Advanced System Solutions for Automated Fault Analysis Using DFR Files

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Abstract - This paper describes possible approaches in implementing a system solution to automate analysis of the fault events that may be recorded by several DFRs. One approach involves automated analysis at a substation level, where DFR records are processed locally and then transferred to central location for further analysis. The other approach involves centralized analysis where all DFR recordings are grouped at a single location and then processed.

Keywords: Automated fault disturbance analysis, digital fault recorders, protective relays, rule-based systems, neural nets

I. Introduction

Digital fault recorders (DFRs) are extensively used by some utilities to record voltages, currents and equipment contacts during power system faults. Typically, the disturbance causes DFRs to trigger collecting several cycles of sampled waveform data together with related contact status. The sampled data is stored locally in the recorder until it is either automatically downloaded or manually transferred to a central location. This data transfer is controlled through the Master Station (MS) software located on a PC at the central location. Once the data is made available at the central location, protection engineers are analyzing this data in order to characterize the fault event and assess operation of the protection system.

One of the main goals of the new software developments is to automate the analysis process so that the overall analysis time is reduced. This paper describes possible approaches in implementing a system solution to automate analysis of the fault events that may be recorded by several DFRs.

The paper starts with a description of an existing software solution that automates the analysis at the substation level. The next section describes possible system solutions. The analysis logic that can be implemented in the system solutions is summarized at the end. Some future developments for further improvements of the analysis logic are discussed at the end.

II. Substation Based Solution

Houston Lighting & Power company contracted Texas A&M University several years ago to develop a system for automated analysis of DFR recording for one of their substations. The development has been completed and system commissioned in 1995. This section summarizes the system configuration and main features [1].

Figure 1 shows the main hardware items and data flow. Local computer interrogates DFR, at pre-specified time intervals, looking for a new recording. The communication between DFR and PC is done via high speed GPIB link that enables transferring of complete records within 20 seconds time intervals. Once the record is archived at local PC, the analysis takes place. Depending on the record size, the analysis is completed in 40 to 60 seconds. After completion of the analysis, the fax message is created and sent to several locations within the company. System dispatcher receives the first fax within 2 minutes after event has been transferred to the PC.

The system, once installed and configured, is completely automated; no operator intervention is needed. This system has "system alive" function that reports its operating status in prescribed time intervals, usually once a day, by faxing a message to corporate office.

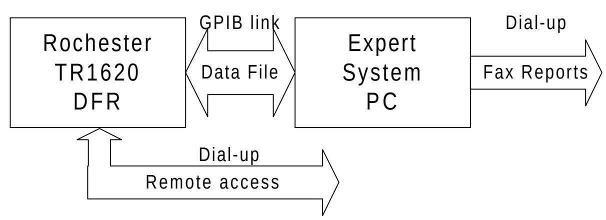

Figure 1. Analysis system configuration in a substation

The system's software consists of several modules. These modules include programs for:

- communication with DFR
- event file archiving
- signal processing of analog and digital channels recorded by DFR
- rule base expert system for analysis and event classification
- faxing analysis reports to remote sites

An example of a typical analysis report that is being faxed is given in Table I. First section of the report presents general information about recorded event. The second and third sections contain information about fault type, transmission line involved and estimated fault location. The next section presents overview of protection system operation with operating times for relays and circuit breakers. The last section shows values for analog waveforms of a faulted transmission line before, during and after disturbance.

During the initial period of field testing, system was calibrated and adjusted to the specific system conditions at selected substation. Since the analysis software includes full blown expert system shell, the addition of new rules to cover changing power system conditions was easy.

TABLE 1.

Analysis system configuration in a substation

EXPERT SYSTEM STATION REPORT

Date\Time Stamp of Event: 04/04/95, 12:44:44.938
Event number: 017 Sample rate: 5.99 [kHz]
Machine name: S.T.P. Serial number: 20299
Number of pretrigger samples: 1198 (12.0 cycles)
Total number of samples: 2926 (29.3 cycles)
Size of the event in tracks: 10 (320Kb)

EVENT DESCRIPTION

D. Velasco Ckt #27 is the circuit with largest current disturbance.
The disturbance is a **phase B to ground** fault.
The fault is cleared by the protection system at this substation.

FAULT LOCATION

Fault is located **21.54** miles from this substation.

