REQUIREMENTS FOR AUTOMATED FAULT AND DISTURBANCE DATA ANALYSIS

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This paper gives an overview of future requirements for fault and disturbance analysis. Special attention is given to the issues of the extent of analysis, data integration, information exchange, speed of processing, database needs, dissemination of analysis results and related user interface, and support through existing and new standards. Selecting implementation options and moving towards more integrated solutions are discussed and supported with a summary of the existing relevant standards as well as the need for defining new ones. Examples of the most advanced solutions deployed by the utility companies are given as well.

Keywords: Fault, Disturbance, Digital Fault Recorder, Automated Analysis, Power Quality

1. INTRODUCTION

Fault and disturbance analysis is typically based on digital fault recorder (DFR) systems. Due to evolving needs and requirements, a given utility may acquire a variety of DFR system solutions and/or upgrades over a period of time. This paper gives an overview of requirements for a universal approach to fault and disturbance analysis where a variety of DRFs from different vendors are merged into one solution. Special attention is given to the issues of the extent of the analysis, data integration, information exchange, database needs, dissemination of analysis results and related user interfaces, and support through existing and new standards.

The extent of the analysis is the most critical issue when considering automating the analysis. What is a "reasonable" level of automating the analysis tasks taking into account the complexity of the software and cost of maintaining are discussed in a separate subsection.

Data integration and information exchange are two most important implementation issues. It is noted what are the possible recording devices that may be considered as the sources of data for the analysis as well as who may be the potential user of the results of analysis. The issues associated with integrating data coming from diverse recording devices and the possibilities of using the results by various utility groups are elaborated on.

Speed of automated processing is yet another rather important implementation requirement. It is pointed out that the speed of operation requirement depends on the final users of the results and their ability to act quickly as a consequence of receiving the results in a timely fashion.

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This requirement translates into the data processing architecture requirement deciding whether the data is processed at the substation or at the centralized location.

Organization of databases is also very important when considering the need to provide both the waveform records and results in an easy to follow display. Retrieving the historical data and making quick searches of stored data by various criteria is presented.

One of the main differences in the new requirements versus the old ones is the ability to share the recorded data and results of analysis with a number of individuals within the company using the “standard” Intranet services. The need to design the automated analysis systems to comply with the internal IT standards of the utility companies is considered a very important requirement.

Last but not least, the discussion indicates that the new requirements need to be matched by appropriate standards. A summary of the existing relevant standards as well as the need to define the new ones is elaborated in a separate section.

The final part of the paper reflects on the requirements of the most advanced solutions deployed by the utility companies co-authoring this paper.

2. REQUIREMENTS FOR AUTOMATED ANALYSIS

Automating the analysis of the fault and disturbance data is based on an idea to use an expert system based solution. Such systems should be able to process the information on signal waveforms and contact changes obtained from substations through Intelligent Electronic Devices (IEDs) such as DFRs, Sequence of Event Recorders (SERs) and Digital Relays. Since the first application of expert systems to fault analysis was reported in mid-eighties, a number of solutions have been proposed [1]-[3]. A fully integrated and automated solution is yet to come [4]. The requirements for an integrated system for automated fault and disturbance data analysis are identified and described in the following subsections.

2.1. Extent of the Analysis

The scope of the analysis has the following general goals [5]:

- Detection and classification of the fault or disturbances
- Verification of the correctness of the protection system operation
- Calculation of fault location and other important parameters (resistance, duration, etc.)

The event analysis should be triggered by an occurrence of the new DFR record. The analysis system should process each DFR file individually. For a single DFR file, the analysis is conducted for each circuit being monitored by that particular DFR.

An example of the conceptual model of the substation as seen by the system for automated analysis is shown in Fig. 1. Primary object of the analysis is a circuit (transmission line, generator, etc.). An example of a breaker-and-a-half scheme is also depicted in Fig. 1. The system must support single-breaker and ring-bus scheme as well.

To achieve the goals, the analysis should rely on two sets of signals: analog and digital. Analog signals should generally be used for fault detection, classification, and location calculation, while digital signals should be used for the analysis of the protection system operation [6]. 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. If we take line currents, for example, one should extract the measurements for the pre-, fault, and post-fault values for a particular event. One typical approach is to use phasors obtained using one-cycle DFT algorithm. To be able to analyze events on a particular circuit, all three phases of line currents (or two phases+zero seq.) should be monitored. Of course, voltage parameters should be used, too. If the voltage measurements are not available, the analysis 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.

