AUTOMATED ANALYSIS OF FAULT RECORDS AND DISSEMINATION OF EVENT REPORTS

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***Abstract* –** This paper describes a new solution for automated analysis of fault records captured by digital fault recorders (DFRs) and automated dissemination of event reports. The solution is based on the client/server architecture consisting of modules installed in substations, central office and user desktops. Substation-based modules perform DFR file conversion, signal processing, event analysis and fault location. Main part of the analysis is centered on the expert system whose knowledge base has been tested in a prototype system over the last five years. Server-based modules provide centralized DFR data archiving and event reports dissemination. Main software modules on the server are the database, report parser and Web site. The installation of the system in Reliant Energy HL&P's substations is underway. Initial field-testing shows that functional requirements are completely met.

Keywords - Fault Analysis, Fault Location, Expert Systems, Digital Fault Recorders

I. INTRODUCTION

The automated fault analysis is of interest to the electric power utilities for several reasons. The most compelling one is the need to restore the system as soon as possible after the occurrence of a fault. Automated and integrated fault analysis facilitates quick assessment of the fault clearing and location, thereby enabling more timely and correct restorative action.

The ultimate fault analysis system should provide a detailed system-wide analysis of an event to the interested users within seconds after the event occurred. This may not be feasible with the existing SCADA technology. The main reason is the lack of detailed information about transient waveforms and contact changes that are not readily available through Remote Terminal Units (RTUs) of a SCADA system. On the other hand, such information is available through other Intelligent Electronic Devices (IEDs) including DFRs, Sequence of Event Recorders (SERs) and Digital Relays (DRs). A new concept for fast and accurate fault analysis can be developed using this technology, high-speed data communication infrastructure and advanced software techniques [1].

The application of expert systems to fault analysis dates back to mid-eighties [2]. Since then, a number of solutions have been proposed [3-5]. However, a fully integrated and automated solution does not exist yet. Synchronized sampling for data acquisition systems, as one of the prerequisites for the system-wide event analysis, is not readily available. Furthermore, utilities are still researching various options for standard communication architecture that will allow high-speed substation-wide data acquisition and system-wide data transfer to the central location.

Centralized DFR data archiving is one of the main benefits of an automated fault analysis process. A database rather than a simple file repository archival system is needed so that archival of data and dissemination of reports can be made more intelligent. Data concentration in a central database makes it possible to perform the system-wide event analysis as well. Incoming event files and reports from various substations can be correlated based on their time stamps and samples that are taken using satellite receivers for synchronization. The system fault analysis is then executed to produce a summary report for protection engineers [1].

Various users have different needs regarding the extent of information and time response provided by the fault analysis system. System dispatchers look for condensed fault analysis reports as soon as possible after the fault. Their main interest is in determining the fault location and status of the switching equipment so that decisions about system restoration can be made. Protection engineers are more interested in receiving detailed information regarding the operation of the protection system and related equipment. Obviously, customized event reporting would be very desirable feature of an automated system.

An automatic DFR file analysis software, developed at Texas A&M University, has been installed at Reliant Energy HL&P South Texas Project substation for several years. The software analyzes events recorded by the local DFR and faxes the event reports to various users [6]. In the light of the positive experience with this system, Reliant Energy HL&P has decided to fund the development of a

LAN based system solution for automated analysis of events coming from all installed DFRs. TLI, Inc. has been contracted for this project. This paper describes the latest development using the client/server paradigm and Internet platform as well as the experience with the initial field-testing [7].

II. DESIGN REQUIREMENTS

A. Motivation

Presently, Reliant Energy HL&P has the following digital fault recorders installed in its substations:

- 22 Rochester TR1620 units
- 1 Rochester TR1640 unit
- 10 Rochester T100 units

A dedicated Master Station PC, located at the central office, auto-polls DFRs for new events on a continuous basis. New events are downloaded and archived on a corporate LAN for analysis by protection engineers. The analysis is done by visually inspecting recordings of currents, voltages and digital contacts.

