THE NEXT GENERATION SYSTEM FOR AUTOMATED DFR FILE CLASSIFICATION

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Abstract: This paper describes an automated digital fault recorder (DFR) file classification and archival system. The system is based on Windows 95 Client and NT Server architecture and provides intelligent classification of DFR files. This allows faster analysis of unexpected power system events as well as confirmation of correct equipment operation. A local area network (LAN) based repository for the classified fault records is created for corporate wide archival and retrieval purposes. In addition, universal viewing software was developed to provide a graphical user interface (GUI) to analyze DFR waveform data as well as classification summary results. This paper presents an overview of the system organization and client/server application implementation details. The data communication for transfer of multiple vendor DFR files and distribution of the analysis reports, as well as DFR file classification logic and system testing results are discussed.

Keywords: Automated Fault Classification - Digital Fault Recorder - Signal Processing - Protective Relay – Circuit Breaker - Expert System

I. INTRODUCTION

The concept of automated analysis of Digital Fault Recorder (DFR) data was introduced in the early nineties [1–3]. The first implemented systems were designed to analyze data from DFRs supplied by one vendor [1, 4, 5]. Further developments included algorithms for fault location and approaches for system-wide analysis [6, 7]. More recent advancements in digital substation control and protection equipment as well as communication requirements for advanced monitoring, control and protection enabled a variety of new automated fault analysis systems to be pursued [8, 9]. Partnerships between utilities and university applied research programs have provided a very effective means for implementing highly automated intelligent systems for the analysis of power system performance under transient fault conditions [10, 11]. The project, discussed in this paper, is sponsored by TU Electric and implemented in conjunction with Texas A&M University.

The paper presents an integrated solution where DFR data analysis is done at a centralized master station location. The DFR data files are brought to their respective central location master station before being processed by the classification system. The automated classification system is designed to accommodate multiple DFR manufacturers. Currently, the system is configured to classify Hathaway DFR II and Mehta Tech TRANSCAN digital fault recorder files. However, the DFR file classification software is readily extendible to other vendors' DFR files provided the data file formats are available.

In addition, universal viewing software was developed to provide a graphical user interface (GUI) to analyze DFR waveform data as well as classification summary results. To allow consistent data access across multiple recorder families, the viewing software was designed to utilize IEEE industry standard C37.111 which outlines the common data format for transient data exchange commonly referred to as COMTRADE [12]. The classification software automatically creates COMTRADE formatted files for analyzed system DFR file events for use by the viewing software.

Both the automated DFR file classification system and the universal viewing software solution prototypes are undergoing field-testing. The resulting integrated fault analysis approach to automated DFR file analysis using substation DFR data, a central expert system, and the corporate LAN is outlined first in the paper. Next system design and implementation issues are discussed. An overview of the automated fault classification system, its components and operating logic is presented. The solution utilizes a customized rule-based system shell capable of incorporating a variety of rules covering present DFR configurations and future extensions. Two major modules: the Classification Engine and the Report Viewer are described in detail. Finally, a brief roadmap for future development, a set of conclusions, and related references are provided.

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II. PROJECT BACKGROUND

The TU Electric Transmission Division digital fault recorder (DFR) monitoring system consists of three vendors' (Mehta Tech, Hathaway, and USI) master station PCs located at the corporate Transmission Division headquarters in Ft. Worth, Texas. The master stations' PCs communicate via high-speed modems with DFRs at 80 remote transmission sites. Protection engineers and technicians analyze the data after it arrives at the central corporate location to assess the operation of the protection system as well as characterize and archive significant disturbance events.

Due to the "ripple effect", depending on the severity of a transmission system disturbance, more DFR records than required to analyze the disturbance are generated. The typical remote transmission DFR has between 32 and 64 analog channels and 64 to 128 digital channels at any one site. Thus, TU Electric's transmission grid DFRs utilize over 3000 analog and 6000 digital channels to record transmission system voltages and currents as well as breaker and protective relaying equipment contacts during power system faults. The location of multiple DFRs in proximity to large load/generation centers and typical severe weather patterns can produce a tidal wave of DFR data for system fault/disturbance events. Prompt manual examination of all DFR records and archival of the significant transmission system disturbances has become a burdensome task.

In addition, the North American Electric Reliability Council (NERC) recently issued a series of compliance standard requirements in regard to disturbance monitoring adequacy in a utility system. According to NERC, "*Each Region shall develop a plan that defines the requirements for the installation of disturbance monitoring equipment to ensure data is available to determine system performance and the causes of system disturbances*" [13].

The Electric Reliability Council of Texas (ERCOT) is presently developing a set of guidelines with regard to utility fault/disturbance recording practices to fulfill the NERC requirements for monitoring equipment and database development of recorded information.

To address the DFR information tidal wave and efficiently analyze, categorize, and prioritize TU Electric's DFR file records for human consumption, DFR screening software development became a formal transmission system imperative in late 1996. As part of TU Electric's support of university research on utility related issues as well as maintenance of graduate student support, a research and development contract was finalized in January, 1997, with Texas A&M University's Electrical Engineering Department to develop automated DFR file classification logic and universal viewing software. In addition, the classification system was designed to comply with recent ERCOT/NERC guidelines regarding disturbance monitoring equipment. The automatic processing, archiving and accessing of DFR data files over TU Electric's corporate LAN are intended as the backbone of TU Electric's disturbance monitoring database.

