AN ADVANCED FAULT DATA/INFORMATION PRESENTATION IN POWER SYSTEMS

Mladen Kezunovic
Electrical and Computer Engineering
Texas A&M University
College Station , TX, 77840,USA
kezunov@ece.tamu.edu

Biljana Matic Cuka
Electrical and Computer Engineering
Texas A&M University
College Station ,TX, 77840, USA
biljana@ece.tamu.edu

Ozgur Gonen
Visualization sciences
Texas A&M University
College Station , TX, 77840,USA
ozgur@viz.tamu.edu

Noah Badayos
Electrical and Computer Engineering
Texas A&M University
College Station , TX, 77840,USA
nbadayos@tamu.edu

Abstract

To help make the power system more reliable huge amount of data generated from different Intelligent Electronic Devices (IEDs) located in substation of power system should be collected, analysed and displayed. Easy way of accessing and viewing recorded data or information obtained through automated analysis is commonly lacking in the existing power systems. Nowadays data and related information presentation is one of the most important requirements in power engineering. Many users find that their work is more efficient when using versatile data/information presentation software. The emphasis in this paper is on implementing user-friendly, device independent data/information presentation with ability for remote access too.

1 INTRODUCTION

This paper focuses on specific class of mostly software solutions in power systems, namely the ones related to automated fault analysis for monitoring, maintenance and control applications. This class of solutions collects data from Intelligent Electronic Devices (IEDs) in substations, organizes it in appropriate databases, and in newer applications processes the data automatically to extract information relevant to different utility groups such as operators, protection engineers, and maintenance personnel.

The approach for automated collection and analysis of IED data has been offered in the past by several vendors of the solutions for power industry [1]. However, most of the focus in the past was on implementing data collection and integration, which are only the first step towards analysis automation [2]. Automated analysis, which is a new technology not previously widely used in the power industry has been deployed only in the last decade and on a very limited scale [3].

The latest developments are an extension of the previous ideas but they explore two distinct directions: a) making the analysis more integrated across data from different IEDs, and b) providing more elaborate tools for viewing the original IED data and results of the analysis using advanced computer graphics. This paper focuses on new solutions for graphical representation of recorded data and computed information developed for various analysis applications and different utility groups.

The paper starts with providing background on fault analysis and IED data. The goal and implementation of some automated analysis applications are discussed next. The needs for presentation of field recorded data and information obtained from automated analysis is outlined and some implementation examples are discussed in the following sections. Conclusion, Acknowledgement and References are given at the end.

2 IED DATA USED FOR FAULT ANALYSIS

The main purpose of the fault analysis in the context of this paper is to precisely determine spot on the transmission line where fault occurred and evaluate performance of the equipment involved in fault clearing. Such analysis can provide information like fault type, confirmation whether a fault has in fact occurred, assessment of the accuracy of the fault location algorithms embedded in relays, performance of the switching elements (circuit breakers) responsible for isolating faults, etc [4]. After a fault in power system takes place automatic actions of controllers responsible for fault detection and classification (protective relays) and related switching equipment (circuit breaker) status is immediately seen by an operator in the control center who will take note of the fault event and inform other staff like protection group or maintenance [5]. The consequences of mentioned events are reconstructed from data collected by recording devices located in substations, and the views of the data/information explaining the events and consequences are displayed in the staff offices that are quite remote from substations. Various groups, such as protection engineers, system operators and maintenance staff are then in a position to take further actions. The protective engineers start analyzing faults in more details. They visually inspect recorded data and also check and compare IED records before making a decision about nature of the fault and related equipment (protective relays and circuit breakers) actions. In the case of permanent fault the maintenance group is requested to go to the field, assess any damages, and fix the damage as needed. For this group it is extremely important to have information about precise location of the fault and surrounding circumstances such as terrain, type of supporting transmission line structures (towers) and performance of the switching equipment (circuit breakers).

Knowing this information ahead of the time helps maintenance crews preparing for the repair job and making sure the job is completed efficiently so that the transmission lines can be brought back to service as quickly as possible. It can be seen from the above that proper data presentation, ability to easily compare signals generated from IEDs and good fault location presentation are important in trying to minimize outage time.

