Substation Data Integration and Utilization

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***Abstract*--Substation Intelligent Electronic Devices (IEDs) generate huge amount of data that may be utilized and integrated automatically. Data recorded by IEDs may be used by analysis applications in attempt to describe disturbance and device action in detail. After collection data may be stored in substation or another database at different enterprise location. The collected data may be merged in real time with data from other data sources, such as Remote Terminal Units (RTU), to allow full substation data utilization. Beside issue of designing analysis applications there are issues of handling different data formats, databases, and interfaces. This paper discusses the research solutions for those issues followed by an implementation example.**

***Index Terms*— data integration, data exchange, intelligent electronic devices, substation automation**

Introduction

NOWADAYS substations are equipped with several different Intelligent Electronic Devices (IEDs), such as Digital Protective Relays (DPRs), Digital Fault Recorders (DFRs), Circuit Breaker Recorders (CBRs), Remote Terminal Units (RTUs), Power Quality Meters (PQMs), Sequence of Event Recorders (SERs), etc. When disturbance occurs the IEDs devices record huge amount of data. The practice in the USA is that only data from RTUs is sent to centralized location automatically by Supervisory Control and Data Acquisition (SCADA) system. All other IED data wait in the device memory to be uploaded manually. The significance of the data from IEDs other then RTUs (typically termed non-operational data) is pointed out lately and there is attempt by some utilities to process those data and extract relevant information automatically for the user in real time [1].

Substation data integration cannot be achieved efficiently without substation automation [2]. Data and function integration bring a lot of improvements in data validation and decision making regarding the disturbance characteristic and impact on the power system, as well as an action that should be taken. Therefore substation data integration that highly depends on substation automation should be considered by each utility since manual means for doing the same are time consuming and cannot provide the same benefits. However, it is not clear what the best ways for achieving substation data integration are [3]. Many utilities have poor communication resources, they are using old technologies and they rely on the following premise: "if there were no big outages, do not change anything". As a result of that many utilities simple do not yet appreciate value of data integration. The utilities are concerned about cost of additional investment that they should spend in data processing architecture improvement required to integrate substation data. EPRI has completed a study about the positive impacts of data integration on efficiency of utility operation [4]. Unfortunately it took the latest blackouts (particularly the northeast blackout in the USA in 2003) to recognize needs for improvement in the disturbance reporting and analysis [5]. It appears that the requirements imposed by the North American Electric Reliability Corporation (NERC) after the northeast blackout can be easily met with the automated substation data integration and analysis [6].

It is evident that utilities are dealing with the process of automating the data integration and analysis in different ways. It is a common approach that different utility departments develop partial solutions that deal only with particular data creating "islands" of automation. However the full advantage of the automation can eventually be achieved if data is integrated across the whole enterprise [4].

Substation data integration can be defined as bringing together data from different IEDs into databases at substation and control center level. This approach requires an architecture that supports open integration based on global accepted standards, such as CIM [7], file naming convection for sequence data [8], and COMTRADE [9,10,11].

In summary, the problems faced by electric utilities regarding automated data integration and analysis are:

- Lack of easy integration between legacy applications
- Communication systems that do not exchange data fast enough for practical uses
- Lack of standards for data models, formats and communications

The purpose of this paper is to discuss solutions and implementations for automated data integration and analysis. First part describes several analysis applications that process IED data and explains how those data can be further integrated. Second part presents several issues that utilities should be aware when defining requirements for integration. Third part presents an example that utilizes integrated data followed by conclusion.

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Background

An IED alone typically may record a large amount of data, but it is usually the case that complete interpretation of an event requires information coming from interpreting data from several substation IEDs. To address the different needs of different utility personnel, it is important that the integrated substation data undergo automated processing to produce more comprehensive interpretation of the data at hand. As an example a few automated analysis applications developed recently are presented next.

A. DPRA

Digital Protective Relay Analysis (DPRA) 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 behavior 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 [12]. DPRA software modules are shown in Fig. 1.

B. DFRA

Digital Fault Recorder Analysis (DFRA), also called DFR Assistant by the vendor that offers this solution, provides automated analysis of DFR event records [13]. 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, as well as statuses of the digital channels corresponding to relay trip, breaker auxiliary contacts, relay communication signals, etc. The expert system determines fault type, faulted phases, and checks and evaluates system protection performance [14]. At the end, the analysis program calculates the fault location. DFRA software modules are shown in Fig. 2.

