

## **Converting Field Recorded Data to Information: New requirements and concepts for the 21<sup>st</sup> century automated monitoring solutions**

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### **SUMMARY**

Automated monitoring of power systems has become an imperative due to two major developments that characterize the 21<sup>st</sup> century electricity grid: a) large scale deployment of intelligent electronic devices (IEDs) has created huge amount of data recorder either continuously or at the time when IED recording is triggered by an event such as disturbance or fault, and b) the power system loading has increased to the point where it operates close to the limits, which requires much better monitoring capability than what is available today to make sure such operation does not create undesirable consequences such as cascading failures. Fully aware of the challenges the North American Electric Reliability Corporation (NERC) has developed standards for event monitoring and reporting, which will assure the bulk electricity system is reliable, adequate and secure. To fulfil NERC and/or internal requirements for improved monitoring utilities have started deploying advance solutions that enable automated collection of field data, extraction of information and distribution of monitoring reports so that the utility staff can respond to the events expeditiously.

The deployment examples illustrated in this paper are aimed at demonstrating various deployment strategies that are possible with such solutions: substation, distributed and centralized-based processing. The substation processing requires installation of a PC that serves as the integration hub which collects recorded files from all substation IEDs, converts data to information and creates event reports that are sent to the groups that need them. The distributed solution retrieves IED records and passes them to a location such as protection office, operator control room or maintenance center where further processing is done. The centralized solution collects all the data to a centralized database, extracts information and sends it to the users per request.

To illustrate the above concepts several hardware and software solutions are developed and deployed in the field: circuit breaker recorder, automated analysis of circuit breaker recorder (CBR) data, automated analysis of digital protective relay (DPR) data, automated analysis of digital fault recorder (DFR) data, automated integration of substation IED data, automated handling of user interfaces. All the solutions are implemented using advanced hardware and software concepts that allow the recorded data to be synchronized and time stamped utilizing receivers for Global Position System (GPS) of satellites. Time stamped data are communicated through variety of modern communication media such as wireless, optical fibre and high speed coaxial cable links. Handling of software applications is through advanced JAVA programming, and user interfaces deploy latest advancements in the web browsers and graphical user interfaces. Practical issues such as cyber security, implementation steps and personnel acceptance are addressed as well.

### **KEYWORDS**

Substation Automation-Disturbance Monitoring-Fault Analysis-Time stamping-GPS receiver

## CONCEPT OF DATA INTEGRATION AND INFORMATION EXCHANGE

The first step in developing future systems that are capable of producing improved information is to integrate data from multiple substation Intelligent Electronic Devices (IEDs) and extract information that may be of interest to different utility groups: protection, operations, and maintenance. This concept is shown in Fig. 1 and has been discussed in detail in earlier publications [1, 2].

In this concept, data from individual substation IEDs such as Digital Protective Relays (DPRs), Digital Fault Recorders (DFRs), Phasor Measurement Units (PMUs) and Circuit Breaker Monitors (CBMs) already provides useful information associated with stand alone IED data capture. The bulk of data recorded by such devices can be combined and streamlined to provide a more relevant and versatile source of information to serve control center applications such as Fault location, Topology Processor for State Estimator and Alarm Processor. An interface to each IED makes those data accessible to the remote Control Center applications. This together with power system component models provides a powerful tool not only for substation-level, but also for system-level disturbance monitoring and analysis.

Every substation IED supplies each utility group with data of interest to that selected group. For example, the protection engineers may use dedicated fault locators (FLs), digital protective relays (DPRs), and digital fault recorders (DFRs) to capture data and extract information to analyze faults and performance of related fault-clearing equipment. The substation operation personnel uses sequence of event recorders (SORs), and lately the integrated systems (ISs), to capture operating conditions of a substation and to execute local control and monitoring functions through dedicated substation control (SC) solutions. Redundancy of the data is very important in data analyzing and decision making process. Because of that, there is attempt to use non operational data from relays, recorders and phasor measurement units as an enhancement to SCADA data. It may be recognized that the topology data and associated measurements are changing dynamically as the substation operation takes place and that IEDs record pre- post- and in time of the fault condition. To correlate such data and make it accessible to the applications located at the Control Center level, new data processing should be implemented. The new data processing should use standardized data and communication formats.

