Automated Integration of Substation IED Data to Generate Event Reports for Protection Engineers

Feng Xu, Student Member, IEEE
Department of Electrical and Computer Engineering
Texas A&M University
College Station, TX, 77843, USA

Mladen Kezunovic, Fellow, IEEE
Department of Electrical and Computer Engineering
Texas A&M University
College Station, TX, 77843, USA

Abstract—**A complete system solution for automated integration of substation Intelligent Electronic Device (IED) data to generate a customized event report for protection engineers is presented in this paper. Detailed strategy for IED data processing and information exchange to meet the needs of protection engineers is proposed. An Implementation approach is discussed next followed by a simulation case used to generate a sample report format.**

I. INTRODUCTION

Intelligent Electronic Devices (IED) is a generic term in power industry that describes various microprocessor-based protection, control, metering and monitoring devices. Compared with traditional solutions at the functional level such as individual meter or protective relay, the functions of IEDs are much more enhanced. For example: (1) modern Digital Fault Recorders (DFRs) are used to capture data for various events with a high sampling frequency and automated event analysis function [1]; (2) modern Digital Protective Relays (DPRs), not only can perform traditional functions of a protective relay, but also have the capability to carry out data recording, fault location, event analysis, etc [2]; (3) Circuit Breaker Monitors (CBMs) are emerging devices specially developed for the monitoring of modern circuit breakers, but also equipped with oscillography and data analysis capability [3].

When there is an event (fault, disturbance, etc.) occurring on the power system, protection engineers are especially concerned with the event type, fault type and location, performance of protection relays, operation of related fault clearing equipment (Circuit Breakers, auto-reclosing relays, etc). They are using data from various IEDs such as DFRs, DPRs and CBMs to analyze the events to be able to suggest what are the remedial measures or actions that need to be taken immediately (fault repair, and equipment restoration) [4, 5]. To perform such task efficiently, they can benefit from a fast integration and exchange of corresponding information produced by different types of IEDs.

However, a fast data integration and information exchange is not very easy considering the existing device-type-specific analysis software packages which are typically provided by device vendors [6], as well as the issue of different file formats and data collecting strategies, etc. what is more, as more and more IEDs are being installed in substations as a part of the monitoring, control and protection solution, the data and information regarding each event or disturbance available for protection engineers to analyze has increased substantially, which even more enhance the necessity of an automated process of data processing directed at the needs of protection engineers.

This paper proposes a scheme for automated collecting, analyzing, archiving, and displaying of IED data recorded by different IED types during a power system event. It focuses on describing how the relevant information is extracted to generate a customized report for protection engineers. This way, the protection engineers can obtain more accurate event details, get more comprehensive understanding of the relay operations, including the performance of fault-clearing equipment, and accordingly take more effective remedial measures in a timely manner. This solution ensures high efficiency in root-cause analysis for tracking down and trouble-shooting relay operations, resulting in improved reliability of power system operation.

II. BACKGROUND

This paper describes a solution aimed at the automated data integration and information exchange of three types of IEDs: DPR, CBM and DFR. As an outcome a customized report for protection engineers is generated when there is a fault occurring on the power system.

A. Digital Protective Relay(DPR)

Two DPRs are used as examples in this project: SEL-421 and GE-D60. By utilizing vendor specific software ACSelerator (Ver. 2.4.10.9) and Enervista (Ver. 5.0), custom event report and recorded data files can be generated, as shown in Table I.

TABLE I.   IED DATA SUMMARY

IED	Device Type	File Type	File Format
DPR	SEL421	Oscillography File	COMTRADE 99
		Event Report	Custom SEL Event Report Format
	D60	Oscillography File	COMTRADE 99
		Event Record	Custom GE Event Report Format
		Fault Report	Custom GE Fault Report Format
CBM	RTR-84	Waveform File	COMTRADE 99
DFR	TR-2100	Waveform File	COMTRADE 99

B. Circuit Breaker Monitor (CMB)

Records obtained by RTR-84 circuit breaker response recorders are used to emulate operation of CBMs aimed at monitoring the operating condition of two circuit breakers and their control circuits. The corresponding recorded data for an event is listed in Table I.

C. Digital Fault Recorder (DFR)

The Digital Fault Recorder (DFR) used in our project and this paper is TR-2100. It can record event data in a standard format of COMTRADE 99.