The new DFR file classification software was designed under the following constraints:

- Compliance with the NERC recommendations
- Minimal hardware enhancements to the rather extensive number of existing DFR installations
- Provision for future expansion
- Provision for new vendor DFRs

To function in the existing TU Electric transmission DFR environment, the automatic DFR file classification system was required to accommodate:

- Multiple DFR vendor data file protocols
- Multiple DFR vendor operating systems
- TU Electric standard PC operating system
- TU Electric standard LAN and server environment
- Development of DFR master station and LAN compatible file archive methodology
- Partial 3 phase modeling in analog channels recorded by the DFR
- Incomplete digital channel modeling of key protective system components (viz. breaker conditions, relay contacts)
- No PC available at the DFR transmission site for local processing of data

A study of the possible existing approaches to automated fault analysis using digital fault recorder (DFR) data did not provide a viable solution given the constraints of the existing TU Electric DFR environment. Most of the currently available methodologies examined had been implemented for only one DFR protocol or vendor [1, 3-6, 11]. Implemented systems were designed on the basis of a local PC for processing DFR files at the substation DFR transmission site [1, 3, 4]. In addition, full three phase modeling of transmission system as well as extensive modeling of protective system components (viz. breaker contacts, protective relay contacts) were often specified.

III. INTEGRATED FAULT ANALYSIS APPROACH

Various types of users have different needs regarding the response time and/or extent of information provided by the fault analysis system (see Figure 1). The protection engineer is interested in getting detailed and specific information regarding the operation of the protection system and related equipment during the event. The technicians require a summary of the fault classification to help them troubleshoot incorrect operations of protection equipment. The system dispatchers are interested in getting the condensed fault analysis information as soon as possible after the occurrence of a fault. The system dispatcher's main interest is determination of accurate fault location and switching equipment status that enables them to make decisions about the system restoration.

In this paper the concept of an integrated fault analysis system that can be built with existing technology and can satisfy two groups of users – protection engineers and technicians is presented. The subsequent sections give detailed presentation of the research and development project that resulted in a prototype of TU Electric integrated DFR file classification system. The system is designed to process DFR files coming from Hathaway DFR II and Mehta Tech TRANSCAN master stations installed at the central location.

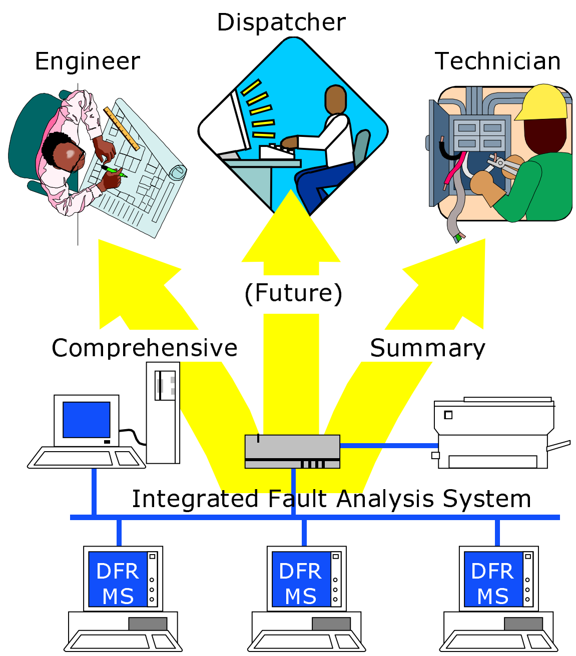

Figure1. Major user groups and levels of information requested by each group

Presently, this system does not provide real-time processing, due to the long file transfer time between remote DFR transmission sites and the master stations. Adding a local processing PC at the substation level could provide improved analysis response time. Currently the system is not integrated with TU Electric's transmission line impedance database or the short circuit fault current modeling program. Therefore, real-time dispatch summaries and automatic fault location data are not available at present.

Figure 2 depicts the major parts of the DFR classification system developed by Texas A&M University and TU Electric. The system consists of a central file server that serves as a repository of DFR files and associated classification reports. Two Hathaway DFR II and one Mehta Tech TRANSCAN master station are responsible for communicating with remote transmission digital fault recorders and transferring data files from the substations to the corporate office.

The system shown in figure 2 is configured to classify files coming from DFRs made by the above-mentioned vendors. The classification system has been generalized to allow easy incorporation of additional digital recording systems from other vendors, as long as the particular DFR vendor provides DFR file format descriptions.

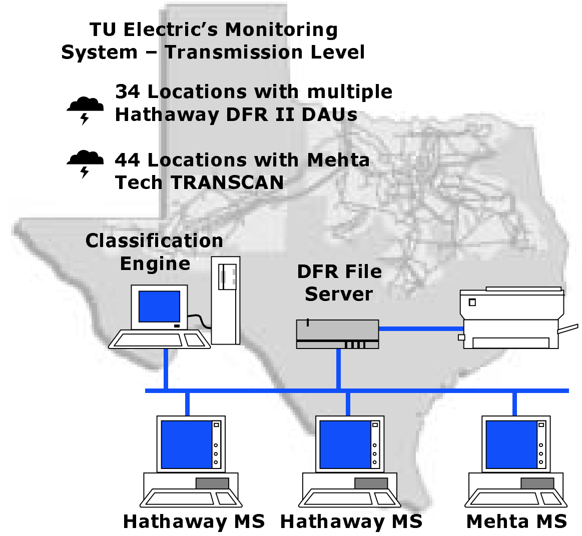

Figure 2. TU Electric's Classification System

This classification system feature provides a common platform for fault analysis and the distribution of results regardless of the evolution of the Master Station software. In addition, the common platform eliminates the need to train employees to use multiple DFR manufacturer analysis packages.

IV. SYSTEM DESIGN AND IMPLEMENTATION

The basic DFR file data flow diagram is shown in Figure 3. The DFR Master Station PC's #1 through #3 are responsible for communicating with remote recording units via dial-up modem lines. The Master Station units can be configured to automatically poll remote recorders on a periodic basis and retrieve new events, or remote substation DFRs can be set-up to automatically call a Master Station when they have a new event to report. For this project, the second option was preferred.