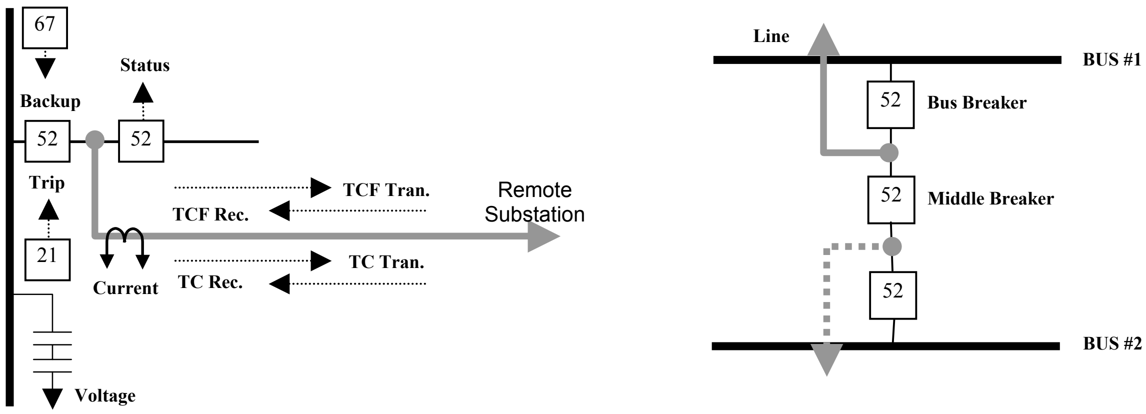

Fig. 1. An example of one line-diagram and the bus-breaker arrangement

Each substation needs to be equipped with one or more IEDs that will provide monitoring of all important signals. For analog signals, it is recommended to monitor all three phases as well as the residual for both voltages and currents. For digitals, it is recommended to monitor as many as possible of the signals related to protection circuits such as primary and backup relay trip, breaker open and close position, breaker failure, carrier start and receive contacts etc.

2.2.Data Integration and Information Exchange

Each substation needs to be equipped with at least one communication channel (e.g. telephone line with modems, Ethernet, etc.) enabling easy access to IED data. Communication has to provide an ability to query IEDs for presence of new data as well as to enable quick data transfer.

Various schemes for collecting data from IEDs may take place. Typically, there is a need for vendor's software to be running continuously and collecting event data automatically. There are two typical setup configurations: 1) auto-poll, when master station software polls IEDs and downloads new data; 2) auto-call, when IED initiates uploading of new data to master station software. An alternative option is to have third-party products for direct communication with and automated data collection from IEDs. This alternative solution may be hard to maintain because of variety of transfer protocols, native IEDs file formats etc.

All the IED data needs to be converted to COMTRADE file format according to the most recent version of the standard, prior to any further processing [7-9]. A standardized approach to file naming should take place as well [11]. This issue will be discussed in more details in the next section. Collecting event data and performing file format conversion need to be a part of the fully automated analysis that is typically triggered by the occurrence of new incoming IED data.

Integrated system needs to be compatible with the PC configuration running Windows operating system and capable of using available communication and network protocols as well as web technologies for intensive data exchange.

2.3. Organization of Databases

It is recommended to provide a centralized database system. The database system should contain two main types of information: 1) system components information; 2) event data and analysis reports.

System should support handling descriptions and important information on system components being monitored. Examples of such parameters are: transmission line and circuit breaker names, line length, line impedances, relation between signals and objects, etc.

The IED data (once converted to COMTRADE), together with the analysis reports and additional available information, should be automatically stored into a centralized database. The database should allow an easy access and retrieval as well as advanced features for searching. Besides, “live” data such as IED recordings and analysis reports, the database has to contain the system configuration data used to describe various components.

2.4.Dissemination of Analysis Results

System needs to provide the means for automated dissemination of both DFR data and relevant additional information such as analysis reports, component parameters etc. System should provide automated file copying over corporate Intranet for the archival purposes as well as sending notifications and reports using emailing, faxing, paging and/or printing services.

2.5. User Interfaces

System needs to provide tools for searching, accessing, and viewing DFR data, analysis reports as well as the system configuration data. All the user interface tools need to be universal and enable viewing the information in the same way regardless of the origin and type.

The implementation of user interfaces should gradually be moved towards use of modern web technologies. Users should be able to navigate through the event tables and specify search criteria in order to quickly locate events of interest. User interfaces, implemented as web applications, should also provide means for detailed inspection of the waveforms and analysis reports.

