanical relays and remote terminal units (RTUs) of supervisory control and data acquisition (SCADA) system were used. If data from different IEDs is integrated and automatically analyzed, full advantage of the data may be taken. Extracted information obtained from data recorded by each device through automated processing can be merged in customized reports and sent directly to different utility groups. The data may be preprocessed and sent to the Control Center as additional data for new applications or redundant data for improvement of existing applications. IED data employed on this way can drastically improves efficiency and decision making capabilities of the utility personnel responsible for analyzing faults, reporting nature of disturbances, repairing damaged equipment and restoring the system.**

Index Terms-- **data processing, intelligent electronic devices, monitoring, protection, substation automation**

I. Nomenclature

A/D – Analog/Digital
AEA - Automated Event Analysis
CB - Circuit Breaker
CBM - Circuit Breaker Monitor
CBMA - Circuit Breaker Monitor Analysis
DPR - Digital Protective Relay
DPRA - Digital Protective Relay Analysis
DFR - Digital Fault Recorder
DFRA - Digital Fault Recorder Assistant
GPS - Global Positioning System
IED - Intelligent Electronic Device
RTU - Remote Terminal Units
SCADA - Supervisory Control and Data Acquisition

II. Introduction

TODAY'S practice in power system monitoring and control is based primarily on the use of SCADA systems that are fed with data collected by Remote Terminal Units (RTUs) located in substations. The RTUs are wired to the circuit breaker (CB) contacts in the substation switchyard, and every change of the CB status contact is prompted in form of alarm to the operators. The RTUs are also collecting analog measurements obtained through connecting transducers and instrument transformers and reporting their value by exception. If an analog value crosses a threshold it is reported either as an operator measurement or an alarm. The user can not access locally the data recorded by RTU. The data has to be sent to the centralized location to become accessible. Moreover, the SCADA system is not the most robust design possible; there may be errors in the readings because of some malfunction occurring in the CB contacts, transducers, SCADA communication equipment or RTUs. Another performance issue with SCADA is it relatively slow scanning rate for measurements (1-10s). Since some of the events may be occurring in short time intervals the data coming from RTU may not be capturing properties of the events closely. The reason is because the SCADA systems are not capable of tracking dynamic changes occurring in the intervals shorter than the SCADA scan time. The limited SCADA capabilities can be extended with the view obtained from the data captured by IEDs [1].

IEDs are capable, besides their main function to monitor, control and protect system, to record various types of data. This way amount and redundancy of data coming from substation can be enhanced. If IEDs are designed with the interface to the Global Positioning System (GPS) providing reference time signal for the synchronization of signal sampling, further enhancement in the uses of data may be achieved when automating system disturbance analysis. Such examples are when time-stamping or synchronized sampling are improving the analysis using intelligent techniques, such as neural networks and fuzzy logic in detecting and classifying the power system faults [2], pattern recognition in relay protection[3],etc.

When new IEDs are installed in substation with automation in data collection and analysis, as well as data integration, process of monitoring, control and protection can be improved. Nowadays substation data from IEDs other then RTUs is mainly collected manually and then sent to protection engineers of maintenance staff for analysis. This process can take from several hours to several days. Quite often the data is in the original vendors' format and it can be displayed only by using vendors' tools. Data integration for automated analysis purposes in the case IEDs from several different vendors are combined is not straight forward due to the use of different data formats. Standardization of data formats is needed when

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developing systems for automated analysis. The integration is also made more difficult due to the fact that different vendors may use different nomenclature for the same signals and settings in the IEDs. Because of this, process of analyzing data becomes quite complex and time consuming and only skilful person with lot of experience can do it.

First part of this paper focuses on the explanation of the differences between data obtained by RTU and IEDs. Then automated analysis options per each device and reports generated by this analysis are presented. Next the means of full IED data utilization by operations, protection and maintenance staff is proposed giving examples of reports for maintenance and protection group. The paper's conclusion outlines the benefits the approach of IED data utilization may bring.

III. Background

Besides identifying the type of data that some device records, understanding of how data is converted from analog to digital form is required. Process of A/D conversion depends on several parameters and if those parameters are set differently in the devices that measure the same signal values outputs will be dissimilar. Although RTUs and different types of IEDs can measure and record the same signals quality of data can be quite different. The difference appears due to the performance characteristics of data processing steps such as filtering, sampling synchronization, sampling frequency, A/D conversion precision, etc.