The IEDs used to collect the data recordings in substations considered in this paper are: digital protective relays (DPRs), circuit breaker monitors (CBMs) and digital fault recorders (DFRs). Those IEDs provide detailed information about fault type, fault location, power quality disturbance, operation of protective relays and operation of circuit breakers.

DPR is designed to calculate operating conditions on an electrical circuit and trip (open) circuit breakers when a fault is found [6]. The DPRs respond to conditions like sudden change in impedance, over-current or voltage, reverse power flow, over- and under- frequency, and they would trip for faults up to a certain distance away from a substation but not beyond that point. The DPR records and generates huge amount of data relevant for the analysis. Figure 1 shows summary of data recorded and/or generated by a typical DPR [7].

CBM is developed at Texas A&M University and main purpose is to monitor circuit breaker (CB) condition on-line [8]. CB is an automatically-operated electrical switch designed to disconnect and hence protect an electrical circuit (transmission line) from damage caused by overload or short circuit [9]. Figure 2 shows list of the signals that are recorded by CBM.

Files & Reports	Description
Setting File	It contains configuration information about the relay at three levels: selecting protection and control elements ,deciding how the selected elements are logically combined, and setting the operating parameters of each selected elements
Performance Specification	It contains information about the element operating parameters.
Event Report	It contains a list of time stamped logic operands in the chronological order
Oscillography Files	It contains analog values of the three-phase voltages and currents and digital status of logic operands selected to be recorded by the users. Digital status data provide complementary information on logic operands if some of them are not reflected in the event report but are selected to be recorded in the oscillography file by users.

Figure 1. Summary of data in DPR files and reports

Group Of Signals	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 Light Wire
Coil Currents	Trip Coil (TC) Current1 Trip Coil (TC) Current2 Closing Coil (CC) Current
Phase Currents	Phase current A Phase current B Phase current C

Figure 2. List of signals in CBM recordings

DFR is a device with an ability to capture and store short transient events, longer-term disturbances and trend of input quantities such as RMS, frequency, harmonics, power and power factor [10]. This device records huge amount of data. Figure 3 shows typical signals recorded by DFRs and used in the analysis.

Description	Type
Line currents:3 phases or 2 phases &zero seq.	Analog
Bus voltage (3 phases or 2 phases & neutral)	Analog
Bus (primary) breaker contact status	Digital
Middle (secondary) breaker contact status	Digital
Primary relay trip status	Digital
Backup relay trip status	Digital
Blocking signal received status	Digital
Blocking signal transmitted status	Digital
Breaker failure signal received status	Digital
Breaker failure signal transmitted status	Digital

Figure 3. Input signals for DFR analysis application

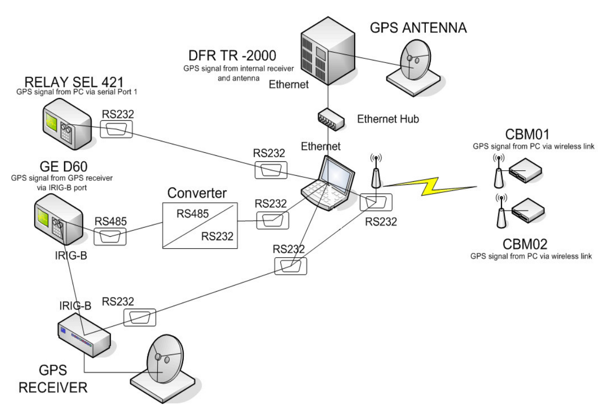

Figure 4. Interconnection diagram of substation IEDs

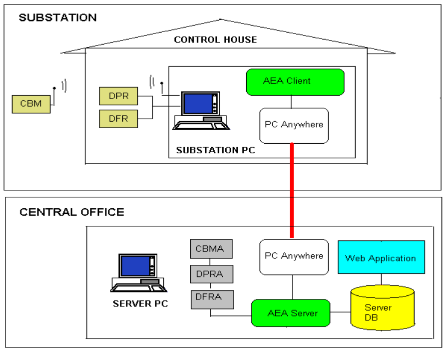

Figure 5. AEA System architecture

The developed system takes IED data as shown in Figure 4 and supports client/server architecture shown in Figure 5. The part that resides on a PC in the substation includes the Automated Event Analysis (AEA) Client which interfaces to the CBM, DPR and DFR devices connected to the Substation PC [11]. The server side resides at remote location and consists of AEA Server software integrating three automated analysis applications (CBMA, DPRA, DFRA), database and web application.