To facilitate the classification process as well as distribute classification results across the corporate LAN, a dedicated Windows NT File Server PC and a Classification engine PC are secured. The Classification Engine is the "brain" of the system. It monitors assigned incoming file directories on a File Server and detects any new DFR data file that has been copied from the Master Stations. These new files are processed using built-in logic to produce a classification report. Finally, the Classification Engine automatically converts the raw Classification Engine DFR data file into the COMTRADE format [12] and copies it with the associated classification report to an assigned directory on the Windows NT File Server.

The File Server is a repository of both the original, raw DFR data files in its native format, and the processed DFR files in the COMTRADE format. The easy access to the processed DFR files is facilitated by archiving all data files into three categories (high, medium, and low priority) based on certain criteria. The user can then access the results of the Classification Engine's automated DFR file analysis utilizing Report Viewer software. This separate universal viewing software package provides an integrated environment for displaying both the conclusions about the analysis of a selected DFR file, as well as waveform graphics in the form of analog and digital traces.

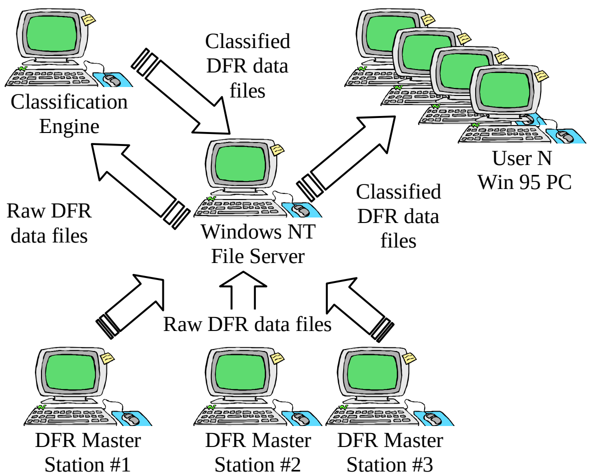

Figure 3. Classification system block diagram

V. The Classification Engine

One of the tasks of the Classification Engine is to reduce the time that system protection personnel spend on manual examination and archival of DFR records. When a fault condition exists, the system automatically classifies and filters DFR records based on the following broad criteria:

- Clearing time is satisfactory.
- Clearing time is longer than expected.
- Carrier misoperation occurs during fault clearing.
- Breaker abnormality occurs (slow clearing, restrike, or failure) during fault clearing.
- PT ferro-resonance occurs during fault clearing.

Table I outlines the DFR file signals that are utilized by the DFR file classification logic. If the signal is not monitored in a particular DFR configuration, associated classification logic can not be implemented. In the case where only the two phase currents plus residual current are monitored, the third phase current will be calculated automatically by the Classification Engine.

Table I. Input signals used by Classification Engine

Digital	Primary and backup relay trip Breaker open position Breaker close position Breaker failure (BF) contact Carrier Start and Carrier Received contacts	
Analog	At least two phase currents Residual current All three phase (bus side) voltages Residual (neutral) voltage	(Ia, Ib, Ic) (Ir) (Va, Vb, Vc) (Vr)

The following parameters are extracted and/or calculated from every DFR record:

- Relay trip duration (initiate and reset time)
- Breaker operate time (position open/close indication time)
- Breaker failure timer pickup duration (initiate and reset time)
- Carrier start/receive/stop duration times
- Calculated fault inception
- Calculated fault clearing time

The classification logic is based on the analysis of the above parameters. The following are events that can be recognized and flagged by the automated analysis system:

- Slow relay clearing
- Breaker slow clearing, restrike, or failure
- Carrier misoperation
- PT Ferro-resonance
- Reclosure failure, or line lockout
- Bus clearing
- Normal fault clearing
- No operation (manual trigger)

Figure 4 shows a snapshot of the Classification Engine's main window. The DFR event processing can be either manually started (clicking on the Go button) or it can be set to automatically start when the system is rebooted. This feature ensures system reactivation in a case of power failures.

Figure 4. The Classification Engine main window

The classification system must be configured before its first use. This one time task is facilitated by user friendly graphical interface. The system administrator is guided through a multi-step configuration process using Windows® wizard dialogs (see Figure 5).

Figure 6 (in the Appendix) illustrates the results of using the Classification Engine's wizard to configure the software for a Hathaway DFR II (composed of 3 DAUs) digital fault recorder at TU Electric's Monticello Lignite Power Plant's transmission switchyard. The standard bus configuration format is illustrated for one of the 3 DAUs. It can be noted that the Classification Engine introduces a hierarchy of objects, starting from a substation that can contain one or more digital fault recorders.

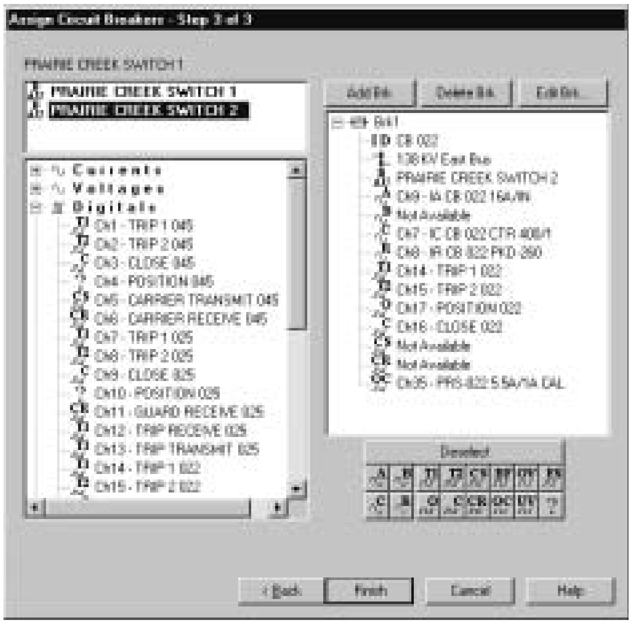

Figure 5. DFR configuration wizard

DFRs, in turn, record analog and digital signals that can be grouped into signals that belong to a bus (viz. phase voltages, breaker failure contact) or a breaker (viz. phase currents, relay trip, breaker position). The Classification Engine utilizes this data format to group diverse analog and digital channel assignments from incoming raw vendor DFR files into a standard Classification Engine configuration format for analysis by the "brains" of the automated DFR file classification system.