Process of A/D signal conversion consists of three major steps: anti-aliasing filtering, sampling and signal amplitude quantization. Anti-aliasing filtering removes noise and high frequency signals components. The substation devices may have one of the two ways of sampling: synchronized sampling or scanning. IED implementation of synchronized sampling on all channels connected to the device is shown in Fig. 1. In the case a sample and hold (S/H) circuit is provided for each input channel all S/H circuits are synchronized to the same reference sampling clock. From signal samples obtained in this way it is possible to obtain the phase difference between different input signals. On the other hand, RTU uses data scanning technique where the samples are taken from all channels with one (S/H) circuit, as shown in Fig. 2. The samples are taken at different time points for each of the channels due to the use of the multiplexer and it is not as easy to establish the phase difference between signals connected to different channels. Another characteristic of signal sampling is the sampling frequency. Accuracy of signal representation depends on sampling frequency. The higher the sampling frequency the better signal representation. The sampling frequency has to be high enough to capture information about signal variation between two samples. There are two ways in implementing data sampling synchronization: local sampling synchronization and system wide (GPS) synchronization. Modern IEDs may be interfaced to GPS receivers and those devices provide synchronization with accurate system wide clock. In this case the sampled data can be correlated system-wide between different substations or internally in a substation between different recording instruments. Quantization is next step in signal transformation from analog to digital form. Accuracy of

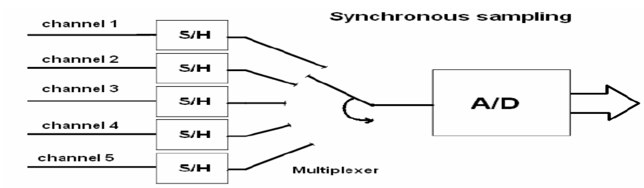

Fig. 1. Synchronous sampling

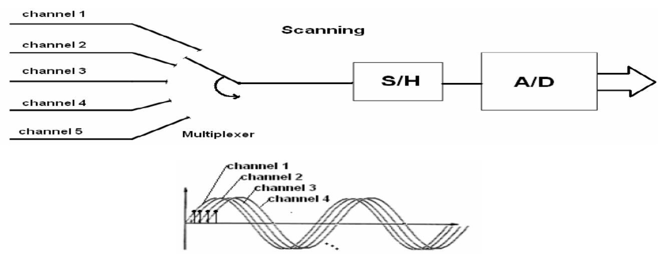

Fig. 2. Scanning

the signal conversion is affected by the selection of the number of bits of A/D convertor, commonly known as the A/D converter resolution. Selection of the resolution is associated with dynamic range of the signal.

Each device can have different way of data recording. Some devices record sampled data continuously in a circular buffer, and after reaching memory capacity of the buffer old data is overwritten with new samples continuously coming. After triggering of an instrument by some disturbance, the buffer record consisting of pre-, during and post- fault data is copied to a permanent memory. DFRs and DPRs use this way of recording and usually are capturing several cycles of pre- fault data. Another approach in data recording is to set a threshold for some signals and only in case this threshold is exceeded the recorded value is reported. This approach has been used by RTUs.

Another characteristic is that some devices may provide only sampled values; some devices have implemented internal logic and can perform calculations and provide pre-calculated values or both. DFR performs only recording functions and provides signal samples. RTU provides pre-calculated data and DPR may provide both, samples and pre- calculate values.

Considering all of above mentioned device characteristics is a necessity in attempting to process and integrate data form substation's devices.

IV. Automated Analysis Applications

IEDs that have been considered in this section are of three types: DPR, DFR and CBM. Those devices can capture following measurements: phase currents and voltages, relay trip signal, internal circuit breaker control signals, oscilography data and internal relay logic operands.

DPR is designed to monitor operating conditions on a transmission line and trip circuit breakers when a fault is detected. The DPR responds to abrupt change in impedance, current, voltage, power flow, or frequency and it will trip substation circuit breakers for faults up to a certain distance away from a substation but not beyond that point. Relays used in this example are SEL 421[4] and GE D 60[5].