3 DATA/INFORMATION FROM AUTOMATED ANALYSIS APPLICATION

An IED alone typically may record an enormous amount of data, but the case usually is that the output cannot sufficiently aid any utility personnel in making complete interpretation of an event without information coming from automated analysis of recorded data. To address the different needs of different utility personnel, it is important that the integrated substation data undergo further processing to produce more useful and readable reports containing information pertinent to the task at hand. Thus, a few automated analysis applications were developed as summarized below:

DFRA (Digital Fault Recorder Analysis) - provides automated analysis of DFR event records. The analysis looks at all the monitored circuits and identifies the one with the most significant disturbance. For that selected circuit, DFRA performs signal processing to identify pre- and post-fault analogue values, statuses of the digital channels corresponding to relay trip, breaker auxiliary, communication signals, etc. The expert system determines fault type, faulted phases, checks and evaluates system protection performance. At the end, the analysis program calculates the fault location [12].

DPRA (Digital Protective Relay Analysis) - is an expert system based analysis application which automates validation and diagnosis of relay operation. Validation and diagnosis of relay operation is based on comparison of expected and actual relay behaviour in terms of the status and timing of logic operands. If actual status and timing of an operand is consistent and as expected, the correctness of the status and timing of that operand is validated. If not, a failure or misoperation is identified and diagnosis is initiated to trace the reasons by the logic of cause-effect chain [13].

CBMA (Circuit Breaker Monitor Analysis) – is an application based on analysis of records of waveforms taken from the circuit breaker control circuit using a Circuit Breaker Monitor (CBM) device. It enables protection engineers, maintenance crews and operators to quickly and consistently evaluate circuit breaker performance identify deficiencies and trace possible reasons for malfunctioning. It can automatically analyse switching operations of large number of circuit breakers under complex switching conditions [14].

Implementation architecture for each of the three solutions is shown in Figures 6-8 respectively.