PROTECTION SYSTEM OPERATION ANALYSIS

Backup relay operation starts at **0.0337 sec [2.0202 cycles]** and ends at **0.0487 sec [2.9202 cycles]**.
The middle 52B contacts operate at **0.0605 sec. [3.63 cycles]**.
The bus 52B contacts operate at **0.0537 sec. [3.2202 cycles]**.
The bus breaker status change after trip is applied is **1.2 [cyc]**.
The middle breaker status change after trip is applied is **1.6 [cyc]**.

LINE CURRENTS AND VOLTAGES

	Prefault	Fault	Postfault	
I0	0.0087	**24.19**	0.001	[kA]
Ia	0.2076	0.801	0.000	[kA]
Ib	0.1868	**22.83**	0.000	[kA]
Ic	0.1672	0.272	0.004	[kA]
V0	0.0008	**0.086**	0.001	[kV]
Va	283.70	272.6	282.2	[kV]
Vb	283.90	**106.4**	282.8	[kV]
Vc	284.70	272.7	283.6	[kV]
Vab	491.20	**327.6**	488.8	[kV]
Vbc	493.10	**342.6**	491.5	[kV]
Vca	492.05	483.5	489.4	[kV]

All above values are peak values.

So far, the analysis system proved to be stable and reliable. The number of analyzed records exceeds 300. In most of the cases system provided accurate analysis for a given event. For the cases not analyzed correctly, changes in the system's knowledge base and/or thresholds were made.

Test Laboratories International Inc. obtained license rights for the software from Texas A&M University with intention to further enhance and commercialize existing technology. Some of the new ideas and developments in this area are presented in the following sections [2].

III. Approaches to Advanced System Solutions for Automated Fault Analysis

The following list outlines main requirements of an automated system for analysis of DFR recordings:

- ***DFR file analysis logic at a system level.***

It correlates data files from all DFRs triggered by the same event. The analysis steps include disturbance detection, identification of the transmission line(s) involved, fault type classification, calculation of fault location as well as analysis of operation of protection relays and associated circuit breakers.

- ***Central database for archiving of analysis results.***

The analysis results are stored at a central database and made readily available to different users over the LAN and via Internet.

- ***Automatic notification via E-mail and faxes.***

The analysis results are E-mailed or faxed automatically to all specified recipients.

The above mentioned requirements can be met in two different ways. One way is to download events to a central location and then analyze them. The other way is to process events locally at substations and then communicate results of the analysis to the central location for further processing.

The benefit of the first solution is lower cost of hardware (one PC is needed at a central location for analysis purposes, but no PCs at substations are required). The shortcoming of this solution is the time delay associated with slow data transfer over a modem dial-up line, which effectively makes the analysis results provided by this system delayed. This may mean that the analysis results are generated with too much of a delay to be useful for on-line action by the system dispatcher.

The benefits of the second solution are high speed local event analysis and reduced data communication between DFR and a central location. This solution will provide system dispatcher with event analysis minutes after the event was recorded. The shortcoming is higher cost of hardware (i.e., PC at each substation is needed).

Two different system implementation options can be identified as follows:

- DFR data files downloaded and analyzed at a central location
- DFR data files first analyzed locally at substation and then results transferred to central location for further processing

A. Centralized Analysis

Figure 2 shows possible hardware configuration consisting of three PCs. DFR Master Station PC communicates with the DFRs in the field over one or more dial-up lines. Transferred DFR event files are automatically archived on a separate PC (DFR Events Archive) over corporate LAN.

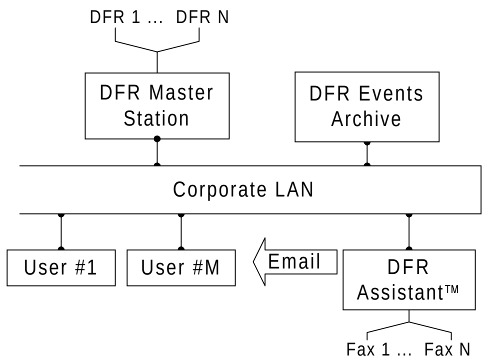

Figure 2. Possible configuration with centralized analysis

The third PC (DFR Assistant™) accesses event files from the server, processes them and returns the results of analysis back to the common database residing on the server. In addition, DFR Assistant sends out Email and fax notifications to specified recipients.