The Classification Engine keeps a detailed log of the system events during its operation (see Figure 7 in the Appendix). System events such as the names of the processed files, changes in DFR configurations, names of the corrupted DFR files, or names of the incomplete DFR files are time stamped and recorded. These logging capabilities help the administrator troubleshoot the system operation on a daily basis.

The Classification Engine archives all incoming DFR files into three categories depending on the type of the event. These categories are High, Medium, and Low priority (see Figure 8). Events such as the breaker failure, or carrier misoperation will be categorized as high priority events and archived in the High priority folder on the central file server. Events such as the normal fault clearing, or reclosure success will be categorized as the medium priority. And finally, the events such as no operation will be stored in the Low priority folder.

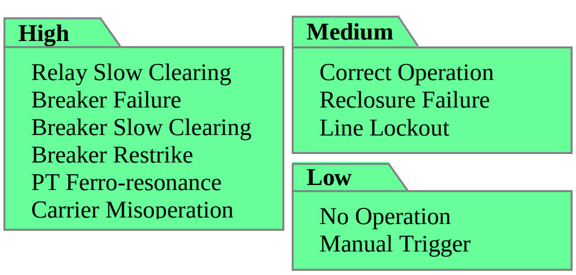

Figure 8. Classification logic categories

VI. THE REPORT VIEWER

The Report Viewer is the Windows 95 client software used for accessing classification reports from the central file server. The module has an extensive graphical user interface (GUI) that allows users to access DFR reports and data files either locally (when directly connected to corporate LAN) or remotely (when connected to corporate LAN over a dial-up modem line). Figure 9 (in the Appendix) illustrates the Report Viewer application's main window consisting of three parts: network/local directory display, waveform display, and classification report display.

The user may choose the event priority that he/she wants to access and display in the directory view. The default priority is High. The network/local directory display contains three columns: name of the DFR that recorded particular event, date/time stamp and short description of the event (see Figure 10 in the Appendix). For accessing the data over WAN (via dial-up connection), the application provides a caching function, similar to Internet browsers. This means that the data once downloaded will be saved in the caching directories on the local drive, thus eliminating the need to retrieve the same event files over the WAN multiple times. In addition, the caching function enables the user to view the downloaded data files off-line.

The textual display (see Figure 11) of the Report Viewer presents the following information to the user:

- Event Date/Time Stamp
- Event type (e.g. breaker failure, etc.)
- Event Size (prefault, fault, postfault cycles)
- DFR type and recorder ID
- Breaker ID and Breaker Operation Time
- Operation of carrier channels
- RMS values for associated Breaker ID's analog channels per cycle for every cycle in the record (the display will be color coded for prefault, fault and postfault intervals)
- Harmonic content of associated analog channels in a tabular form.

Figure 11. The Report Viewer text display

The waveform display of the DFR file presents graphs of analog and digital signals (see Figure 12 in the Appendix). This display has the following properties:

- selectable DFR channels to display
- tickmarks on the x and y axis
- auto-scalable x and y axis
- selectable time axis (milliseconds, cycles, or samples)
- selectable waveform coloring
- colored markers on the analog traces where the digital channel operation occurred
- zooming capability
- legend containing channel description and values of analog and digital signals at cursor position
- measure the time span between two points on the screen
- waveform printing and print preview

An example of a waveform print preview screen, consisting of several analog channels and digital contacts, is depicted in Figure 13 (in the Appendix).

VII. FUTURE DEVELOPMENT

The system prototype described in the previous sections is currently undergoing extensive field-testing. Additional classification logic is being added and existing rules fine-tuned to improve the overall system performance. In order to meet the NERC database requirement compliance issues, 1998 development plans include the use of the Internet/Intranet as well as database technologies to enhance the applications' PC client/server platform. Phase II of this project expands the integrated DFR classification system using 3-tier client/server architecture. The system will be implemented in the following layers:

- **Database** – Set of relational tables containing DFR configuration data, DFR data files, and classification reports
- **Application** – Existing classification logic for fault detection, and event type identification
- **Presentation** – The client software such as the Internet browsers, or the Internet-enabled Report Viewer

Figure 14 depicts the enhanced architecture, where the Classification Engine (application layer) archives incoming DFR events into a relational database (such as Microsoft SQL Server or Access). The database will also store all pertinent DFR configuration data, thus allowing tracking of changes made to DFR master station software.

The Web server will have access to the DFR event database and be able to execute queries against database. An example of a transaction may be as follows:

- User accesses the Classification Engine web site using any Internet browser.
- User specifies search criteria (e.g., retrieve "all breaker failure events in the last 3 months on breaker CB4130 Sulphur Springs) and sends the query to the web server
- Web server runs the query against the DFR event database and compiles the set of records
- Web server generates report file in HTML format and sends it to the browser over internet/intranet/extranet
- Browser displays the requested information to the user

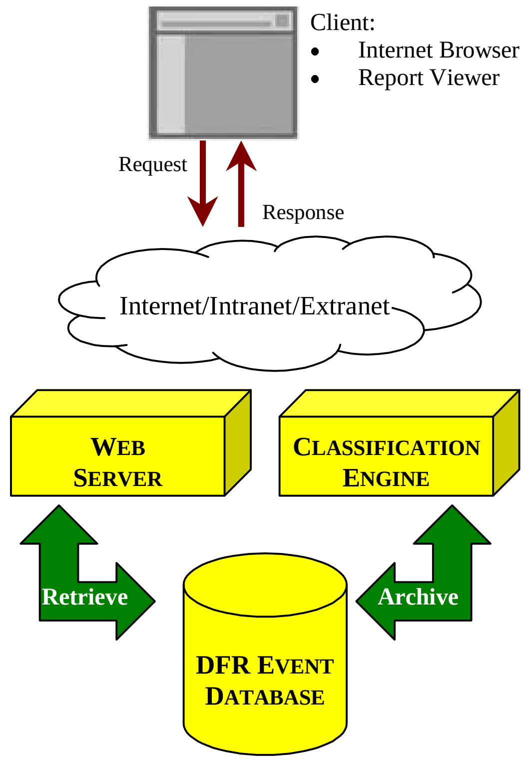

Figure 14. New 3-tier system architecture

This architecture will result in a system where the data, the logic and the user interface are separated, thus allowing scalability and extendibility of the solution. Also, different users will be able to choose their preferred client software for record viewing analysis. The access to the classification system will be ubiquitous.