B. System Requirements

The following set of system requirements for the new automated event analysis has been defined:

- Each substation needs to be equipped with a PC directly connected with a local DFR over a high-speed GPIB or Ethernet communication link. This would enable short downloading time and local processing for all events recorded by DFR. The PC needs to communicate the event classification results and compressed data event files to the central data server over a dial-up or LAN link (if available).
- DFR file analysis logic at a system level needs to maintain the files from all DFRs classified as being triggered by the same event. The analysis steps must include the ones found presently in the STP Expert System: detecting the disturbance, identifying the line involved, determining the fault type, calculating the fault location and checking the operation of the protection relays and circuit breakers.
- The results of the analysis need to be stored in a central database and made available to the users across Reliant Energy HL&P system over the LAN.
- The event reports need to be e-mailed and faxed to all specified recipients automatically. In addition, notification need to be sent to specified users via alphanumeric pagers.
- The incoming event reports need to be printed automatically along with the corresponding waveform charts on a local printer.
- The Web Site containing analysis reports and graphical images of the recorded events (analog waveforms and digital contacts) needs to be maintained.
- The substation PC must be controlled remotely for the purpose of maintenance of the local DFR system and configuration files (e.g., changing trigger mode, changing trigger levels, etc.)
- The operating system of choice is the Windows NT Server (for central PC) and Windows NT Workstation (for substation PCs)

C. Functional Requirements

This section summarizes details relevant to the substation-level analysis of DFR files in one of the representative substations.

<u>Scope of the Analysis:</u>

The event analysis currently conducted by the STP expert system has the following general goals [6]:

- Detection and classification of the fault or the disturbances
- Verification of the correctness of the protection system operation
- Calculation of fault location

The STP expert system has been implemented as a rule-based system. About half of the rules deal with the detection/classification while the others deal with the protection system operation analysis [4].

<u>Object of the Analysis:</u>

The event analysis is triggered as soon as a new DFR file is detected in a designated folder on the hard disk of the substation PC. The system does processing of each detected DFR file individually. Furthermore, for one DFR file, the analysis is conducted for each circuit being monitored by that particular DFR.

The conceptual model of the substation as seen by the system for automated event analysis is shown in Fig. 1. Primary object of the analysis is a circuit (transmission line, generator, etc.). The scope of the analysis is related to the object of the analysis. One of the first steps in the analysis is to determine the circuit that has been affected by the disturbance to a greatest degree.