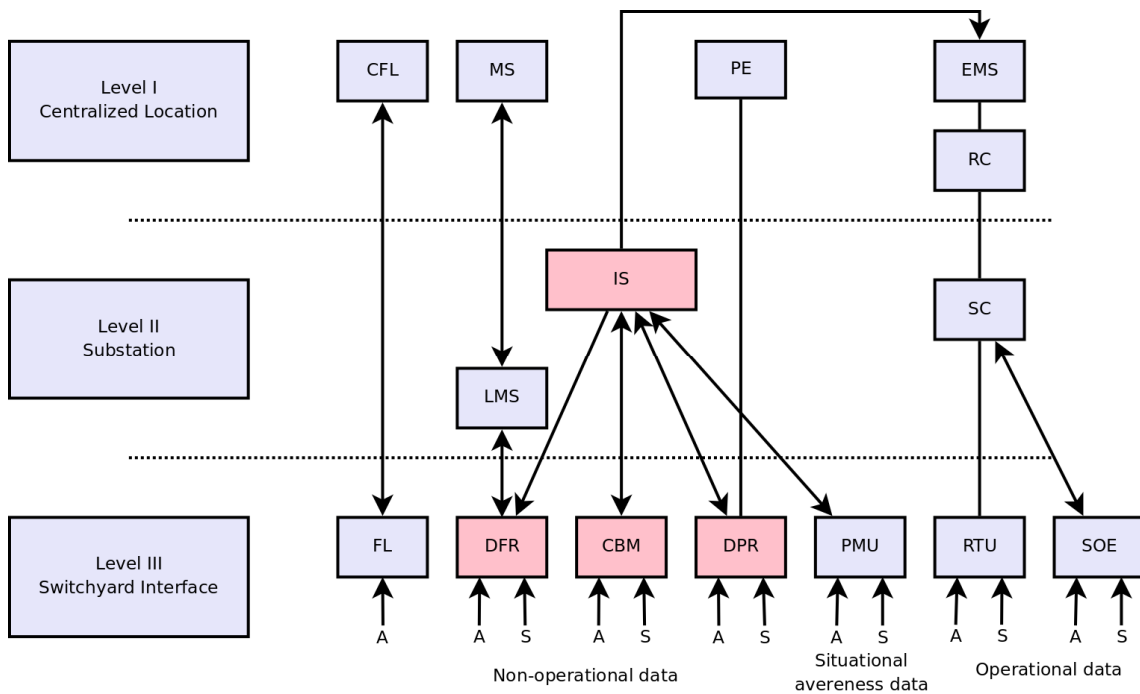


Figure 1. Concept of Data Integration and Information Exchange

## SYSTEM ARCHITECTURE

Fig. 2 shows a simplified example of the system architecture for integration of operational (SCADA) and non-operational (DFR, DPR, CBM) data. Data is collected from IEDs in COMTRADE file format [3]. Then the data is processed at the substation level and populated into the database together with the automated analysis reports and recording system configuration information. Integrated IED data and analysis reports can be accessed and visually inspected using individual graphical user interfaces (GUIs) that display results from each of the automated analysis applications. The changes in the database containing integrated and processed IED data are monitored by Control Center Adapter that merges those data with SCADA information and translates SCADA and IED data into the CIM data format. The analysis and processing applications at control center level, in this case Optimal Fault Location and Intelligent Alarm Processing, use the translated data in CIM format for further processing [4,5].

The Automated Event Analysis (AEA) Client software package is installed on the substation PC and it performs only data acquisition from all IEDs while AEA Server installed in the Control Center room does automated functions such as: converting data formats, classifying events, renaming IED data from substations, interfacing custom analysis applications, allowing immediate processing of acquired data, as well as uploading IED raw and processed data into IED database [6]. There are three types of the automated analysis applications: Circuit Breaker Monitor Analysis (CBMA), Digital Protective Relay Analysis (DPRA) and Digital Fault Recorder Analysis (DFRA) [7-9]. It may be noted that multiple user interfaces are possible: Local AEA graphical user interface for substation engineers, engineering office interface for enterprise-wide engineering support and user interfaces for system operators and back office staff located in the Control Center.