III.   AUTOMEATED INTEGRATION OF IED DATA

Automated Event Analysis (AEA) software package developed in earlier projects is used here to perform automated data processing related to fault events [7]. The AEA application will work with following groups of data according to Table I:

- Event data (ASCII and binary COMTRADE, ASCII text)
- Log data (ASCII and binary COMTRADE, ASCII text)
- Analysis Reports (ASCII text)

There are four key implementation issues addressed next:

A. IED configuration

The configuration and management of different types of IEDs requires corresponding settings for the purpose of collecting IED data files in an automatic and timely manner to be selected using the AEA software Graphic User Interface (GUI). For each IED, the responsible staff will manually enter the information about existing IEDs, designation, vendor, model and related local folders into the program. The program will save the information into standard XML format file. After that the recording, acquisition and conversion of IED data needs to be configured to meet the following needs:

- Log data needs to be uploaded from IEDs by using vendor software and stored into the predefined folders on substation PC.
- Event data needs to be automatically sent by IEDs after the recording is triggered. The data is stored to the predefined folders on substation PC shortly after event occurrence.
- IEDs need to be synchronized with GPS time signal provided either from Substation PC or from internal GPS receiver.
- Other settings (IED parameters, monitoring frequency, folders, and communication with the PC) should also be confiured.

B. DATA format

The next step is the introduction of standardized data formats. IEEE COMTRADE standard file format aiming at the information interchange between different IED types or IEDs from different vendors is used in this application [8, 9, 10].

C. File naming convention

Standardized IEEE file naming convention for the time sequence data is used for more efficient and simple file management. The file naming solution, which contains unique information about an event (date, time, station, company, duration, location etc), can enable easier handling of large volume of files by allowing unique file identification.

The file extension will depend on the file type and the file name will consist of mandatory and optional fields according to the IEEE file naming convention standard developed by IEEE Power System Relaying Committee. All fields are delimited by comma separator [11].

For all groups of data, mandatory fields will follow the format given in Table II:

D. Automated DATA analysis

For the automatic analysis of IED data, three intelligent analysis application software packages are utilized (together shown as Intelligent Analysis Application in Fig. 1):

- *Digital Fault Recorder Analysis (DFRA),*
  The Digital Fault Recorder Analysis (DFRA) [12, 13]

TABLE II.   FILE NAMING CONVENTION

File name	yyyy mmdd	hhmm ssmm m	Xyz	ssss	dddd	cccc
length	Fixed length (8)	Fixed length (9)	Fixed length (3 or 2) (-5D, -5A, -5S, UT)	Variable length	Variable length	Variable length
Mean	Start date	Start time	Time code	Station identifier	Device identifier	Company name

application provides automated analysis and data integration of DFR event records. It provides import filters for different DFR native file formats and their conversion to COMTRADE format. Once converted to COMTRADE file format, all the event files are being analyzed utilizing signal processing and rule-based expert system. The outcome of DFRA is a conclusion report – (represented by DFRA.txt).

- *Digital Protective Relay Data Analysis (DPRA)*

The Digital Protective Relay Data Analysis (DPRA) application performs an expert system based analysis, which automates validation and diagnosis of relay operations. It takes various relay reports and files as inputs, displays their contents using graphical user interface, and utilizes embedded expert system to automate the analysis and generate 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. If expected and actual status and timing of an operand are consistent, the correctness of the status and timing of that operand is validated. If not, certain failure or mis-operation is identified and diagnosis is initiated to trace the reasons by the logic and cause-effect chain. The outcome of DPRA is a conclusion report especially for relays– (represented by DPRA.txt) [14].

- *Circuit Breaker Monitor Analysis (CBMA).*

The Circuit Breaker Monitor Analysis (CBMA) application is based on analysis of records of waveforms taken from the circuit breaker control circuit using a Circuit Breaker Monitor (CBM) device. The solution is implemented using advanced wavelet transforms for waveform feature extraction and an expert system for decision making. The outcome of CBMA is also a summary report containing operation details and conclusions for circuit breakers, as shown in Table III with other report files – (represented by CBMA.txt) [15].
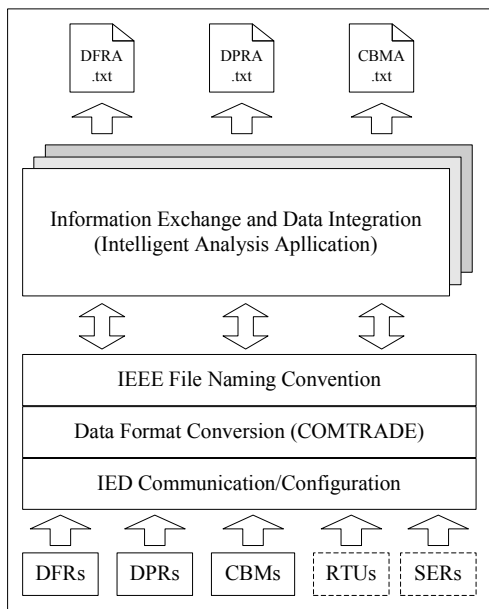