New CBM design is developed to monitor circuit breaker condition on-line [6]. It monitors signals in the control circuit during the opening/closing process. CB is an automatically-operated electrical switch designed to disconnect and hence protect a transmission line from damage caused by overload or other short circuit condition. Table 1 shows list of the signals that are recorded by CBM.

DFR is a device with an ability to capture and store short duration transient events, longer-term disturbances and trends of input quantities such as RMS, frequency, harmonics, power and power factor. This device records large amount of data after being triggered by a pre-set trigger value.

For each type of devices automated analysis application can be developed. The application converts data recorded by each device to a standard format and generates reports per each IED type. Those reports are small in size and they can easily be sent trough communication infrastructure out of substation in case of multiple events. All data and extracted information are accessible immediately after event occurrence.

A. *Circuit breaker Monitor Analysis- CBMA*

The Circuit Breaker Monitor Analysis (CBMA) performs analysis of waveform records taken from the circuit breaker control circuit using a Circuit Breaker Monitor (CBM) and generates report that explains event and suggests repair actions. The solution is implemented using advanced wavelet transforms for waveform feature extraction and an expert system for decision making [7]. It enables protection engineers, maintenance crews and operators to quickly and consistently evaluate circuit breaker performance, identify performance deficiencies and trace possible reasons for malfunctioning. CBMA software modules are shown in Fig. 3. An example of CBMA report for the case where CB gets stuck in an attempt to open is show in Fig. 4. The inputs for this case were simulated in a lab using advanced digital simulators with replay capability. The report consists of several sections. First section provides information regarding time and date when event occurred, as well as general information about recording device. Signal Processing Log provides information regarding analysis operation and if there is no problem in data processing this area is empty. Expert System Log provides information about signals affected by tripping operation and points out abnormities. Maintenance and Repair Operation section suggests possible actions to be taken in repairing the device.

A. *Digital Protective Relay Analysis- DPRA*

The Digital Protective Relay Data Analysis (DPRA) is an expert system which automates validation and diagnosis of relay operation [8], [9]. It takes various relay reports and files as inputs and using embedded expert system generates a report on the results of analysis. Validation and diagnosis of relay operation is based on comparison of expected and actual relay behavior in terms of the status and timing of logic operands. DPRA software modules are shown in Fig. 5. Fig. 6. Shows DPRA report generated for "normal" case i.e. when fault is cleared without any device misoperation. The report consists of several sections. The Disturbance Information from SEL421 section display event summary (fault inception time, fault clearance time, fault type and location). Conclusion in SEL421 section shows status of the relay logic operands. This part of the report is obtained from expected SEL421 and actual SEL421 operations.

TABLE I
LIST OF SIGNALS THAT ARE RECORDED BY CBM

Signal Name	Analog(A)/ Status(S)	Nominal Range	Function
		VOLTAGES	
Control Voltage	A	125V± 15V	Provides Pos/Neg voltage for contacts
Light Wire	A	125V± 15V	ON/OFF Indicator
Aux. Contact B	A	125V± 15V	Establishes connection from Light to Neg
Yard DC	A	125V± 15V	Runs CB motor
Aux. Contact A	A	125V± 15V	Indicates breaker status
		CURRENTS	
Close Coil Current	A	< 10	Used to physically close the CB
Trip 1 Coil Current	A	<10A	Used to physically open the CB
Trip 2 Coil Current	A	<10A	Used to physically open the CB
Phase A Current	A	5A	Indicates breaker status
Phase B Current	A	5A	Indicates breaker status
Phase C Current	A	5A	Indicates breaker status
		EVENTS	
Close Initiate	S	125V± 15V	Initiates a close operation
Trip Initiate	S	125V± 15V	Initiates a trip operation
X Coil	S	125V± 15V	Closes all 52X contacts, Establishes a path from POS to 52CC
Y Coil	S	125V± 15V	Opens all 52Y contacts, Interrupts 52CC and X coil currents