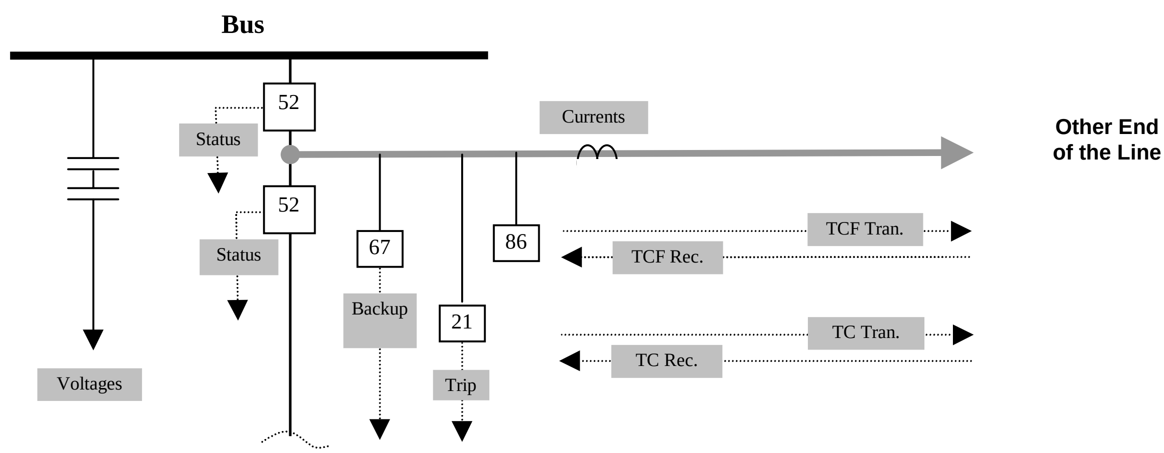

Fig. 1. Typical Breaker-and-a-half Bus Arrangement

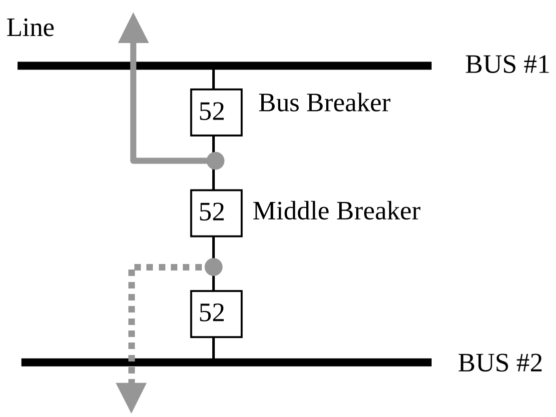

Fig. 2. Typical STP Bus-Breaker Arrangement

The example of typical bus-breaker-line scheme for the STP substation is depicted in Figure 2. The system must support single-breaker and ring-bus scheme as well.

Inputs to the Analysis:

As mentioned earlier, the objectives of the event analysis are detection and classification of the disturbance and verification of the correctness of the protection system operation. The analysis should be based on two sets of signals: analog and digital. Table I lists typical signals obtained as shown in Fig. 1.

Analog signals should be generally used for fault detection, classification and location, while digital signals should be used for the analysis of the protection system operation. Depending on the relaying scheme and protection system details, some of the digital signals may not be actually used.

Table I: Input Signals to the Analysis

Symbol	Description	Type
I	Line currents: 3 phases or 2 phases + zero seq.	Analog
V	Bus voltage (3 phases or 2 phases + delta)	Analog
CBP	Bus (primary) breaker contact (status)	Digital
CBS	Middle (secondary) breaker contact (status)	Digital
PRT	Primary relay trip (status)	Digital
BRT	Backup relay trip (status)	Digital
TCR	Blocking signal received (status)	Digital
TCT	Blocking signal transmitted (status)	Digital
TCFR	Breaker failure signal received (status)	Digital
TCFT	Breaker failure signal transmitted (status)	Digital

Analog Signal Processing

Prior to being passed to the expert system, analog signals must be processed to extract a set of parameters used by the expert system's rules. For the sake of illustration, some of the extracted parameters are listed in Table II. Note that all the quantities shown are phasors obtained using one-cycle DFT algorithm.

Of course, the voltage parameters should be used, too. If the voltage measurements are not available, the system can use the voltage from some other reference taking into account the transformer ratio (if needed). Digital signals in the preprocessed form should be used as well.

Table II: Expert System Input Paramters

Symbol	Description	Type
Iap	Current, phase A	Pre-fault
I0p	Zero-sequence current	Pre-fault
IA	Current, phase A	Post-fault
I0	Zero-sequence current	Post-fault

III. IMPLEMENTATION CHARACTERISTICS

This section of the paper presents the main implementation characteristics of the system. First, the system architecture and its characteristics are outlined. Then, some design details are described.

A. Architecture

As explained earlier, the system is built using a client/server concept. The client part of the system is responsible for data processing and substation based analysis while the server part is responsible for the storage and dissemination of data and event reports. This architecture has significant degree of flexibility. In the Reliant Energy HL&P solution, the client part of the system resides in the substation and the server part resides in the central office.

The system architecture consists of three layers:

- Application Layer
- Data Management Layer
- Presentation Layer

The following sections describe each of these layers in more details.

B. Application Layer

Application layer consists of the modules implementing the core system functionality (Fig. 3). The following functional modules can be distinguished in this layer: Client, Expert System, File Format Filters and Fault Locator.

The following typical scenario describes the functions of individual modules:

- Client constantly monitors incoming folders for new events
- When a new DFR file is detected, Client reads it and prepares for the analysis
- Client uses embedded file format filters to extract event data from DFR files
- Client module does signal processing to extract representative parameters of an event

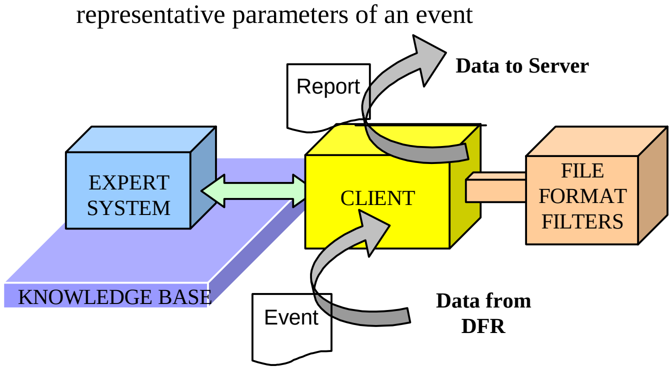

Fig. 3. The Application Layer

- Expert system uses calculated event parameters to classify/analyze the event
- If the event is classified as a fault, Fault Locator calculates fault location
- Expert system report and the event file are passed to the Data Management Layer