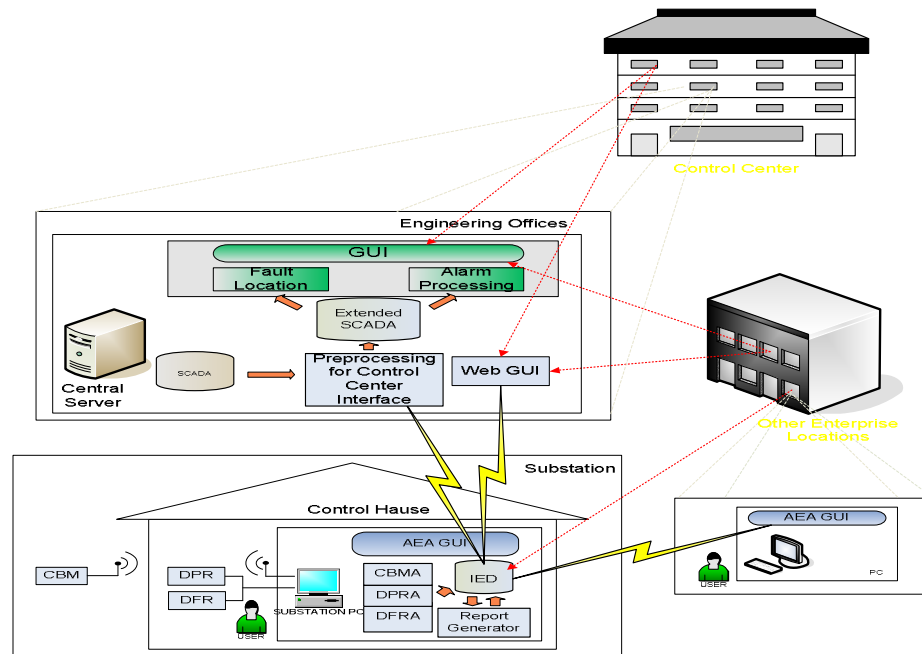


Figure 2. System Architecture

## AUTOMATED ANALYSIS APPLICATIONS FOR SELECTED TYPES OF IEDs

In this example three types of IEDs are considered and per-device analyses is developed. All devices are synchronized to the Global Positioning System (GPS) reference clock and knowledge of precise time of sampling allows easier integration of data from different IEDs. Since field recorded data files generated by IEDs do not have standardized naming format, it is difficult to integrate those

data directly without further processing. Developed applications rename all files to standardized File Naming Convention format [10].

### **Digital Protective Relay Data Analysis (DPRA)**

Modern digital protective relays (DPRs) are capable of generating various files and reports containing a specific category of data : samples of analog currents and voltages, statuses of protection elements and control elements of relay logic, statuses of contacts of relays, communication channels and circuit breakers. Generally, DPR outputs the following data files : oscillography, fault, setting and event data. Oscillography data contains the records of external signals that a relay sees during disturbance and they are typically stored in COMTRADE file format. Usually setting data configures the relay at three levels: selecting protection and control elements, deciding how the selected elements that are logically combined, and setting operating parameters of each selected element. Fault data contained in a fault report include fault type, fault location and voltage and current phasors during pre-fault and fault periods. They are calculated by a relay and used for its decision making. Sequential Event Data contained in an event report are time stamped logic operands in chronological order. It contains most of the information through which the external behavior of a relay and its associated protection system components and the internal states of the relay may be observed.

The Digital Protective Relay Analysis (DPRA) is an expert system which automates validation and diagnosis of relay operation [11]. It takes various relay files as inputs and using embedded expert system generates a report on the results of analysis. If some abnormalities are detected in the event report the process of determining the reasons will be utilized. The report consists of section that summarizes general fault information such as fault inception/clearance time, fault type and location. The subsequent report section lists logic operands and notifies their status and operating speed. In case that some operand failed to operate the verifying action will be suggested. The DPRA is developed for two types of relays: SEL 421 [12] and GE D 60 [13], and it can be extended to another relay variety.