Figure 1. Automated integration and analysis of IED data

TABLE III.   OUT PUT FILES OF AEA SOFTWARE APPLICATION

Applications	File Type	File Format
CBMA	CBM Device Recordings	Binary COMTRADE 99
	Analysis Report	ASCII TEXT
DPRA	Relay Event File	ASCII TEXT
	Waveform File	Binary COMTRADE 99
	Relay Fault File	ASCII TEXT
	Analysis Report	ASCII TEXT
DFRA	Waveform File	Binary COMTRADE 99 (w/o HDR file), Rochester File Format
	Analysis Report	ASCII TEXT

To sum it up, after the automated data collection by AEA software and operation analysis by intelligent applications are completed, three kinds of '.txt' files are generated. They contain conclusion reports for DFR, DPR, CBM respectively created for further uses described in the next section.

IV.   GENERATION OF A CUSTOMIZED REPORT FOR PROTECTION ENGINEERS

The software package discussed here is called "Report Generator for Protection Engineers". It is developed specifically for protection engineers. As shown in Fig. 2, its function is to take the three kinds of analysis report files (DFRA.txt, DPRA.txt, CBMA.txt) as input, and to create a customized report for protection engineers– (PRENG.txt) at the occurrence of each disturbance or fault event. Each generated report consists of four parts: "Event Detail", "Relay Information", "Circuit Breaker Information", and "Suggested Actions", as discussed next.

A.   Event Details:

There are two sections in this part of the report. First section gives some general information about the event type, time of event, substation name, as well as affected circuit name. If the event is a fault, the second part will provide more detailed information about the fault type (for example, single phase A to ground fault), fault location, including the fault inception time and clearance time. One key point is that the fault detail information has been validated and integrated between DFRA.txt and DPRA.txt reports, so the accuracy and comprehensiveness of the information provided is enhanced. In the cases where the information in these two reports does not match, the software generates a warning notice and the specific mismatch will be shown.

B.   Relay Information:

This part also has two sections. In the first section, the profiles of relays including the device name and ID are given. In the second section, the goal is to provide a concise conclusion about the correctness of operation for each protective relay. The conclusions are expressed as "Normal" or "Abnormal". The "Normal" means the actual operation of signals or operands for the relay is the same as expected. The
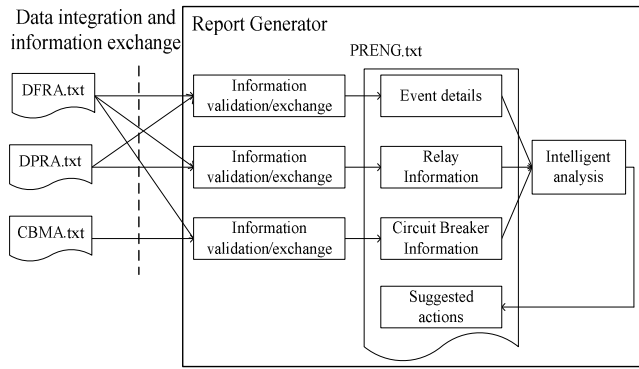
Figure 2.   Report Generator for Protection Engineers

Figure 3.   Substation Protection Scenario

"Abnormal" means the actual operation of signals or operands is different from expected: delayed, or mis-operated, or the recorded operations in the DFRA.txt file and DPRA.txt file do not match each other.

C.   Circuit Breaker Information:

The first section in this part provides the profile data of related circuit breaker. The content and conclusion in the second section comes from DFPA.txt and CBMA.txt files after data validation and integration. It tells protection engineers whether or not the operation of circuit breakers is correct. The predefined term "Normal" and "Abnormal" are again used here, with similar definitions as mentioned above: "Normal" means the actual opening or closing operation, or the control circuit signal is correct, and "Abnormal" means the opposite, or the circuit breaker operation information (for example, opening or closing) in DFRA.txt and CAMA.txt do not match with each other.

D.   Suggested Actions:

Based on conclusions obtained from the three reports, an intelligent analysis is performed to provide some concise suggested actions which should be taken by protection engineers immediately if possible. These suggestions for example can give guidelines for protection engineers to check the setting of certain protection elements of a specified protective relay. If some of the reports (DFPA.txt, DPRA.txt, CBMA.txt) which serve as input to the software need to be further investigated by protection engineer personally due to very complex event circumstances, they are listed and shown with direct link provided in this part.