VIII. CONCLUSIONS

This paper has introduced a general concept of integrated fault classification system utilizing data collected by digital fault recorders, and processing at a central location. In addition, a prototype of such a system was described in detail. The existing TU Electric system is geared toward the off-line use by the protection engineers and technicians.

The classification system is designed to comply with National Electric Reliability Council guidelines regarding disturbance monitoring equipment. Automation of the processing, archiving and accessing of DFR data files is achieved over the TU Electric corporate LAN.

ACKNOWLEDGEMENTS

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BIOGRAPHIES

Mladen Kezunović (S'77, M'80, SM'85) received his Dipl. Ing. degree in electrical engineering in 1974, and the M.S. and Ph.D. degree, in electrical engineering in 1977 and 1980 respectively. Dr. Kezunovic joined Texas A&M University in 1987 where he is a Professor. He is member of the IEEE PSRC, member of CIGRE and a registered Professional Engineer in the State of Texas.

Igor Rikalo received his Bachelor of Science degree from the University of Sarajevo, and Master of Science degree from Texas A&M University, all in electrical engineering in 1992, and 1994, respectively. Currently, he is working for TLI, Inc. as a senior systems engineer and for Texas A&M University as a research engineer. Mr. Rikalo is also attending Master of Business Administration program at Texas A&M University and expected to graduate in December 1998. He has worked in the area of intelligent system applications to power industry since 1992.

Bogdan Vešović earned his Graduated Engineer degree in Electrical Engineering from University of Belgrade, Yugoslavia in 1991. Since than he has been working in the area of software engineering, power system control and operation planning. His current research works include optimization methods, fuzzy set theory and object-oriented analysis and design. He is now employee of Siemens Power Transmission and Distribution LLC.

Sherry L. Goiffon received her Bachelor of Science degree in electrical engineering in 1977 from Texas A&M University. Currently, she is working part time for TU Electric as a senior engineer in System Protection. She has 20 years of experience in transmission grid system protection and fault recorder analysis. She serves on the Transient Recorders Users Council and facilitates the Georgia Tech Fault Disturbance and Analysis Conference.