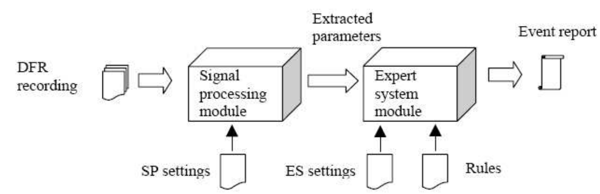

Fig. 3. CBMA Architecture

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REPORT ON EXPERT SYSTEM CB RECORDS AUTOMATED ANALYSIS
   Copyright: Texas A&M University, 2001, 2002,2005,2006
   Customized for: CenterPoint Energy
**************************************************************************
CBM record file name: 20060818,162727370,+5D,OBR,CBM02,CNP,WAVE
Creation date: 15 Aug 2006
Creation time: 19:02:50.727
Station ID: OBR
Device ID: F280
Company name: CenterPoint Energy
Brkr manufacturer: WH
Brkr type: R3
SAP ID: 1234567
Comment: opening

 -------------Signal Processing Log--------------


-------------Expert System Log--------------
The record indicates an opening operation!
 R20: 'A' contact flat!
 R26: 'B' contact flat!
 R42: Phase A Current did not drop!
 R45: Phase B Current did not drop!
 R48: Phase C Current did not drop!
 R66: Stuck breaker while opening!
------Maintenance & Repair Information------
 Check auxiliary assembly, contacts, and linkage.
 Check Phase currents connections. There may be a bad interrupter.
```

Fig. 4. CBMA Report

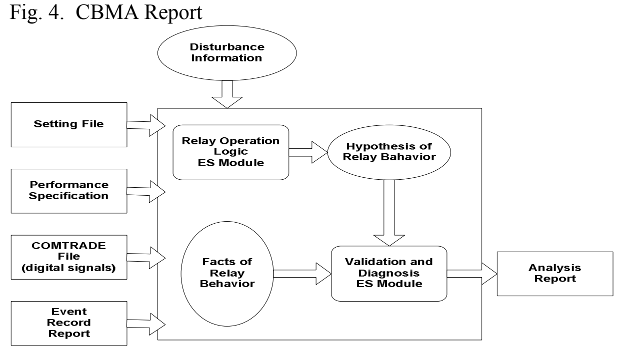

Fig. 5. DPRA Architecture

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DISTURBANCE INFORMATION FROM SEL421
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Fault Inception Time: 16/08/2006,21:59:45.7796
Fault Clearance Time: 16/08/2006,21:59:45.8356
Fault Type: A B 0 0
Fault Location: 16.39 miles

CONCLUSIONS ON SEL421:
---------------------
IN101 deasserted as expected <-- CB < IN101 > opened as expected
IN102 deasserted as expected <-- CB < IN102 > opened as expected
OUT102 asserted as expected <-- Relay tripped OUT102 as expected
OUT106 asserted as expected <-- Relay tripped OUT106 as expected
TRIP asserted as expected
MPT Z1 asserted as expected
67P Z1 asserted as expected
50P Z1 asserted as expected
MP Z4 asserted as expected
MP Z2 asserted as expected
MP Z1 asserted as expected
Z2PGS asserted as expected
STOP asserted as expected

EXPECTED SEL421 OPERATIONS:
--------------------------
MP Z1 asserts at 0.025 sec
MP Z2 asserts at 0.025 sec
MP Z4 asserts at 0.025 sec
50P Z1 asserts at 0.025 sec
67P Z1 asserts at 0.025 sec
TR asserts at 0.025 sec
67PT Z1 asserts at 0.025 sec
MPT Z1 asserts at 0.025 sec
TRIP asserts at 0.025 sec
OUT106 asserts at 0.025 sec
OUT102 asserts at 0.025 sec
IN102 deasserts at 0.057 sec
IN101 deasserts at 0.057 sec
STOP asserts at 0.041 sec
Z2PGS asserts at 0.041 sec

ACTUAL SEL421 OPERATIONS:
------------------------
67P Z1 asserted at 0.0125 sec
50P Z1 asserted at 0.0125 sec
MP Z4 asserted at 0.0125 sec
MP Z2 asserted at 0.0125 sec
MP Z1 asserted at 0.017 sec
MPT Z1 asserted at 0.017 sec
TRIP asserted at 0.017 sec
OUT102 asserted at 0.017 sec
OUT106 asserted at 0.017 sec
IN101 deasserted at 0.05 sec
IN102 deasserted at 0.05 sec
Z2PGS asserted at 0.0295 sec
STOP asserted at 0.0295 sec
```