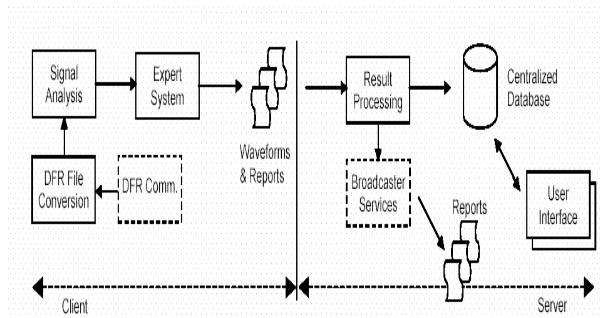

Figure 6. DFRA Architecture

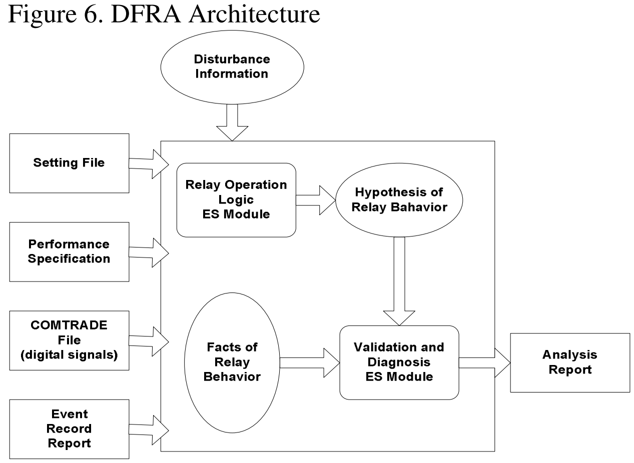

Figure 7. DPRA Architecture

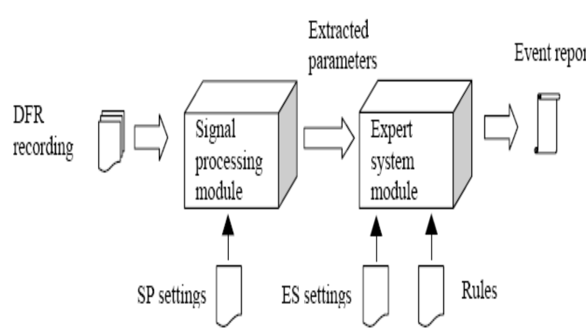

Figure 8. CBMA Architecture

To present data/information, there is a need for two types of graphical user interfaces: the desktop and web user interface. The desktop user interface, which is meant to support local user connected to the computer at a substation site, may be used by protection engineers. The developed user interface provides advanced waveform viewer, which will be further discussed in the next section. Also this application can be used for testing purpose since it provides ability to change device connections and settings. That means that a new IED can be easily connected, configured and tested using this interface. The interface allows determining which data will be deleted and which archived in the database. On the other hand, the web user interface can be used by protection and maintenance groups, as well as the system operators. It requires only a web browser coupled with cell phone to be used to access data from the field (substations) at remote site (control centre or staff offices). This interface has ability to show physical environment of faulted area, which will be discussed later. The fault location can be shown in 2D and 3D view as will be elaborated in the following section. This data/information viewing approach makes it easier to assess fault location accuracy and handle related tasks.

4 DATA/INFORMATION DISPLAYING

In the fault analysis process, several utility groups are involved: operators are the first to make note of the fault, then protection engineers are asked to perform detailed analysis of causes and consequences, and maintenance crews are sent to inspect and if needed repair damaged parts of the system caused by a fault.

Before protection engineers make final decision regarding the fault, they usually visually inspect generated analysis reports and data recorded by IEDs (signal waveforms). The inspection of signal waveforms can be improved by a few additional functionalities allowing easy manipulation and viewing. The visibility of each signal can be enhanced by providing several graphycal display features: selection of signals to be viewed including an option to remove some signals from the dispaly, comparison of signal waveforms by displaying them superimposed in the same view with a color code, user ability to move a displayed signal to any other view by dragging its label, and signal zooming to view further details. The user should be able to see in single view a time sequence of all the signals that occured during the same event and got recorded by IEDs. An example is shown in Figure 9.

The reports generated by IEDs are usually difficult to interpret, as shown in Figure 10. Because of that, automated analysis applications are developed and implemented. As an example of the analysis application for each IED, the module that generates reports specialized only for protection engineers is developed. Such automated analysis report contains only essential information as shown in Figure11.