APPENDIX

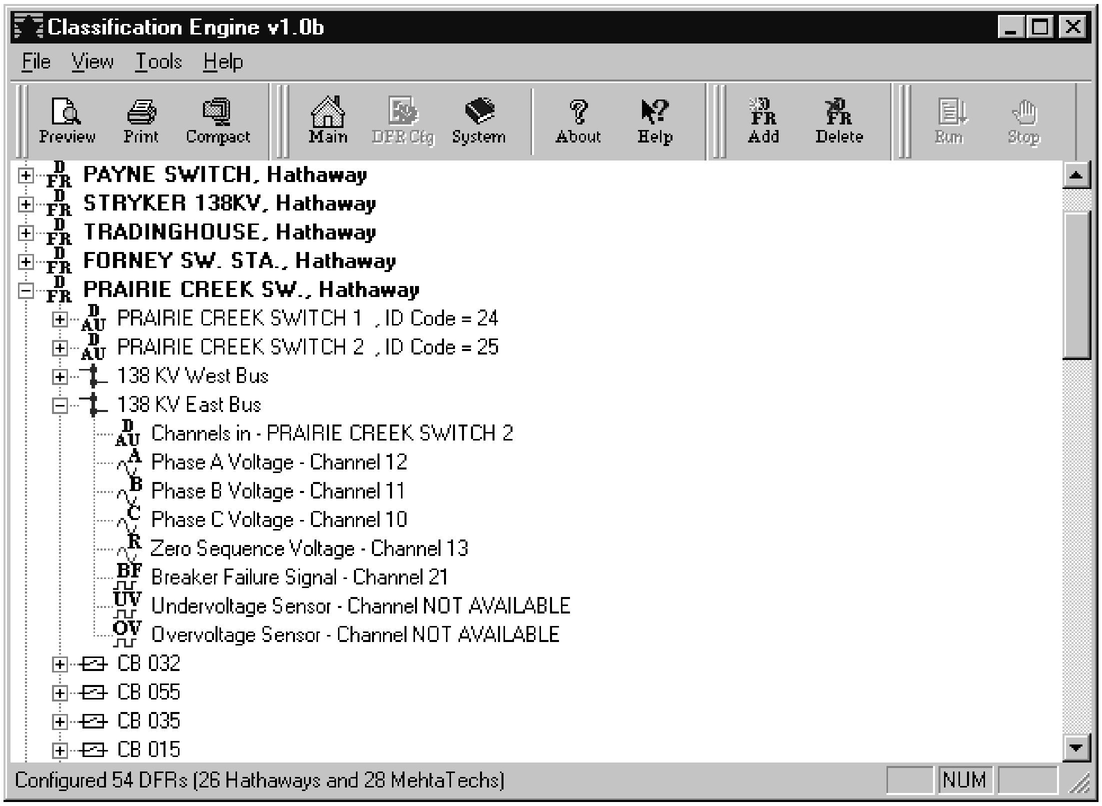


Figure 6. The Classification Engine configuration display

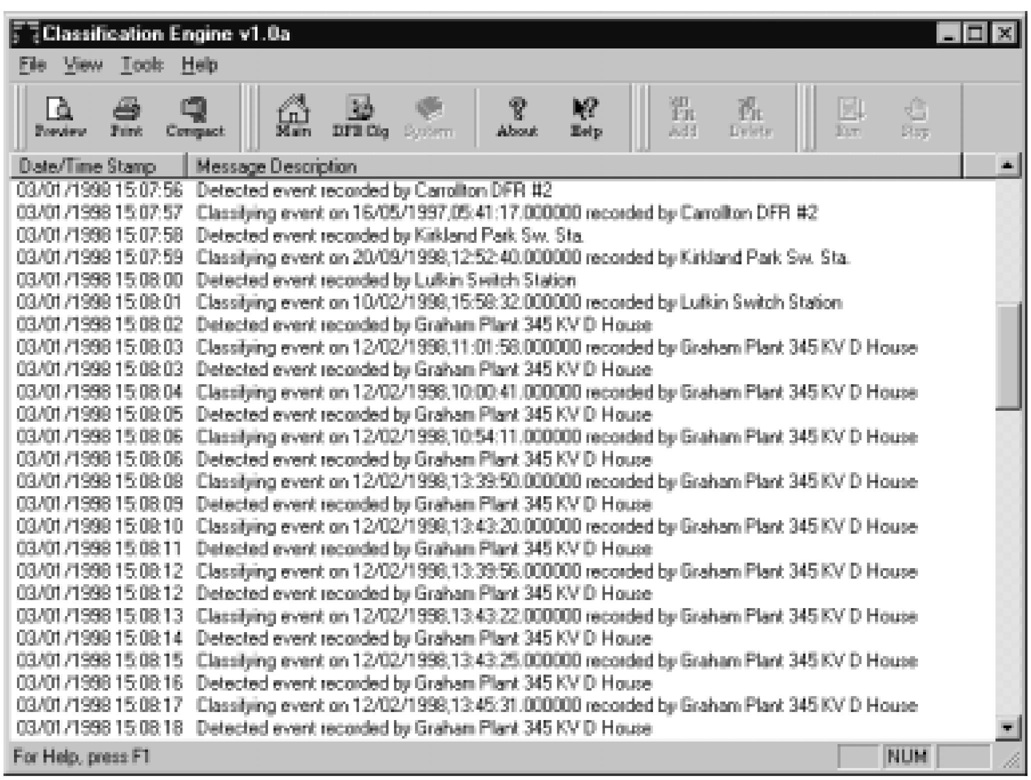


Figure 7. The Classification Engine event log

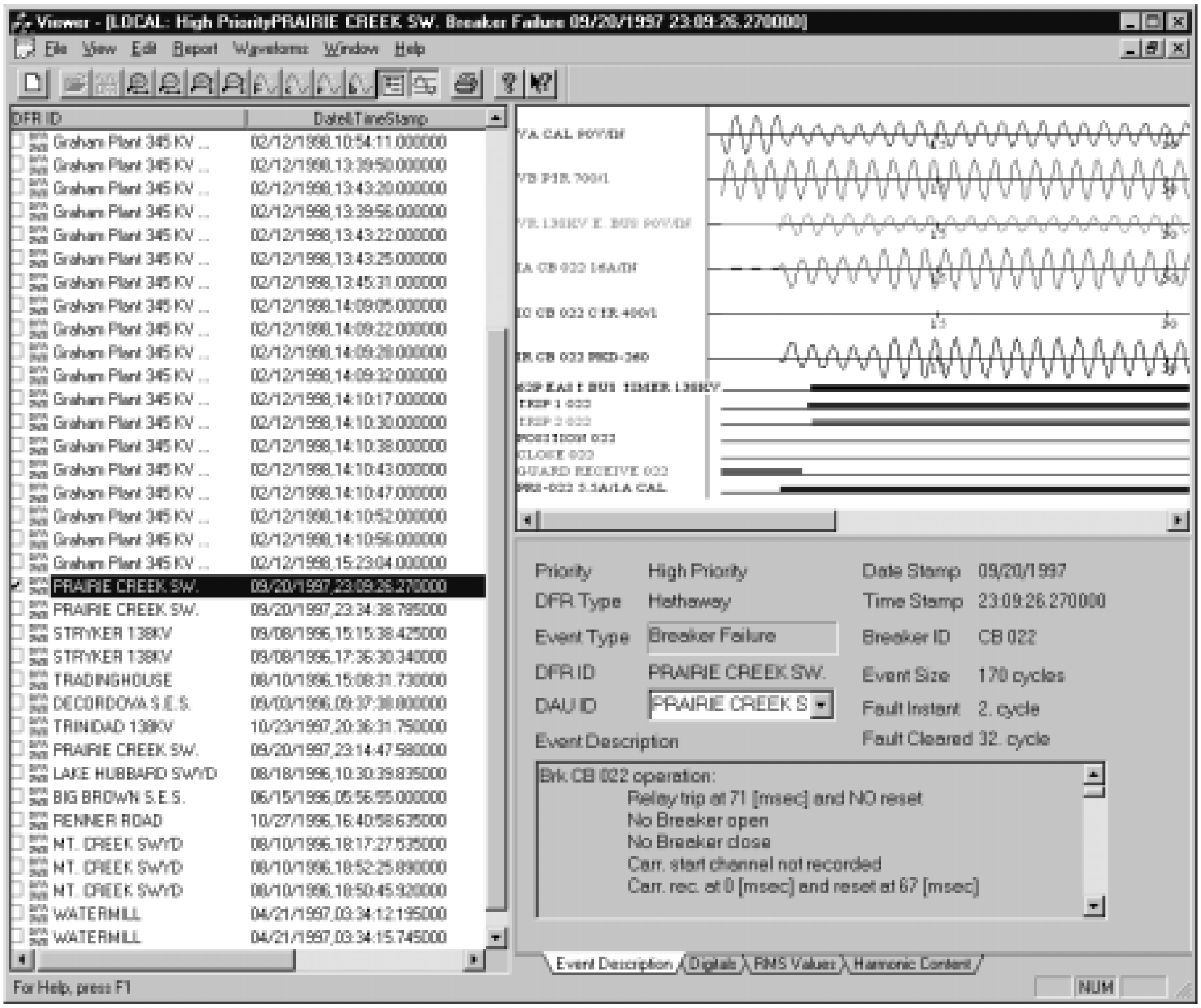
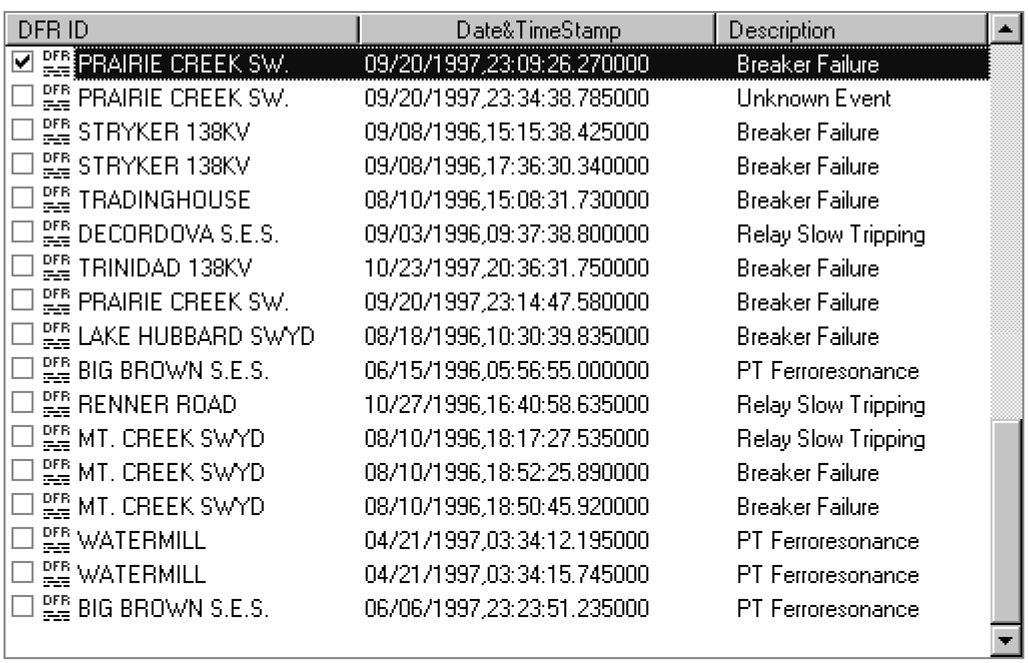