The modules of this layer are user-configurable. This feature helps accommodating different user needs in a very convenient way. The extent of the analysis that Expert System does depends on the data available. If needed, Client reconstructs missing phase signal based on signals of two other phases and zero sequence signal.

C. Data Management Layer

The main building blocks of the Data Management Layer are shown in Fig. 4. The functionality of each of the main elements is as follows:

- Database is used for storing the system and event related data (files and reports)
- GUI is used for setting up the system database and client configuration files
- Server Manager constantly monitors the incoming folders for new event reports and files
- Event Parser parses the event report and archives pertinent data into the database

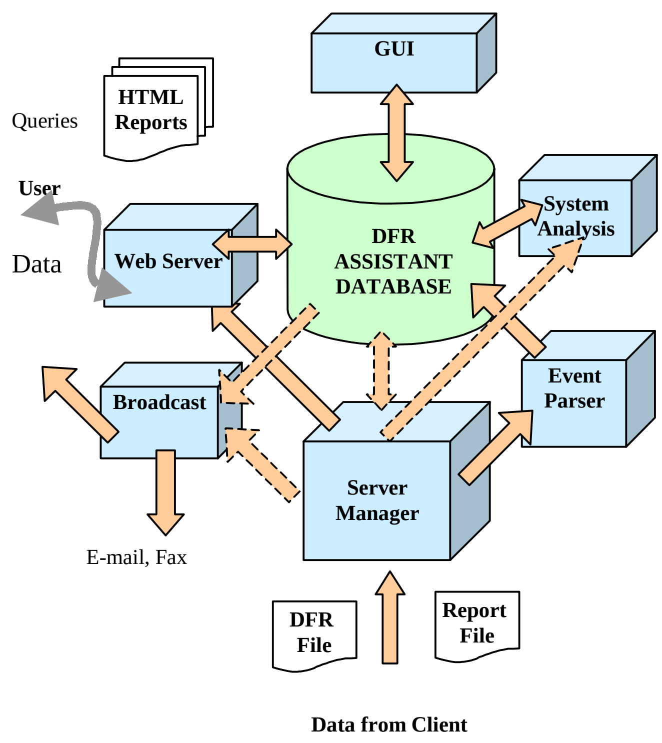

Fig. 4. The Data Management Layer

- Web Server responds to the user queries by retrieving and preparing requested data
- Broadcaster sends data (files, reports, pages) to the users that have requested them
- System wide analysis is performed using the stored events and system data.

D. *Data Presentation Layer*

The Data Presentation Layer is shown in Fig. 5. This layer consists of the standard Web browser and event data viewing application (Report Viewer). The main tasks performed here are:

- A user gets notified via e-mail, fax or pager (from Data Management Layer) that a new event has occurred in the system.
- Using standard Web browser the user visits Web site and views the event page
- The user browses the event table and inspects the event and related system records in more details
- The user downloads the event report and event file to his/her desk computer for further analysis
- Report Viewer is invoked after the event file is downloaded for detailed event data viewing

The three-tier architecture, consisting of the Application, Data Management and Presentation layers, carries out automated analysis of fault records and dissemination of event reports. As these layers are losely connected, there is no need for one particular layer to be always functional for any other layer to function properly. Due to this flexibility, any change in the physical system (e.g adding or deleting a Substation/DFR) does not require the user to shutdown the whole system. This solution also gives the flexibility to customize the system to an extent that meets the user's needs best. In this system, the user gets the opportunity to acquire information about an event of his/her interest without requiring him/her to be present at a particular site.