Figure 9. Signal waveforms display

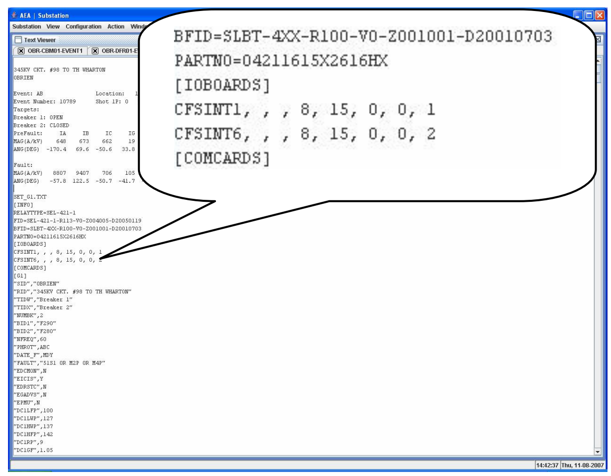

Figure 10. DFR report

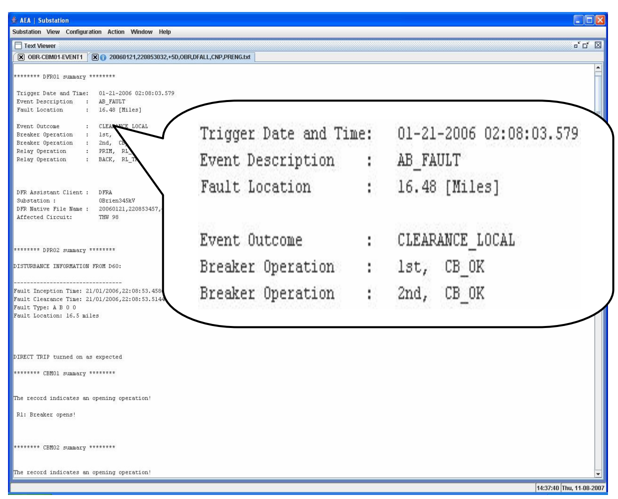

Figure 11. Report for protection engineers

To improve presentation of data/information, customized techniques may be combined with the standard ones typically used for data/information presentation in other applications unrelated to power systems. Commercial software for power system presentation may be combined with automated analysis software to improve access and make data/information presentation more user friendly and understandable. For instance, the results of fault data analysis that point out to the fault location in the electric circuit representation of the power system network may be combined with geographical and model data about the same network producing more comprehensive views of the troubled area. An example of using Power World commercial software to represent power system network and enhancing it with custom designed software to accurately determine fault location is shown in Figure 12 [15]. The same results for fault location may be overlayed on the earth satellite pictures obtained from Google Earth, as shown Figure 13 [16]. This way, in case of outage it is easy not only to determine where the fault location may be in the electrical network but also to know what to expect from the physical terrain surrounding actual equipment around fault location. This information is important for the maintenance crews that are supposed to patrol the area, locate the fault, assess possible damage from the fault, and fix the problem. To give even better information about the equipment and area characteristics, a 3D model of the equipment and physical area may be developed as shown in Figure 14. This model allows maintenance crews to view the area from different angles allowing better assessment of what may be involved in repairing transmission line structures (towers), and what equipment and parts may be needed to complete the job. This versatility of graphical options for representing data/information associated with field recordings, electrical networks, and physical outline of the equipment is not available today and yet offers significant benefits to various utility groups.

Besides the examples shown in this paper, some additional graphical views of the switching equipment are developed by the authors and reported earlier [17].

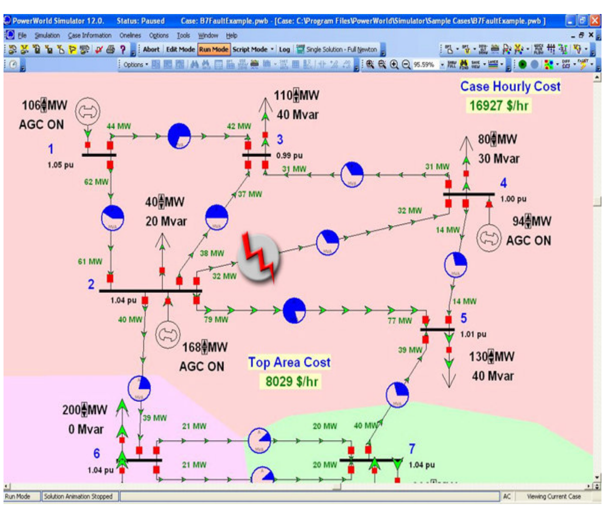

Figure 12. Power world fault display

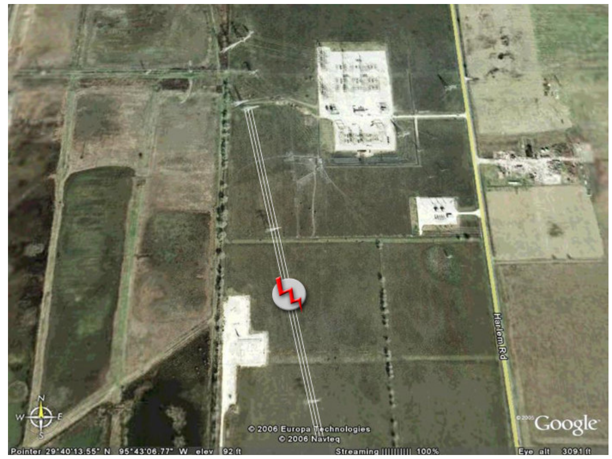

Figure13. Satellite view of fault location area


Figure 14. 3D view of fault location area

5 CONCLUSION

This paper introduced new concepts of utilization and presentation of substation data/information. It emphasizes the importance of good data/information presentation when attempting to reduce outage time in power systems and make the remedial process easier. The following are major conclusions:

- Desktop viewing of signal waveforms captured by recording devices in substations allows utility personnel to deal with test and evaluation tasks for individual recording devices, which is very important to be able to maintain and evaluate performance of the all-digital monitoring solutions
- Web browser viewing of recorded data and information produced through automated analysis allows utility personal located in control canter and/or other offices remote from the substations to maintain timely awareness of the critical events in power system such as occurrence of faults
- The graphical interfaces can significantly benefit from mixing the data/information derived from recorded signals with other data such as satellite images of certain geographical area or 2D and 3D views of

various power apparatus obtained from advanced equipment models.

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