Figure 9. The Report Viewer main window



DFR ID	Date&TimeStamp	Description
PRAIRIE CREEK SW.	09/20/1997,23:09:26.270000	Breaker Failure
PRAIRIE CREEK SW.	09/20/1997,23:34:38.785000	Unknown Event
STRYKER 138KV	09/08/1996,15:15:38.425000	Breaker Failure
STRYKER 138KV	09/08/1996,17:36:30.340000	Breaker Failure
TRADINGHOUSE	08/10/1996,15:08:31.730000	Breaker Failure
DECORDOVA S.E.S.	09/03/1996,09:37:38.800000	Relay Slow Tripping
TRINIDAD 138KV	10/23/1997,20:36:31.750000	Breaker Failure
PRAIRIE CREEK SW.	09/20/1997,23:14:47.580000	Breaker Failure
LAKE HUBBARD SWYD	08/18/1996,10:30:39.835000	Breaker Failure
BIG BROWN S.E.S.	06/15/1996,05:56:55.000000	PT Ferroresonance
RENNER ROAD	10/27/1996,16:40:58.635000	Relay Slow Tripping
MT. CREEK SWYD	08/10/1996,18:17:27.535000	Relay Slow Tripping
MT. CREEK SWYD	08/10/1996,18:52:25.890000	Breaker Failure
MT. CREEK SWYD	08/10/1996,18:50:45.920000	Breaker Failure
WATERMILL	04/21/1997,03:34:12.195000	PT Ferroresonance
WATERMILL	04/21/1997,03:34:15.745000	PT Ferroresonance
BIG BROWN S.E.S.	06/06/1997,23:23:51.235000	PT Ferroresonance