### **Digital Fault Recorder Analysis (DFRA)**

DFR is a device with an ability to capture and store huge amounts of data without possibility for automated data processing. It captures transient events, longer-term disturbances and trends of input quantities such as RMS, frequency, harmonics, power and power factor and stores it vendor's file format. This device records large amount of data after being triggered by a pre-set trigger value.

The Digital Fault Recorder Analysis (DFRA) (also called DFR Assistant [14]) provides automated analysis and data integration of DFR event records. It provides conversion from different DFR native file formats to COMTRADE file format. 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.

### **Circuit Breaker Recorder Analysis (CBRA)**

The CBR design is developed to monitor circuit breaker condition on-line [15]. It monitors signals in the control circuit during the opening/closing process and records it in the COMTRADE file format.

The Circuit Breaker Recorder Analysis (CBRA) analyzes waveform records taken from the circuit breaker control circuit using a CBR and generates report that explains event and suggests repair actions [16]. Based on detected status of circuit breaker contacts, CBR is providing information on final status of the circuit breakers such as "OPEN" or "CLOSE". The timing of transitions of control signals, such as Trip or Close Initiate, X and Y coil currents, Control and Yard DC voltages, Closing Coil and others is monitored. This enables protection engineers, maintenance crews and operators to quickly and consistently evaluate circuit breaker performance identify performance deficiencies and trace possible reasons for malfunctioning. Permanently monitoring and automatically analyzing the circuit breaker data recorded for each operation enables real time monitoring of integrity and topology

of the entire power network. This solution facilitates the analysis process by providing timely results that are consistent, irrespective who runs the analysis. Enhanced reasoning, consistency and speed are achieved by using advanced signal processing and expert system techniques.

## IMPLEMENTATION EXAMPLE

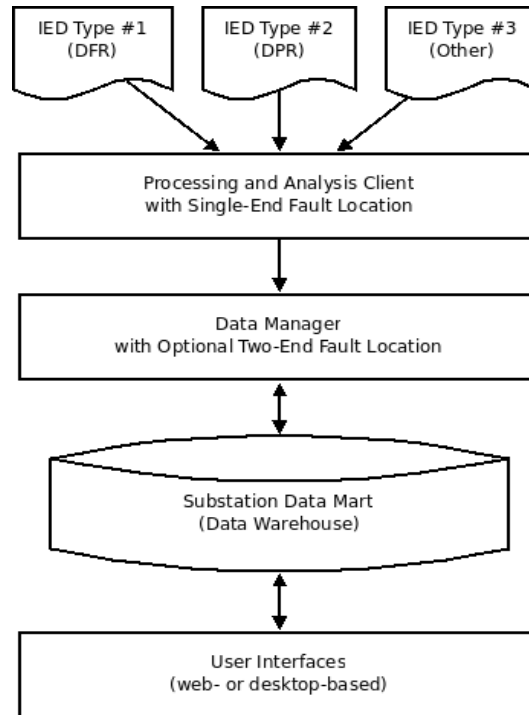


Figure 3. Software Implementation flowchart

An implementation of substation automated analysis solution is depicted in Figure 3 [17]. Actual substation layout is shown in Figure 4. Substation IED data such as event records from digital fault recorders (DFRs), digital protective relays (DPRs), and other types are automatically collected and made available to the solution [18].

- The solution consists of:
- Processing and Analysis Client
  - Data Manager
  - Substation Data Mart (Data Warehouse)
  - User interface

### Processing and Analysis Client

All the IED records are being automatically converted into a unified non-proprietary file format. Signal waveforms, namely voltages and currents, are being mapped to monitored power system components (transmission lines, transformers) and the processing includes fault type detection, disturbance classification, and single-end fault location calculation [18]. There could also be a processing and analysis software module for each IED type group (DFR, DPR, CBR, etc.) and these modules typically correspond to IED level functionalities described in the previous section.