In addition to DFR data and analysis reports, user interface should provide the means for accessing and configuring the system component information (parameters describing transmission lines, circuit breakers etc.).

Besides the obvious benefits of accessing the database using web application through the corporate Intranet, there is a benefit of easier maintenance. The web application, typically stored only on the server computer and users’ workstations, does not require installation of any software except the web browser that is typically a part of the operating stem.

2.6. Implementation Options

A system for automated analysis must provide options to be configured in several different ways to match various system requirements and to serve the various needs of different users. For example, system should be able to support different protection schemes. An implementation of the system should use modular approach to enable different configuration options. Examples of systems deployed in the utilities are illustrated in the following section.

3. APPLICATION EXAMPLES

In this section, examples of the advanced solutions recently deployed by the utility companies co-authoring this paper are described. The presented examples cover three main types of the implementation options: autonomous, centralized, and distributed.

The solution is based on the suite of software applications that feature client/server platform [5]. The architecture of the client and server modules is depicted in Fig. 2.

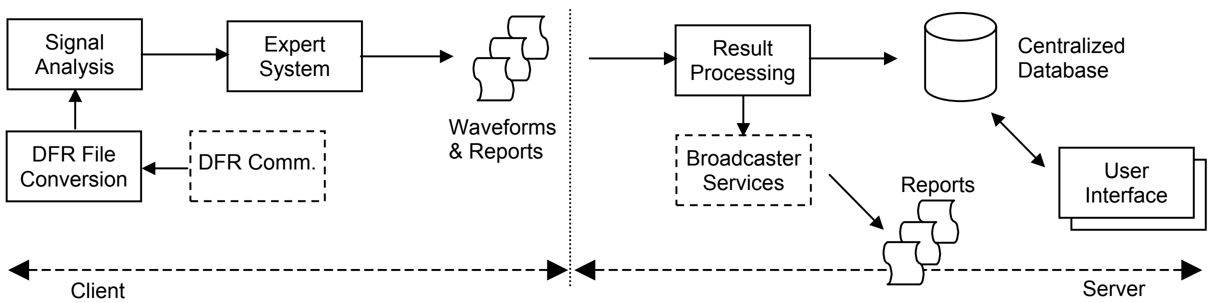

Fig. 2. Client/server architecture of the software for automated analysis

Both client and server applications can be configured in several ways in order to better accommodate the specific system requirements. The client performs file format conversion, signal processing and expert system analysis, and delivers waveforms and reports to the server. The server processes all the incoming client data, broadcasts the reports and notifications, and finally hosts the web application for interfacing to data and reports stored in database.

The following building blocks used for describing the application:

- File format filters – modules for converting native disturbance and event data into COMTRADE file format.
- Signal Analysis – module for signal processing and extraction of all the parameters needed for the analysis.
- Expert System – module for analysis, classification, and fault location calculation.
- DFR Communication – module for direct interfacing to DFRs (without master station)
- Broadcaster – modules that provides services for dissemination of both event data and analysis reports (fax, email, print, pager, web).
- Database – centralized database and file repository for archival of event data, analysis reports, system configuration.
- System Analysis – module for more elaborate substation and system-wide analysis.
- GUI – set of user interface applications.
- Web server – centralized web-based application for Intranet access to event data and reports.

3.1. Autonomous System – CenterPoint Energy

An automated fault and disturbance data analysis system, configured as autonomous (substation based) system has been installed at CenterPoint Energy's South Texas Project (STP) switchyard for several years. The heart of the system was DFR file analysis software capable of analyzing events recorded by the local DFR and faxing event reports to various users [6]. The configuration is shown in Fig. 3.

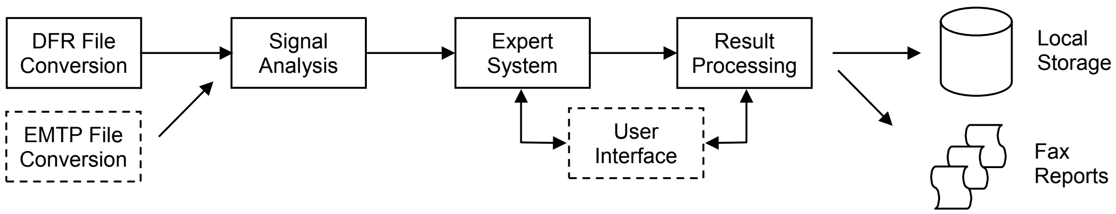

Fig. 3. The "old" system as it was installed in STP switchyard

In the light of the positive experience, CenterPoint Energy has decided to deploy an integrated LAN based system solution for automated analysis of events coming from all installed DFRs. This solution has evolved into a client application as described next.