Figure 10. The Report Viewer network/local directory display

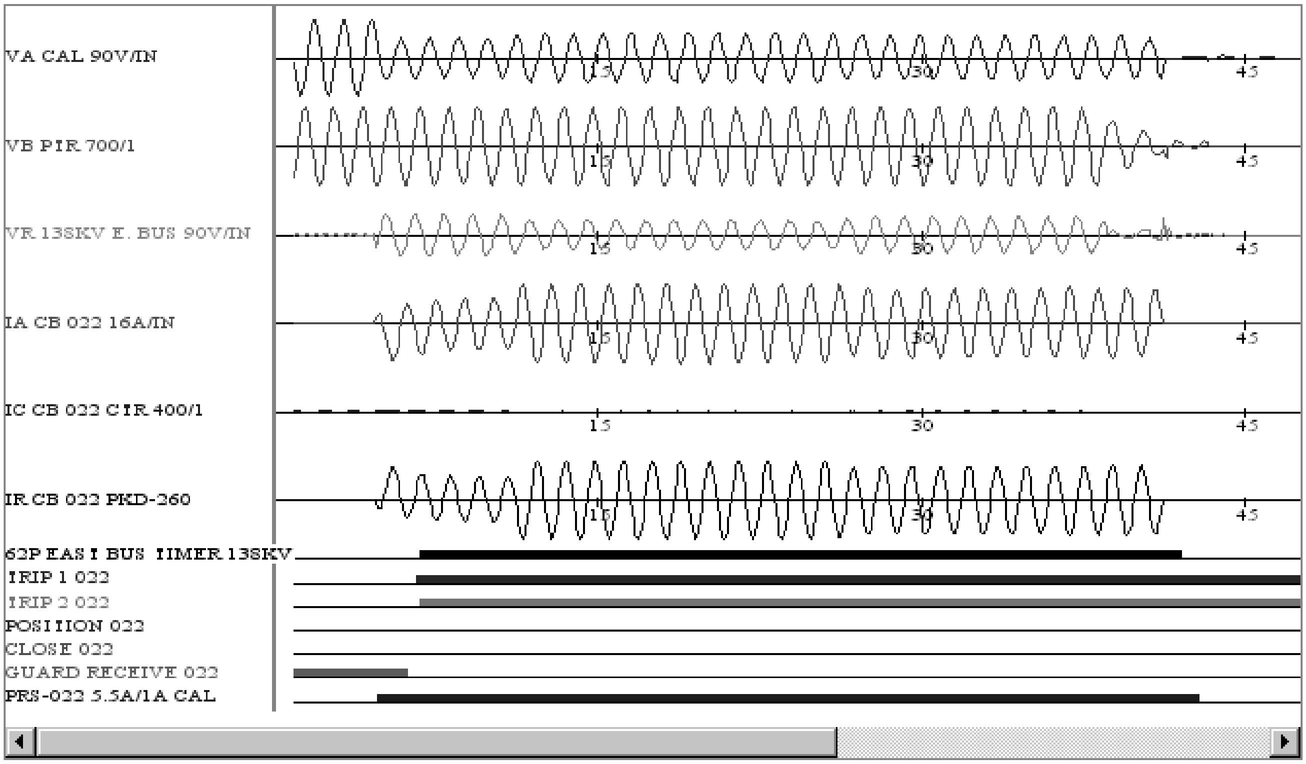


Figure 12. The Report Viewer waveform display

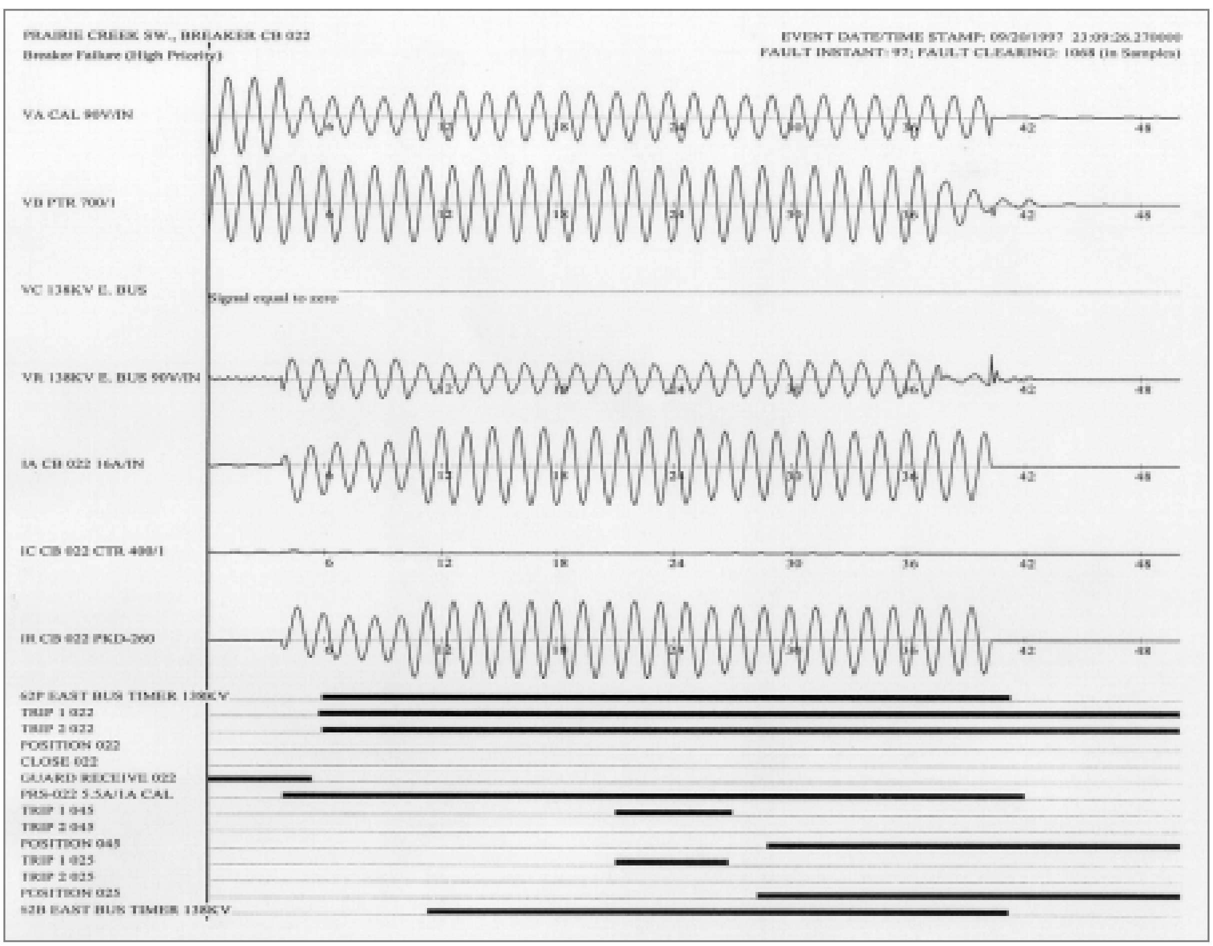


Figure 13. The paper printout generated by the Report Viewer software