### Data Manager

The Data Manager is responsible for broadcasting reports and proper maintenance of the data warehouse and centralized repository. In addition, it provides functions for broadcasting notifications

to selected users via email and/or pager service. Optionally, the two-end fault location function can be attached to data manager. The module demonstrated later in the paper utilizes phasor-based two-end fault location calculation [19]. Every time the data manager receives a new event file from one end of the line, it checks the data warehouse for an event file from the remote end that falls into predefined time frame. If such a file is located, the two-end calculation is executed.

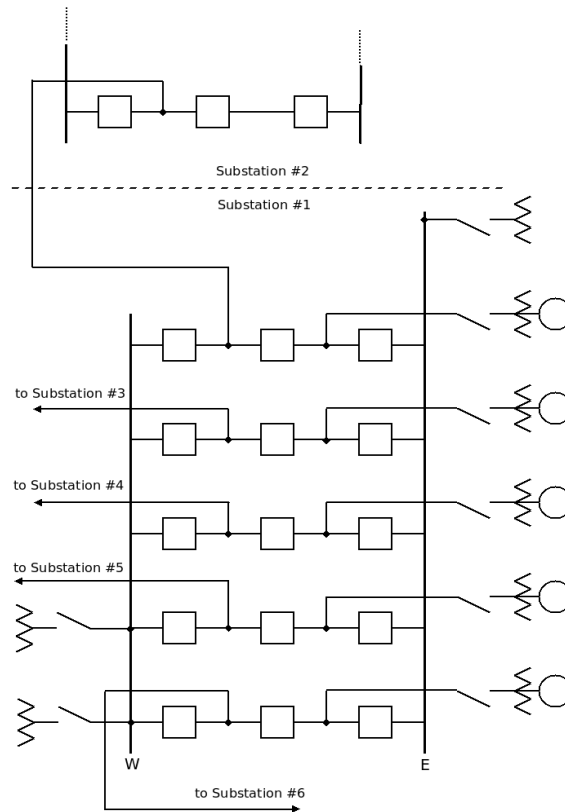


Figure 4. Substation deployment configuration

### Substation Data Mart (Data Warehouse)

All the converted event data, analysis reports, and system configuration are kept in the data warehouse. The data warehouse implementation utilizes a standard database engine and a centralized file repository. Keeping the event data in non-proprietary standard file format [17,18] enables direct access and use of fault data even with standard file managers such as Windows Explorer or Gnome Nautilus. The data base implementation should utilize standard database interfaces such as the SQL subset that will work with most database engines [20]. The solution discussed implements the database interface using Java technologies and JDBC, which allows easy interfacing to majority of modern database engines [21].

### User Interface

The main user interface is web-based and enables users to access data warehouse utilizing just a standard web browser (for example, Internet Explorer or Firefox). The layout is displayed in Fig. 5 below. It is important to note that the interface is using only standard and “clean” HTML/CSS technology [22]. For more elaborate user interfaces (not only web-based), there are variety of technologies available. In this solution, for example, one of the latest Java technologies, Web Start, is used for implementing the waveform and report viewer, shown in Fig. 5, that runs as a desktop application on a client computer, but starts via web server and does not need to be installed locally on the user's computer. User interface is also designed to meet NERC disturbance reporting and cyber security standards [22,23]