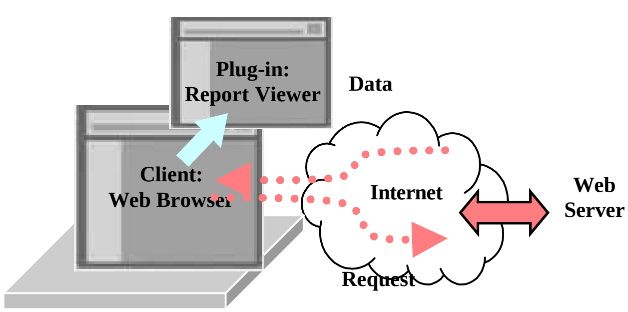

Fig. 5. The Data Presentation Layer

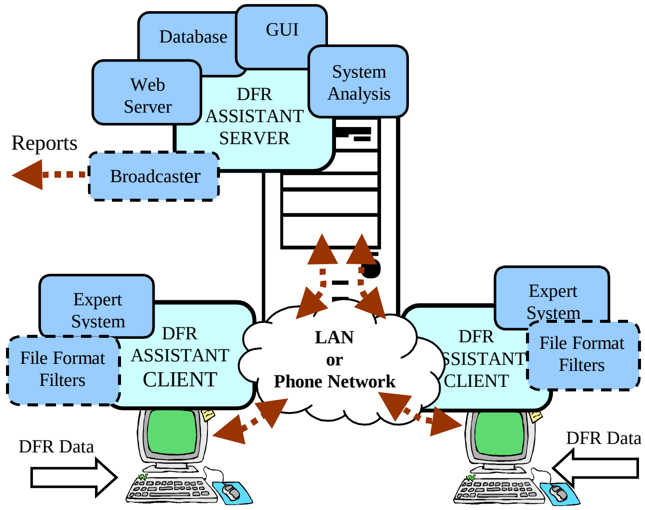

Fig 6. Architecture of the Installed System

IV. FIELD EXPERIENCE

A. *Configuration*

A distributed system configuration was used in the case of the Reliant Energy HL&P installation. As mentioned before, the system consists of a central server (in the central office) and 33 local PC's (one in each substation). Each substation is equipped with a PC directly linked with local DFR. Rochester TR1620 units communicate with substation PC using IEEE-488 interface, while Rochester TR100 units (whose installation is underway) use Ethernet link. Direct communication between the substation PC and a local DFR enables immediate downloading of DFR data files to the PC. Substation PCs are connected to the server in central offices via telephone network (dial-up access). Fig. 6 displays the architecture of the installed system.

The Web Server feature allows other users (not shown in Fig. 6) connected to the corporate LAN to access reports and event data using Web browser and Report Viewer.

B. *In-house Testing*

The in-house testing was based on two sets of test events:

- set of test events for which the fault type and exact location were known
- set of test events from the STP substation (previous version of the expert system) that were also well understood.

The number of test events in the first set was limited to the set of existing DFR data files for the known faults. Therefore, it was decided to extend the set of test events with the existing events from the STP substation and to use the STP expert system as a comparative reference as well.

Table III on following page shows the results of the in-house testing of the fault location calculation module.

Table III: In-house Testing Results

Event File		Fault Location	
Case #	Fault Type	DFR Assistant	STP Expert
203	C-GND	22.78	22.50
272	C-GND	79.18	63.76
275	C-GND	77.17	58.97
303	C-GND	86.62	-
530	B-GND	55.40	51.35
551	A-GND	19.88	19.56
635	B-GND	48.93	47.49
617	A-GND	32.86	-

Please note that the event # 617 was not originally processed by the STP Expert, but the exact location and fault type for that event were known and match the calculated ones very well.

Fig. 7 shows details of the waveforms for the event # 617 using the Report Viewer.

For in-house testing both the server and client were installed on the LAN in TLI offices. There was no live communications between clients and DFRs, nor between clients and server using telephone network.

The results from in-house testing were initially used for tuning both the expert system and fault location algorithm.

C. *Field-Testing*

Field-testing is underway on the system configuration with several clients installed in substations. Various options available with the client were tested. The initial results are reported below.

Substation PCs are directly linked to the local DFRs. In addition, communication between the substation PCs and the server is established using remote dial-up access (via telephone network). All installed substation DFRs are directly queried for new events. Occurrence of new event triggers downloading, converting, analyzing and classifying event files and producing data package that contains all relevant information (reports, data files, native files, etc.). Data packages are sent to the server via telephone network. The data transfer rate over the telephone lines satisfies system requirements.