Fig. 6. DPRA Report

A. *Digital Fault Recorder Assistant- DFRA*

The Digital Fault Recorder Analysis (DFRA) (also called DFR Assistant by the vendor that offers this solution [10]) provides automated analysis and data integration of DFR event records. It provides conversion from different DFR native file formats to COMTRADE[11], [12]. Moreover, DFRA performs signal processing to identify pre- and post-fault analog values, statuses of the digital channels (corresponding to relay trip, breaker auxiliary, communication signals), fault type, faulted phases. It also checks and evaluates system protection, fault location, etc. The software modules are shown in Fig. 7. Fig. 8. shows DFRA report generated for "normal" case. The report consists of several sections. Expert System Log displays event summary and time (in cycles) required for device to act in detecting faulted line and clearing fault. Event Origin displays affected circuit and substation. Event Summary provides general information about fault clearing and device operation. Analog Signal Values displays pre-, during and post- fault value of voltage and current. Digital signal status displays time of device trip operations.

V. IED DATA UTILIZATION

While the mentioned IEDs record some of the same signals still certain IEDs record signals not recorded by other IEDs. The applications, such as DPRA and DFRA can perform detailed disturbance event analysis. However, DFRA analysis cannot perform full analysis of protective relay operation because the DFR device cannot record internal states of a protective relay. On the other hand, the DPRA can validate and diagnose the relay operations in great details, but disturbance information may not be comprehensive since DPR records data from one transmission line only. DFRA cannot perform analysis of the CB tripping operations because DFR device is not used to monitor CB control circuit signals, but CBMA provide this information in details. To achieve full IED data utilization there is need for data integration across the entire substation. The results of different analysis applications

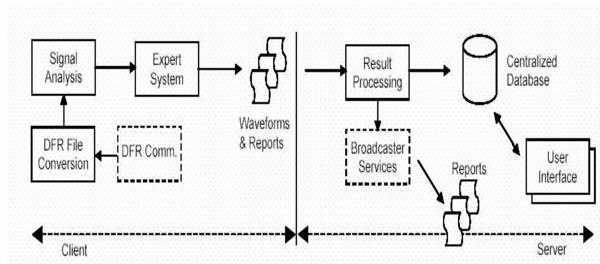

Fig. 7. DFRA Architecture

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DFR Asistant - Expert System for Automated Analysis of DFR Recordings
Copyright: Test Laboratories International, Inc., 1996-2005

*** Expert System Log ***
The bus breaker opened in 3 cycle
The middle breaker opened in 3 cycle!
Line breaker(s) open after the disturbance!
The event is a non-ground fault!
The event is a line A to line B fault!
The fault is cleared by the protection at this substation!
Primary relay tripped in 1 cycle!
Backup relay tripped in 1 cycle!
The bus breaker opened in 2 cycle after the trip!
The middle breaker opened in 2 cycle after the trip!
The bus breaker opened in 2 cycle after the trip!
The middle breaker opened in 2 cycle after the trip!
The bus breaker OK!
The middle breaker OK!
Primary relay did trip correctly!
Backup relay did trip correctly!

*** Event Origin ***
DFR Assistant Client :   DFRA
Substation :             OBrien345kV
DFR Native File Name :   20060816,215945777,+5D,OBR,DFR01,CNP,WAVE.zq
Affected Circuit:        THW 98

*** Event Summary ***
Trigger Date and Time:   08-16-2006 01:09:05.777
Event Description    :   AB_FAULT
Fault Location       :   16.42 [Miles]

Event Outcome        :   CLEARANCE_LOCAL
Breaker Operation    :   1st,  CB_OK
Breaker Operation    :   2nd,  CB_OK
Relay Operation      :   PRIM,  RL_TRIP_OK
Relay Operation      :   BACK,  RL_TRIP_OK

*** Analog Signal Values ***
    Prefault Values:            Fault Values:              Postfault Values:
  I0  =    0.0020 [kA]      I0  =    0.0155 [kA]      I0  =    0.0002 [kA]
  Ia  =    0.6341 [kA]      Ia  =    8.6765 [kA]      Ia  =    0.0027 [kA]
  Ib  =    0.6279 [kA]      Ib  =    8.8945 [kA]      Ib  =    0.0020 [kA]
  Ic  =    0.6279 [kA]      Ic  =    0.6282 [kA]      Ic  =    0.0021 [kA]