V.   EXAMPLE

Taking advantage of an elaborate test setup [16], a substation protection scenario (Selected substation from CNP) was built to evaluate our solution. In this case a transmission line with so-called breaker and a half configuration is protected by two circuit breakers - middle breaker and bus breaker, and they are tripped by two (redundant) digital protective relays, as show in Fig. 3.

In this simulated system, the power system transmission line model is first constructed using ATP/ ATPDraw software package and then BGEN and Relay Assistant [17] commercial
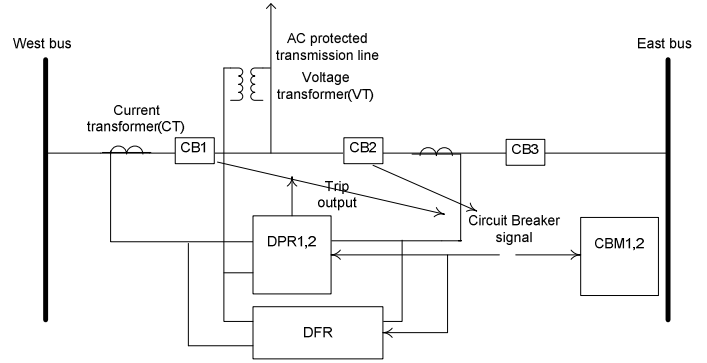
packages are used to generate desired fault scenarios and save related measurement files in a specified repository. The files are used by the simulator in the next step to generate physical status signals , as well as analog voltage and current signals, which serve as input for two CBMs, one DFR [18] and two DPRs [19,20] as mentioned above. During an event simulation process the disturbance data and related information are recorded by each IED, and then the automatic processing of these records is done by using the AEA software with the three intelligent analysis tools integrated. After that the output analysis report is automatically sent to the "Report Generator for Protection Engineers" and a customized report with predefined formats is created.

Here a sample generated report is provided for a detailed case of relay-fail-to-trip type of event which occurred during a transmission line single phase to ground fault.

The event description is shown in Table IV and the wave form recorded by DFR is shown in Fig. 4:

TABLE IV.   EVENT DESCRIPTION

Fault Type	Fault Location	Protection zone	IED/Device failure
AG	40% (12.6 miles)	Z1	Back up fails to trip

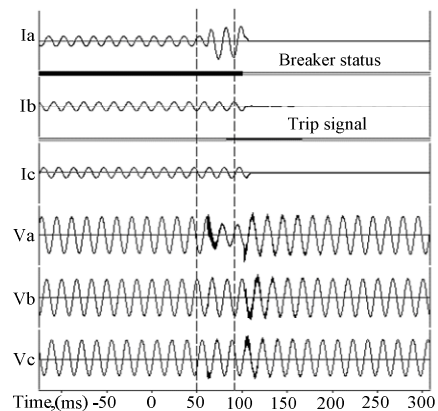The generated sample report for protection engineers is shown in Fig. 5.

Figure 4.   Recorded waveform by DFR

```
Event Report for Protection Engineers

[Event Report No: = ##]
-----------------------------------Event Details-----------------------------------
[Event Type]    = Fault

Date            = 10/30/2008        Time              =11:17:26.325
Substation Name = OBRIEN 345kv      Affected circuit name = THW 98

[Fault Location]
Fault type      = AG                Fault location    = 14.17 miles +/-1.08
Inception time  = 11:17:26.328      Clearance time:   = 11:17:26.337
-----------------------------------Relay Information-----------------------------------
No.1 Relay: Name and ID    = Sel 421

Operation Conclusion       = Normal

No.2 Relay

No.2 Relay: Name and ID    = GE D60

Operation Conclusion       = Abnormal

-----------------------------Circuit Breaker Information-----------------------------
No.1 Circuit Breaker: Name and ID   = OBR, F280

Operation Conclusion       = Normal

No.2 Circuit Breaker: Name and ID   = OBR, F290

Operation Conclusion       = Normal

-----------------------------------Suggested Actions-----------------------------------
[Suggestion for relays]
1. Suggested report to investigate: 20081030, 111726325, +5D, OBR, DPR02, CNP, DPRA. txt.
2. Check "PH DIST Z1" element settings for relay "GE D60".

[Suggestion for circuit breakers]
1. Suggested report to investigate:
2. Suggested actions.
```

Figure 5. Sample Report for Protection Engineers

VI.   CONCLUSION

An automated substation IED data processing and event report generating software for protection engineer needs is proposed in this paper. It consists of an AEA software package with three integrated analysis applications which perform the role of automated data processing. Another "Report Generator" software package creates customized report for protection engineers with predefined formats based on the analysis result of the preceding data processing. Besides the traditional benefits, the protection engineers can obtain more accurate event details; get more comprehensive understanding of the relay operations, including the performance of fault-clearing equipment. This enables them to track down and fix the problem with more efficiency, resulting in improved reliability of power system operation. Some special features brought about by the solution proposed in this paper are listed as follows:

- Automated and real time data collection and processing for different types of IEDs.