C. CBRA

Circuit Breaker Recorder Analysis (CBRA) is an application based on analysis of records of waveforms taken from the circuit breaker control circuit using a Circuit Breaker Recorder (CBR) 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 analyze switching operations of large number of circuit breakers under complex switching conditions [15]. CBRA software modules are shown in Fig. 3.

IED data can also be made available at the control center level and merged with the data from SCADA database or short circuit programs to achieve full IED data utilization. This requires not only implementation of substation data integration but also implementation of control center data integration. The integration and processing at both levels have to be automated to provide required benefits for multiple utility groups. Following discussions are related to such a solution.

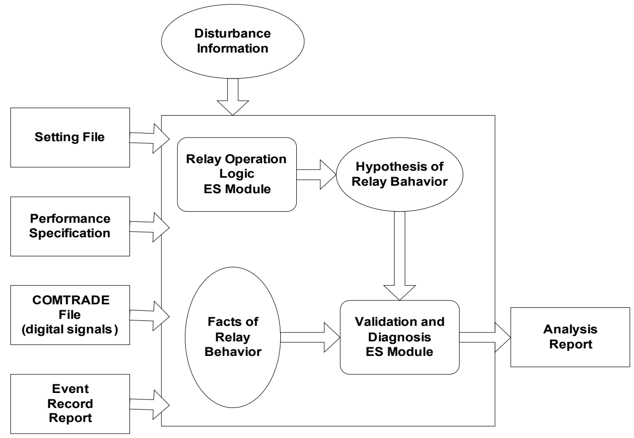

Fig. 1. Digital Protective Relay Analysis Software Modules

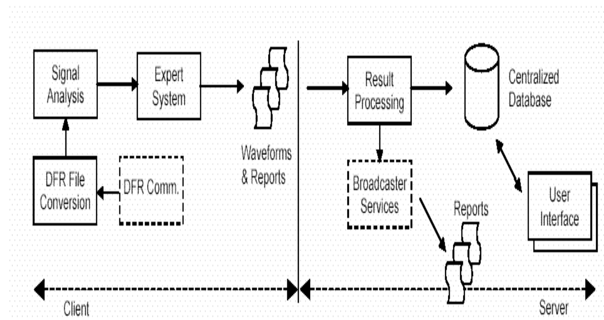

Fig. 2. Digital Fault Recorder Analysis Software Modules

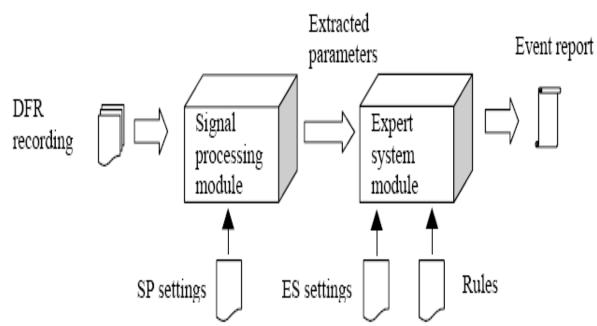

Fig. 3. Circuit Breaker Recorder Analysis Software Modules

Enterprise Data Integration

The idea of supporting end-user needs over a data integration system requires a set of data integration processes that are more complex than just collecting data from the remote source, storing it in databases and then querying and display the information to the user. The issues regarding different data formats, database building and querying, as well as individual applications and centralized user interfaces are discussed in this section. A solution for enterprise data integration is presented pointing out the issues that have been faced in system implementation.

Fig. 4. displays a simplified example of the system architecture for enterprise data integration. Data is collected from IEDs in COMTRADE file format. The data is processed at substation level and populated into the database together with the automated analysis results 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 Fault Location and Alarm Processing, use the translated data in CIM format for further processing. During the implementation of the mentioned solution, several issues have been identified.