The server PC receives data packages from substation PCs and performs extraction, archiving and dissemination of the results of the analysis. The results are automatically stored into a system database implemented in the MS Access format. The database is connected to both the Server and Web Server. Connection to the web server allows registered users to view and use data from the database using standard Web browser and Report Viewer (Fig. 8).

The broadcasting services (creating HTML static pages, signal charts in JPG format, printing, faxing, sending emails and pager notifications) as well as remote maintenance functions were also initially tested. However, the primary emphasis was on testing the expert system, fault location, the server side operation and proper handling of database connection.

The DFR Assistant System Builder application is used for describing the system in the database as well as for creating the configuration files.

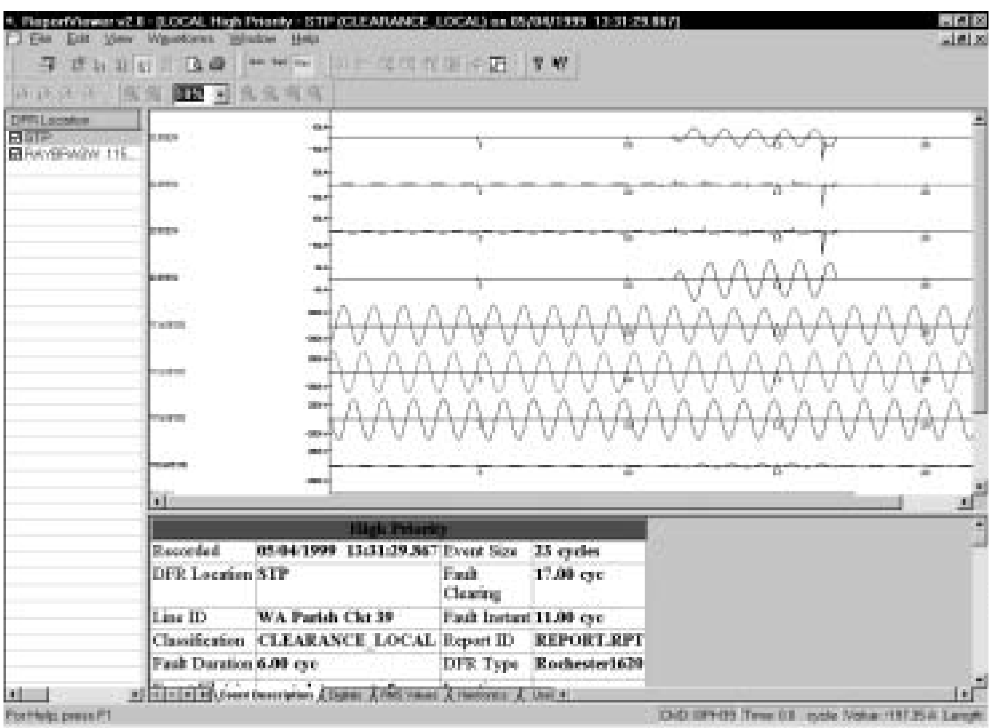

Fig 7. Report Viewer Displays Waveform Plot for Event # 617

VI. CONCLUSIONS

This paper has described a new solution for automated analysis of fault records and dissemination of event reports. The system has been built around the client/server software and hardware platform, which has enabled distributing system functions. Consequently, the main system modules are installed in substations, central office and user desktops. A faster system response and an increased reliability have been achieved.

The system has been configured for Reliant Energy HL&P to improve the quality of event classification and analysis and to increase the efficiency of report archival and dissemination. The installation of the system in 33 substations of the Reliant Energy HL&P's transmission grid is underway. Once completely installed, the system will enable Reliant Energy HL&P to significantly reduce the time required for performing the analysis. This will enable personnel to spend more time on “difficult to analyze” cases.

VI. ACKNOWLEDGMENTS

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BIOGRAPHIES

Donald R. Sevcik received his BS degree in electrical engineering from Texas A&M University. He has been with Reliant Energy HL&P since 1975 and is currently a consulting engineer, substation projects section. He has worked in following areas: power plant electrical systems, system studies, as well as transmission and generation protection. He is registered professional engineer in the State of Texas.

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