- Automated and intelligent power system event analysis and IED operation cause-effect diagnosis.

- Real time data validation for event details and IED device operation information.

- Real time data integration and information exchange between different IED types.

- Effective information organization, especially during event in which many devices are involved.

- Real time remedial action suggestion.

REFERENCE

[1] D. R. Sevcik, R.B. Lunsford, Mladen Kezunovic, Z. Glijasevic, S. Banu, T. Popovic, "Automated Analysis of Fault Records and Dissemination of Event Reports" Fault and Distuibance Analysis Conference, Atlanta, May 2000.

[2] Kasztenny, B., Rosolowski, E, "A Digital Protective relay as a Real-time Microprocessor System", International Conference and Workshop on Engineering of Computer–Based Systems, Monterey, California, 1997.

[3] Knezev, M, Djekic, Z, Kezunovic, M, "Automated Circuit Breaker Monitoring", IEEE Power Engineering Society General Meeting, Tampa, Florida, 2007.

[4] M. Kezunovic, A. Abur, A. Edris, D. Sobajic, "Data Integration/Exchange Part I: exsisting technical and business opportunities" IEEE Power & Energy Magazine, Vol. 2, No. 2, March/April 2004, pp. 14-19.

[5] M. Kezunovic, A. Abur, A. Edris, D. Sobajic, "Data Integration/Exchange Part II: future technical and business opportunities" IEEE Power & Energy Magazine, Vol. 2, No. 3, May/June 2004, pp. 24-29.

[6] J. D. McDonald, "Substation Automation, IED integration and availability of information", IEEE Power&Energy Magazine, Vol. 1, No. 2, March/April 2003, pp. 22-31.

[7] Kezunovic, M., Sevcik, D., Lunsford, R., Popovic, T., "Integration of Substation Data", 60th Annual Conference for Protective Relay Engineers, College Station, TX, 2007.

[8] IEEE Standard Common Format For Transient Data Exchange, IEEE standard C37.111-1991,1991.

[9] IEEE Standard Common Format For Transient Data Exchange, IEEE standard C37.111-1999,1999.

[10] IEC Std. 60255-24, "Common Format for transient data exchange (COMTRADE) for power systems", First Edition 2001-05, International Electrotechnical Commission, 2001.

[11] IEEE Standard Recommended Practice for Naming Time Sequence Data Files, IEEE C37.232, 2007.

[12] M. Kezunovic, C.C. Liu, J. McDonald, L.E. Smith, "Automated Fault Analyisis", IEEE Tutorial, IEEE PES, 2000.

[13] M. Kezunovic, B. Lunsford, J.Lucey, D. Sevcik, M. Bruckner, T. Popvic, "Automated Analysis Using IED-Recorded Data:Integration and Implementation" Fault Disturbance Conference, Atlanta, Georgia, May 2005.

[14] X. Luo, M. Kezunovic, "An Expert System for Diagnosis of Digital Relay Operation", 13th Conference on Intelligent Systems Application to Power Systems, Washington DC, USA, November 2005.

[15] M. Kezunovic, Z. Ren, G. Latisko, D.R. Sevcik, J, Lucey, W. Cook, E. Koch, "Automated Monitoring and Analysis of Circuit Breaker Operation", IEEE Transaction on Power Delivery, Vol. 20, No. 3, July 2005, pp. 1910-1918.

[16] A. Abur, M. Kezunovic, "A Simulation and Testing Laboratory for Addressing Power Quality Issues in Power Systems", IEEE Transaction on Power Systems, Vol.14, No. 1, February 1999, pp. 3-8.

[17] Relay Assistant Line of Products, Test Laboratories Intl., Inc [Online] Available: www.tli-inc.com

[18] Operation Manual for TR-2100 Multi-function Recorder, AMETEK Power Instuments, [Online] Available: www.ametekpower.com

[19] Instruction Manual for D60 Line Distance Relay, General Electric Company, Fairfield, CT, 2004. [Online] Available: www.ge.com

[20] Instruction Manual for SEL-421 Relay – Protection and Automation System, Schweitzer Engineering Laboratories, Inc, 2005. [Online] Available: www.selinc.com