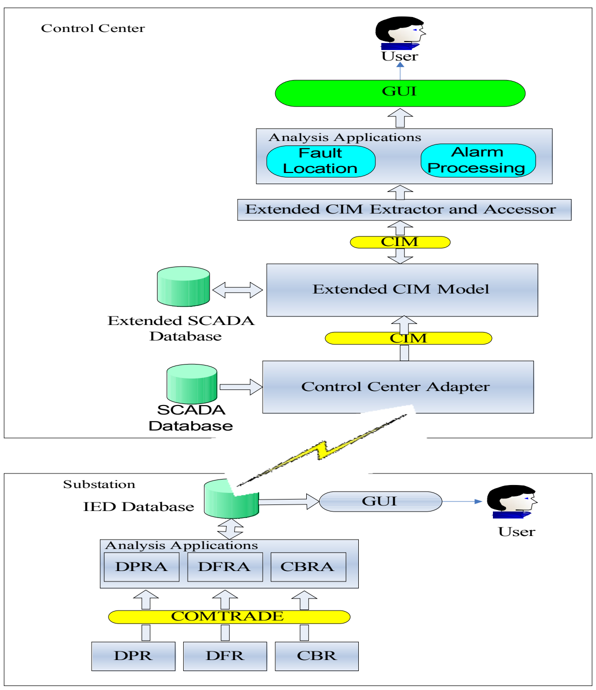

Fig. 4. Enterprise data integration architecture

D. Data Format Inconsistency

Different substation IEDs record and save data in different file formats. Each vendor device records data in its own file format and provides tool for data retrieval and presentation. Thus to integrate data from different IEDs or from the same device type but from different vendors or vintages may be a complex task. To simplify the process, standardized data formats such as COMTRADE file format have been accepted by vendors. Many vendors still keep their own data format and provide tool for converting data to the COMTRADE format but this tool quite often cannot be configured to do the conversion process automatically. Even if vendors support COMTRADE file format , process of data integration can still be challeanging. The COMTRADE standard specification does not define completely configuration data that is needed to interpret the recorded data automatically. Over the period of time, various attempts to improve various COMTRADE issues result in three COMTRADE standard versions published so far [9-11]. If IEDs use different COMTRADE file format versions, exchange and integration of the data, as well as automated processing applications have to be expanded with additional routines that will take care of missing information or data format inconsistencies. In addition, attempt to combine COMTRADE data with SCADA data is difficult because COMTRADE does not provide data model compatible with the SCADA database model described by IEC 61970 [7].

Moreover, handling data recording system configuration information is also critical when trying to automatically collect and interpret data recorded by different substation IEDs. There is a need to know how each IED is configured to be able to interpret information about channel assignments, parameters (sampling rate), communication channel parameters, etc. There is a lack of standardized approach to defining universal convention for describing power system objects monitored by IEDs and making that description part of the event data files. One possible approach to solve this is to use the Substation Control Language (SCL) defined in IEC 61850 [16] but such approach also does not provide full compatibility with the SCADA database model as described in IEC 61970 [7].

E. Database Design

After being recorded by an IED, data may be preprocessed and sent to the database. To be able to deal with the time sequenced data, beside putting the data into COMTRADE file format data description has to follow IEEE standardized naming convection for the time sequence data [8]. The file name should consist of: date, time, station, company, device name, etc. By using this file name format it becomes easier to identify particular file by the automated analysis applications.

Data integration has to include integration of all IED data as well as system configuration and component descriptions data. To enable automated analysis IED data collected in substation has to be matched against the power system configuration and components. The system configuration has to be retrievable for any given time stamp. Power utilities have their system data entered in different databases. System configuration is changing over time and it is important to restore system configuration data for given time stamp. Keeping IED data in a database without knowing corresponding configuration and IED settings may make the database useless for automated analysis application.

Also some applications merge already preprocessed data with raw data and analysis results populated in other or the same database. This may require a lot of consolidation between data from different databases by applications located at the control center level. Those interactions should not delay any preprocessing and loading of incoming data into database. Unpredictable behavior of the data transmission from remote database systems makes estimation of query processing time imprecise. Because of that query optimizations, as well as adaptive query processing and data integration management have to be considered [17].

F. Centralized and Individual User Interfaces

Data integration may be done at substation and control center level. Generally, user wants to have access to data and analysis results immediately after disturbance occurred.

Time response of an analysis application that processes only individual IED data may be reduced by processing data into cache memory before loading it to database and by sending results to the user immediately. Besides, IED data can be loaded together with configuration data into a database at substation level. It takes time to send raw IED data files to higher level to be processed. IED raw files have size of several Mb and in the case of multiple disturbances taking place sequentially communication resources may not be able to transfer such a huge amount without time delay. Because of that, IED data has to be processed and stored at substation level. User can easily access and view the analysis results that have size of several Kb using an individual interface tailored for displaying results from local IED processing and analysis applications executed at the substation level.