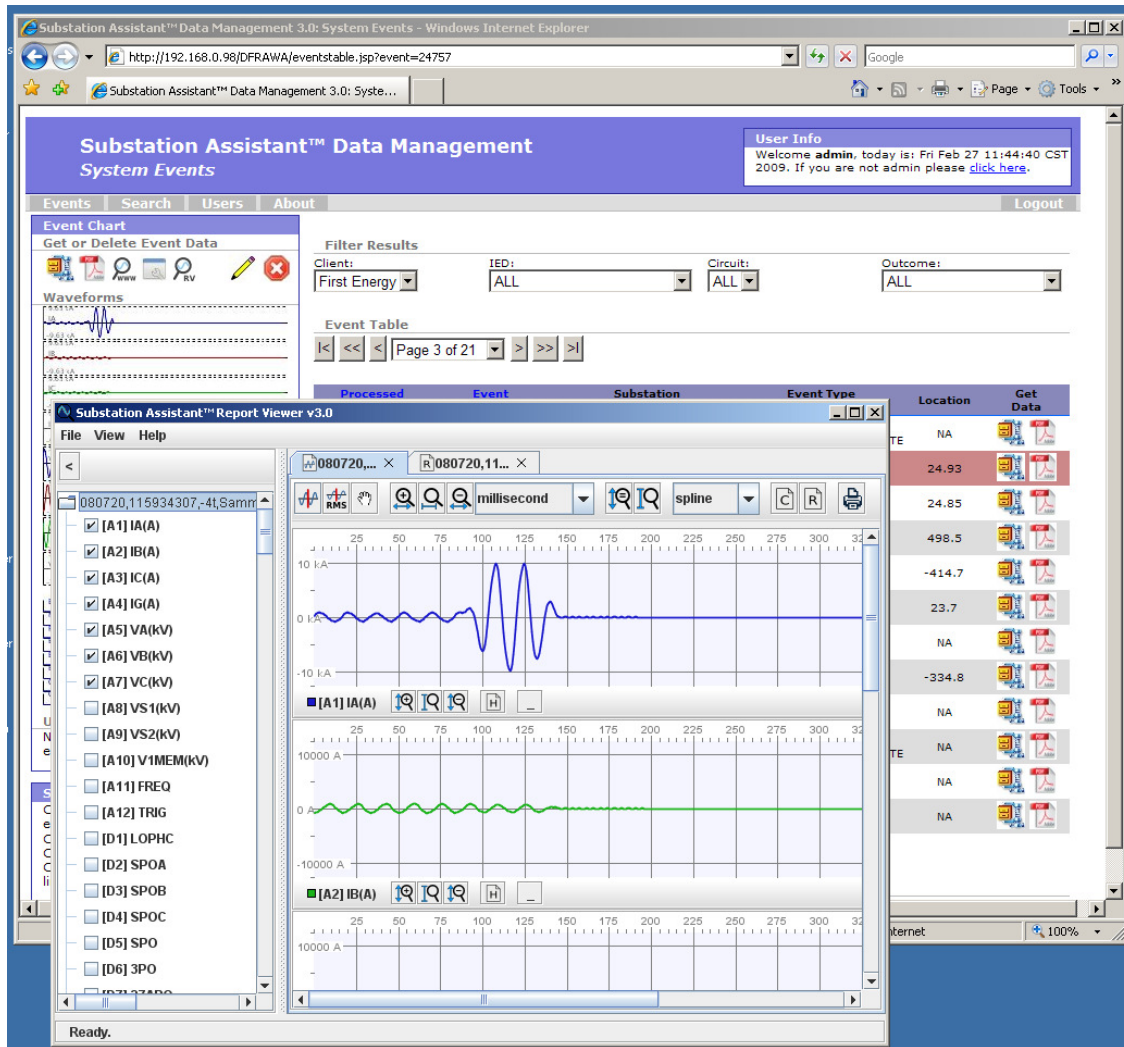


Figure. 5. Web- and desktop-based user interface

## CONCLUSIONS

The conclusions based on the development experiences reported in this paper are:

- The expansion of field recorded data caused by continued IED deployment creates an analysis burden which requires automated means for extracting relevant information
- Integration of IED data allows more comprehensive view of the fault events and related consequences, which leads to a requirement for an automated data integration
- The data from IEDs may be used by many utility groups including protection, maintenance and operation, but relevant information has to be extracted automatically
- Field installations demonstrate feasibility of the proposed concept of automated data integration and information extraction and future wide-scale deployments are expected
- Further automation of proposed data integration and information exchange seem to be inevitable due to a large amount of data to be provided from multifunctional IEDs
- Automated data integration and information extraction requires not only IEC 61859 and IEC 61970 harmonization but also power system model standardization

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