  V0  =    0.0843 [kV]      V0  =    0.0151 [kV]      V0  =    0.0838 [kV]
  Va  = 198.6462 [kV]       Va  = 136.3199 [kV]       Va  = 198.6464 [kV]
  Vb  = 198.6218 [kV]       Vb  = 128.8124 [kV]       Vb  = 198.6297 [kV]
  Vc  = 198.9099 [kV]       Vc  = 198.9043 [kV]       Vc  = 198.9079 [kV]

  Vab = 344.0301 [kV]       Vab = 175.4281 [kV]       Vab = 344.0397 [kV]
  Vbc = 344.2828 [kV]       Vbc = 306.1704 [kV]       Vbc = 344.2890 [kV]
  Vca = 344.2978 [kV]       Vca = 315.7541 [kV]       Vca = 344.2922 [kV]

*** Digital Signal Status ***
                        Trips        Resets
  Primary Relay:       1 cycle      6 cycle
  Backup Relay:        1 cycle      5 cycle

                       Operates     Operates
  Main CB:             3 cycle        N/A
  Second CB:           3 cycle        N/A
```

Fig. 8. DFRA Report

have to be merged to achieve full event explanation. The data validity may be checked due to redundant measurements and comprehensive reports may be generated due to completeness of integrated data. The idea is to automatically collect and integrate data from all substation IEDs, analyze it and extract and integrate information of interest for various types of users such as operators, protection engineers, maintenance group, etc. Data may be analyzed at substation level and conclusion may be sent directly to the protection and maintenance group. Another approach is to preprocess data and send extracted information to a Control Center, where this information may be merged with data from SCADA, processed by centralized applications, and the results prepared for various user groups. A report for each type of users consists of information that describe disturbance from the user's point of view. They consist of several layers. First layer is a short report that summarize event with information of high priority for decision making about event. Each layer after first extends explanation in further details and priority of data become lower. Comprehensive reports are generated combining data from DFRA, DPRA and CBMA reports.

Fig. 9 displays single line diagram of the 345KV transmission line that has been used to test those applications. The protection system consists of two relays, DFR and two CBMs.

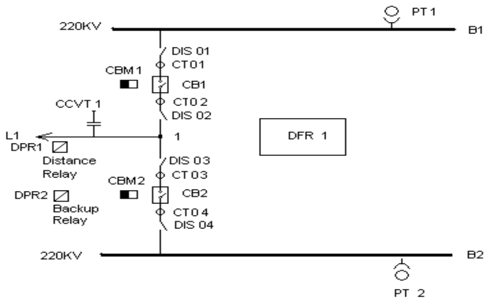

Fig. 9. Single line diagram of the test system

A. Information for system operators

Operators are responsible for making decision about system operation and restoration. In the case of an event occurring on the system they are interested in knowing if the fault is permanent, where is fault location, and whether relays and circuit breakers operated correctly (reclosing sequence). To easier interface information extracted from IED data to Control Center level database, the information must be compatible with IEC 61970 and IEC 61968 [13], [14].

Nowadays the trend in operations department is to make conclusion about some event based on SCADA system data. Since IED devices can measure more data than RTUs the additional data can be used to verify and supplement SCADA reading. Often right conclusion may only be made using IED data. As an example, if consequences of relay operations are to be assessed, the pickup and operation information of protection elements usually presented in the form of logic operands that can be extracted from relays will be more informative than SCADA data collected by RTUs that only captures relay trip signals and circuit breaker status signals. In this case, combining data from digital relays with SCADA data can be utilized to improve the accuracy of analysis applications that will in turn provide better results for the operator.

B. Information for protection engineers

Protection engineers are responsible for the final assessment of the correctness of any system response to a given fault condition. They have to check operation of each protection related IED and in case of misoperation to find the cause for device failure or misoperation. Mostly they are interested in DPR operation during the event.

Fig. 10. and Fig. 11. shows first and second level of reports for protection engineers in case where one relay on the line has not tripped. Summary section in Fig. 10 shows major information of interest to protection engineers, such as substation name, affected circuit, triggered time and date, fault type, duration and range, event outcome and devices operation with main focus on relay operation. In the case the fault was cleared in a reasonable time and all devices operated correctly, there is no need for additional data and second level of report that contains further details will not be generated. In the presented case the fault is cleared by the second relay, and because of relay misoperation protection engineers require further details leading to the second level report being generated. Second layer of the report describes relay internal logic operation and displays signal waveforms. It lists