On the other hand, some automated analysis functions require IED data to be brought to a centralized location and merged with SCADA data and short circuit data typically stored at control center. Time response to view and assess such information is longer than in the case of individual interfaces allowing displaying and viewing data from local automated processing applications.

Implementation and Deployment Examples

This section provides examples of an open system design and its uses in building different solutions.

A. Data Integration (Multiple IED Types)

In the data integration deployment example, the concept is being implemented in a two-substation setup. The setup requirements are:

- One Digital Fault Recorder (DFR), five Digital Protective Relays (DPRs), and ten Circuit Breaker Recorders (CBRs) in the first substation.
- Radio modem communication from CBRs to the control house.
- One DFR and two DPRs in adjacent substation (for collecting two-end transmission line records).
- Data warehouse for storing all the IED data
- Automated data processing (analysis) agents for the three IED types.
- User interfaces (web based)

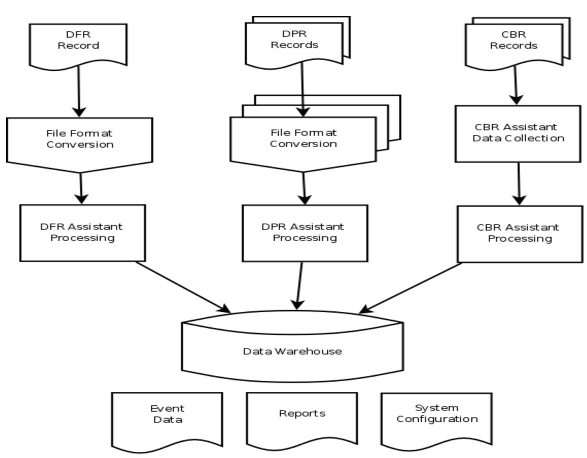

Fig. 5. Data Integration Solution

The data from three different types of IEDs is being integrated and automatically processed by individual IED-based processing agents (Fig. 5). All the data coming from digital fault recorders (DFR), digital protective relays (DPR), and new circuit breaker recorder (CBR) is collected and stored in the data warehouse. The processing and analysis agents make sure that the data file formats are being unified (COMTRADE, proper file naming). DFR Assistant™ agent provides detailed analysis and fault location calculation based on DFR data [18]. DPR Assistant creates the packages with event data (oscillography) and reports obtained from relays.

Circuit breaker recorder (CBR) monitors the signals inside the control circuit of circuit breakers. CBR Assistant™ agent creates reports based on extracted signal features and status changes relevant to the trip and close operations of circuit breakers [18].

All the IED data is integrated into universal data warehouse and accessible through web-based user interface, also implemented as an application agent.

B. Adding Digital Relay Data to DFR Data Analysis System

In a different deployment example, existing system with DFR data integration and analysis solution based on the DFR Assistant™ Agent is being expanded with digital relay data. The setup requirements are:

- ~50 substations
- ~50 DFRs, one DFR vendor, different vintages (old and new models)
- Two master stations
- Data Warehouse for storing all the IED data
- DFR data processing agent
- User interfaces (web and desktop)

Primary focus in this example is to expand the DFR solution to include the relay data coming from digital protective relays installed in the transmission system. Initially, a small number of relays are being added into the solution with a goal of covering different vendors and models in the future. The main features are:

- Two major relay vendors
- Distance and current differential relays
- File format conversion, proper file naming
- Relay data processing agent