3.2. Centralized System – CenterPoint Energy

A more complex solution that includes most of the implementation issues described in the requirements section is implemented in this case. In the centralized system, as installed at CenterPoint Energy, both client and server are installed on a single Windows 2000 server computer in the central office. There are around 30 Rochester DFRs (~20 TR 1620 and ~10 TR100/2000 units) and two master station computers. First one polls the TR1620 DFRs and downloads new event records automatically. The second one receives calls and uploads from TR100/2000 DFRs, which are configured for auto-call. All the DFR data files are automatically transferred to the server computer that hosts the analysis software.

3.3.Distributed System – Entergy Services

Entergy Services deployed a distributed system configuration. It features acquiring event data from more than a hundred DFRs made by several vendors: Rochester, Hathaway, Mehta-Tech, E-MAX. The installation is also based on the client/server architecture described in the previous example. However, this installation covers six regional centers and each regional center has its own client installation. Master stations software of each vendor takes care of collecting event data and delivers the event files in native DFR file format to the corresponding client. The data and reports from each client are then sent to the server in the centralized office via corporate network.

4. FURTHER INTEGRATION

In this section, a summary of the existing relevant standards and the need for defining the new ones is discussed.

4.1. COMTRADE file format

The introduction of the COMTRADE file format was the first big move towards the integration in the field of DFR systems [7]. The new file format is gradually being accepted by DFR vendors, which opens a door for easier data integration. Most of the vendors are still keeping their own native DFR file formats or developing new ones and just providing additional utility programs or commands for exporting data in COMTRADE file format. Unfortunately, this export-to-COMTRADE feature, in most cases, is not configurable for automated operation. Also, the COMTRADE format specification allows freedom, to some extent, on how to provide information inside the files. This leads to situations where different software packages supporting COMTRADE file format cannot exchange data among themselves due to the lack of standardized descriptions of the files and signals inside. In addition to the original COMTRADE standard specification [7], there are the latest IEEE revision [8] and IEC version [9]. Having three versions currently being widely accepted and used increases a possibility not to be able to exchange DFR data among different types of software packages due to incompatibilities among different versions.

4.2. IEEE File Naming Convention

One step further towards more integrated solutions was the introduction of the standardized IEEE file naming convention for the time sequence data [10]. The proposed convention defines coded schema for naming the data files. Such file names can enable easier handling of large volume of files as well as unique file identification since the file name should contain unique information about the event: date, time, station, company, duration, location, etc. The naming convention anticipates using only two digits for the year in the date info, but that is most likely going to be improved to using four digits. Benefits of using this standardized file-naming schema should encourage vendors of DFR and other IEDs provide the support, which is not a common feature today.

4.3. Communication Protocols

There is still a lack of a standardized approach to communication protocols. First, the standard communication channels for DFR systems (examples are RS-232, RS-422/485, Ethernet, etc) need to be utilized. Then formats for data exchange over the communication channels need to be defined as well. Having a standardized communication protocols would allow much easier integration of DFR systems and enable interchangeability of one type of DFRs with another. Future DFR systems may utilize standards like the one recently proposed by IEC for substation automation [11]. Unfortunately, at present, we may still be far from that possibility.

4.4. System Objects Description

There is an obvious need for establishing a convention for providing information on parameters that describe system objects (signals and associated equipment) monitored by DFRs. The COMTRADE standard allows entering some basic information on system objects inside the .CFG or .INF files, but to enable automated processing and analysis of the DFR records, there should be a standardized way of describing monitored system objects. The IEC substation automation standard and IEEE file naming convention do not address this issue either.

5. CONCLUSIONS

The paper outlines implementation requirements for an automated fault and disturbance data analysis. The main topics related to the requirements are the extent of analysis, data integration and information exchange, database needs, dissemination of analysis results and related user interfaces. Flexibility in implementation options is a very important requirement, too. Different configurations of the most advanced solutions deployed by the utility companies co-authoring this paper are described.

The existence of relevant standards related to IEDs file formats and file naming as well as the use of LAN connections allow moving towards more integrated solutions. However, implementation of the existing standards is still not a common practice. At the same time, there is a lack of the standardized approach to communicating data as well as describing the parameters for system components. Ideally, any information system dealing with DFR system files should be able to communicate, read and interpret, and analyze DFR data in the same manner regardless of the DFR type.

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