```
===================== EVENT SUMMARY =====================
Substation :                   TAMU
Affected Circuit:              T 98
Trigger Date and Time:         08-30-2006 22:08:53.457

Fault Type   :                 AB_FAULT
Fault Duration:                3 cycles

Fault Range:                   [16.41-16.50] miles from TAMU

Event Outcome              : CLEARANCE_LOCAL
Relay Operation (SEL)      : NO_TRIP
Relay Operation (GE)       : TRIP_OK
Breakers Operation         : OK
```

Fig. 10. Event Summary of the Report for Protection Engineers

```
=================== CONCLUSIONS============================

Description of Misoperation/Failure:

SEL Relay failed to trip contact to bus breaker
SEL Relay failed to trip contact to middle breaker

Investigation Results:

Trip contact for bus breaker (OUT102) failed to assert
Trip contact for middle breaker (OUT106) failed to assert
Relay trip failed to assert
Phase Distance Zone 4 Element (M4P) failed to assert
Phase Distance Zone 2 Element(M2P) failed to assert
Zone 2 Delay Timer Element (Z2PGS) failed to assert
Stopping Element Pickup failed to assert

Phase distance Zone 1 Element Operation (M1PT) asserted as expected
Level 1 Phase Directional  Overcurrent Element (67P1) asserted as expected
Level 1 Instantaneous Phase Overcurrent Element(50P1) asserted as expected
Phase Distance Zone 1 Element  asserted as expected

Corrective Actions:

Check Phase Distance Zone 4 Element (M4P) setting
Check Phase Distance Zone 2 Element (M4P) setting
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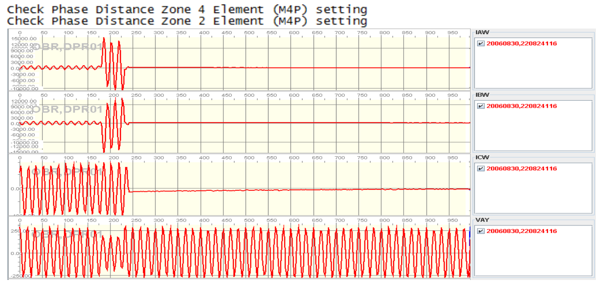

Fig. 11. Report Conclusion aimed at Protection Engineers

sequence of the relay signals state and suggests remedial actions. In scenario for this case wrong relay phase distance settings has been set during tests. The analysis suggests that phase distance settings should be checked.

C. Information for maintenance staff

Maintenance group is responsible for system repair and restoration. This group is responsible for monitoring circuit breaker operation. Fig. 12. shows Summary report for maintenance staff in the case the breaker got stuck. Summary report display data of high priority for maintenance group, such as substation name, effected circuit, triggered time and date, fault type and duration , event outcome and devices operation with main focus on CB operation. Fig. 13. shows report conclusions aimed at the maintenance staff for the same case. Report conclusion consists of information about signals affected by tripping operation, suggestion remedial actions, pre-, during and post- fault analog signals values and waveforms display.

VI. Conclusions

The approach presented in this paper performs IED data analysis process automatically and generates reports per each IED type. It also extracts information to the customized report for protection and maintenance staff. The approaches enables using IED data as a complement to SCADA data to help the system operators make more informed decisions.

```
==================== EVENT SUMMARY ====================
 Substation :                  TAMU
 Affected Circuit:             T 98
 Trigger Date and Time:        08-30-2006 16:27:27.6505

 Event Type  :                 ABC_FAULT
 Fault Duration:               There is no clearance!|

 Event Outcome              :  NO_CLEARANCE
 Relay Operation(SEL)       :  TRIP_OK
 Relay Operation(GE)        :  TRIP_OK
 Bus Breaker Operation      :  OK
 Middle Breaker Operation:     FAILED
```