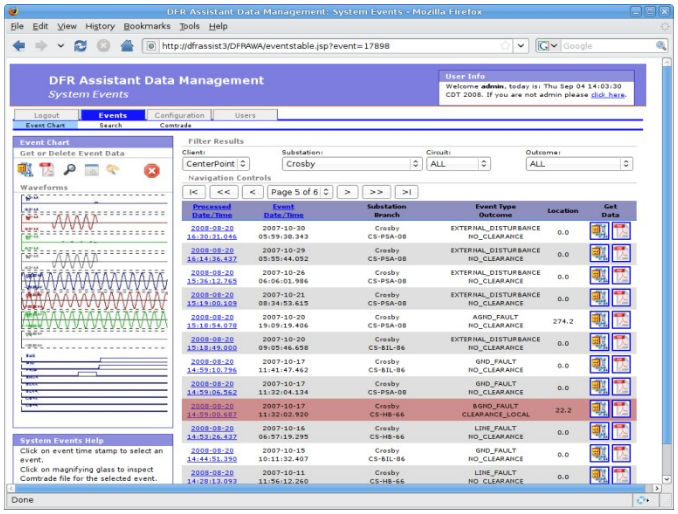

Fig. 6. DFR Assistant™ Web-based Interface

The primary feature in this example is utilizing universal presentation layer for all the data, as well as the results/reports. Both the web-based and desktop-based user interface versions utilize transparent access to the data in the warehouse for different purposes. The events are listed and accessed the same way regardless of the IED type, model, or vintage. An example of the web and desktop interface solutions are shown in Fig. 6 and 7.

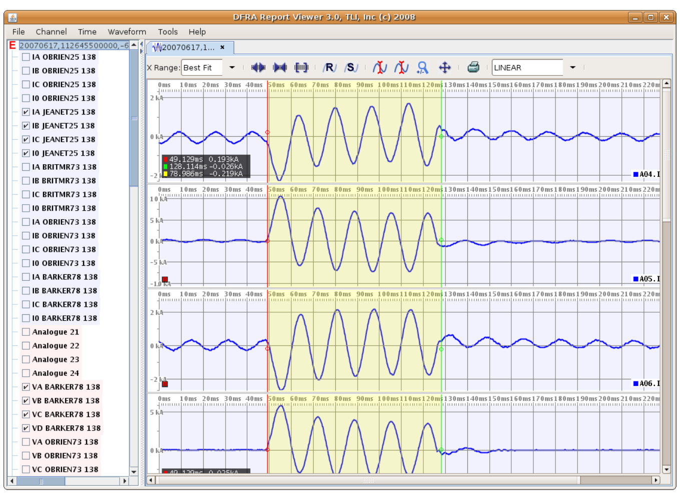

Fig. 7. DFR Assistant™ Desktop-based Interface

C. *Two-End Transmission Line Fault Location Calculation Agent*

This example covers an implementation of a DFR data integration and analysis solution enhanced with two-ended fault location [19]. The main setup requirements are:

- ~20 substations
- ~20 DFRs, two vendors, different vintages
- ~20 master station setups (in each substation)
- Data Warehouse
- DFR data processing agent
- User interfaces (web and desktop)
- Two-end fault location calculation agent

The two-end fault location agent in this example is being implemented to work off of the data from the data warehouse that combines records from two ends of a transmission line. The configuration of the two-end Fault location algorithm deployment is shown in Fig. 7. The agent interfaces to the repository and scans the newly stored event data looking for pairs of DFR records that correspond to two ends of the same transmission line and same fault event. The actual operation of the agent is triggered by occurrence of a DFR data record and report created by the analysis agent taking data from one transmission line end. The biggest challenge in this case is obtaining "good" test data as the DFR records have to be time synchronized and there is not much historical data available. For the purpose of initial setup and evaluation the two-end fault location algorithm is being tested with in-house simulated faults.

Conclusions

This paper describes issues and challenges common to the substation data integration and utilization efforts:

- The data from different substation IEDs may have to be combined, transferred, processed, stored and accesses in real time to get full benefits for various utility groups
- The data has to be converted to the unique data format and stored in database using file forming and naming standards that make the process of retrieving data of interest more efficient.
- Besides the raw data, results of automated analysis and system configuration data need to be accommodated to serve various applications at the substation and control center levels
- The integration brings the advantages in viewing the data and results by the users ranging from individual IED applications to system-wide disturbance analysis applications
- Deployment examples demonstrate that if the system design is open it becomes relatively easy to implement different system configurations covering variety of utility needs and applications.

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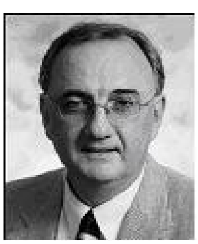
Biographies



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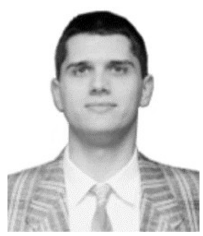

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