Fig.12. Event Summary of the Report for Maintenance Staff

```
================== REPORT CONCLUSION ====================
*** Middle breaker expert system log ***

 'A' contact flat!
 'B' contact flat!
 Phase A Current did not drop!
 Phase B Current did not drop!
 Phase C Current did not drop!
 Stuck breaker while opening!

*** Middle breaker expert maintenance and repair information ***

 Check auxiliary assembly, contacts, and linkage.
 Check Phase currents connections. There may be a bad interrupter.

*** Analog Signal Values from DFR***

      Prefault Values:            Fault Values:             Postfault Values:
   I0  =   0.0010 [kA]      I0  =   0.0005 [kA]      I0  =   0.0013 [kA]
   Ia  =   0.7653 [kA]      Ia  =  12.2826 [kA]      Ia  =  12.2881 [kA]
   Ib  =   0.7559 [kA]      Ib  =  11.9846 [kA]      Ib  =  11.9844 [kA]
   Ic  =   0.7609 [kA]      Ic  =  12.3566 [kA]      Ic  =  12.3566 [kA]
```

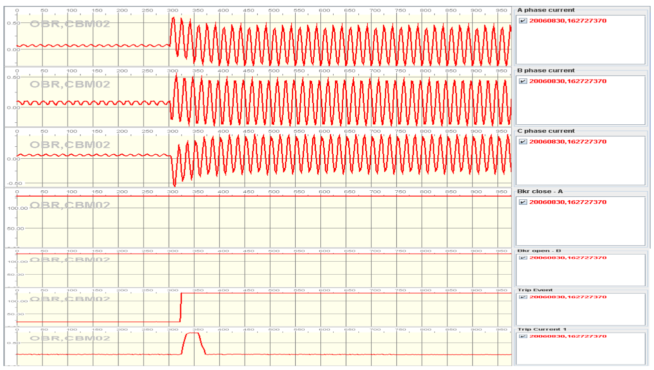

Fig. 13. Report Conclusion aimed at Maintenance staff

The improvements offered by this approach are:

1. Increased efficiency of utility personnel responsible for analyzing the faults. On the contrary, manual analysis of IED data takes time especially if several records supplied by different IEDs for the same event must be uploaded and analyzed. Also, IED records are not categorized by priority.
2. Reduced time in repairing damaged equipment and more informed decision-making in restoring the system. With the proposed approach the outage time may be drastically reduced, and the area affected by fault may be determined more accurately.
3. Reduced personal training costs. The use of different vendor specific programs increases personnel training costs due to distinctively different features as well as the look and feel of different packages. This approach avoids that by offering a universal user interface for all applications.
4. Increased ability to efficiently integrate data coming from different IED types and models. This approach first integrates data and then provides it in a convenient form to any applications that wish to use it.

VII. Acknowledgements

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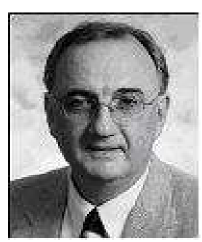
IX. Biographies

Biljana Matic Cuka (S'07) received her Dipl. Ing. Degree in Computer and Electrical Engineering from University of Novi Sad, Serbia, in 2006. Currently she is pursuing the M.S degree in the Department of Computer and Electrical Engineering, Texas A&M University, College Station, TX, USA. She worked as a Research Associate for Texas A&M University, College Station, TX, USA during 2006-2007. Her research interest includes substation automation, power system monitoring and protective relaying.



Mladen Kezunovic (S'77-M'80–SM'85–F'99) received the Dipl. Ing., M.S. and Ph.D. degrees in electrical engineering in 1974, 1977 and 1980, respectively. Currently, he is the Eugene E. Webb Professor and Site Director of Power Engineering Research Center (PSerc), an NSF I/UCRC.at Texas A&M University He worked for Westinghouse Electric Corp., Pittsburgh, PA, 1979-1980 and the Energoinvest Company, in Europe 1980-1986, and spent a sabbatical at EdF in Clamart 1999-2000. He was also a Visiting Professor at Washington State University, Pullman, 1986-1987 and The University of Hong Kong, fall of 2007. His main research interests are digital simulators and simulation methods for relay testing as well as application of intelligent methods to power system monitoring, control, and protection. Dr. Kezunovic is a Fellow of the IEEE, member of CIGRE and Registered Professional Engineer in Texas.