B. Substation Level Analysis

Figure 3 shows system block diagram for this approach. This solution requires a local PC connected to DFR at each substation. Typically a low cost PC configuration (<$1,500) can be used for this purpose. These local PCs retrieve and process DFR data files almost immediately after they are recorded. The event analysis is based on the data available at local substation and analysis reports are available in less than a minute. Analysis reports are, then, communicated to the PC residing at a central location (DFR Assistant™) for further processing. This processing includes correlating the analysis reports coming from various substations and generating a summary report for a given event.

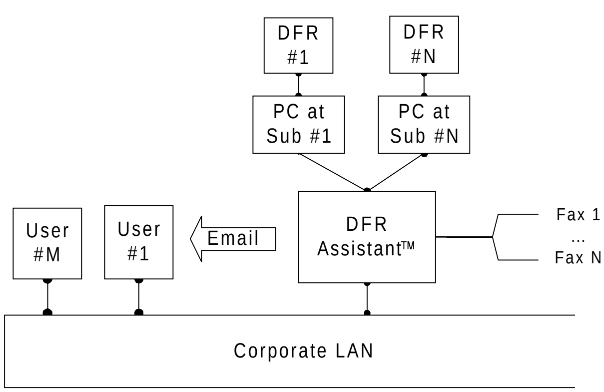

Figure 3. Possible configuration with substation level analysis

IV. The Analysis Logic and System Set-up

The task of the analysis logic in each of before mentioned configurations is to answer the following questions:

- Which DFR has triggered and recorded waveforms for a particular power system disturbance?
- What was the disturbance and what lines were affected?
- Where is the fault located (in the case disturbance is a fault)?
- Did protection system operate correctly?

The analysis logic for classification of DFR recordings in all of before mentioned cases consists of the following steps:

- identification of the faulted transmission line
- identification of all records pertaining to the same event
- correlation and analysis of all records identified in the previous step

The event detection and classification analysis is based on several algorithms that take into consideration both analog signals and digital contacts. The analog waveforms are divided into three sections. One section corresponds to prefault, one to fault and one to postfault conditions. Similarly the status change of digital channels is extracted from the record and correlated to the calculated fault inception time.

The following types of input signals are used by the analysis system:

- Phase currents (A, B, C, 0)
- Bus or line voltages (A, B, C, 0)
- Relay trip contacts
- Breaker open/close position
- Pilot channels (send, receive, stop)

Figure 4 shows top level window of DFR Assistant™ [2]. Left hand side presents information about configured DFRs, their connections (e.g., buses, transmission lines), while right hand side lists DFR recordings that are transferred from the remote substations. User can easily access database of processed events by clicking on the toolbar buttons (denoted by H, M, L). Clicking on any of these buttons brings contents of either high, medium or low priority directories. The filtering logic for storing analysis reports into these three directories is based on the following criteria:

- **High Priority**
  - fault confirmed; relay did not operate (failure)
  - no-fault confirmed; relay operated (misoperation)
  - fault confirmed; breaker restrike occurred
  - relay trips and breaker does not open
  - relay trips and breaker opens slowly
  - relay trips and carrier signaling incorrect
  - ferro-resonance condition occurs
  - unable to classify DFR record
- **Medium Priority**
  - fault confirmed and backup relay trips instead of primary relay
  - relay trips but relay pick-up time slow
- **Low Priority**
  - correct fault clearance by the protection equipment
  - DFR manual triggering

Figure 5 shows the window used for analysis report's viewing. This window displays the same type of information as given in Table 1 using different format.

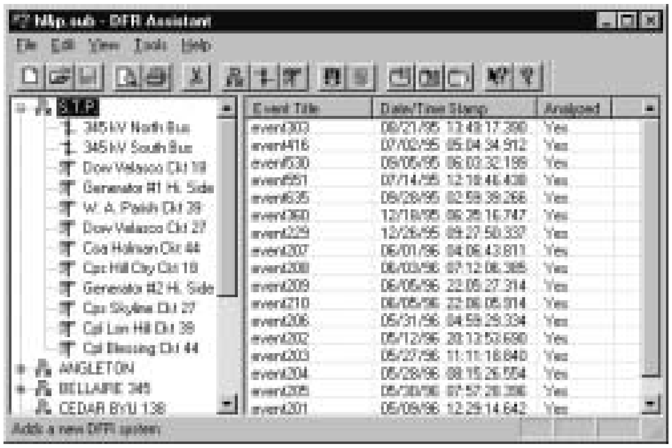

Figure 4. DFR Assistant's top level window

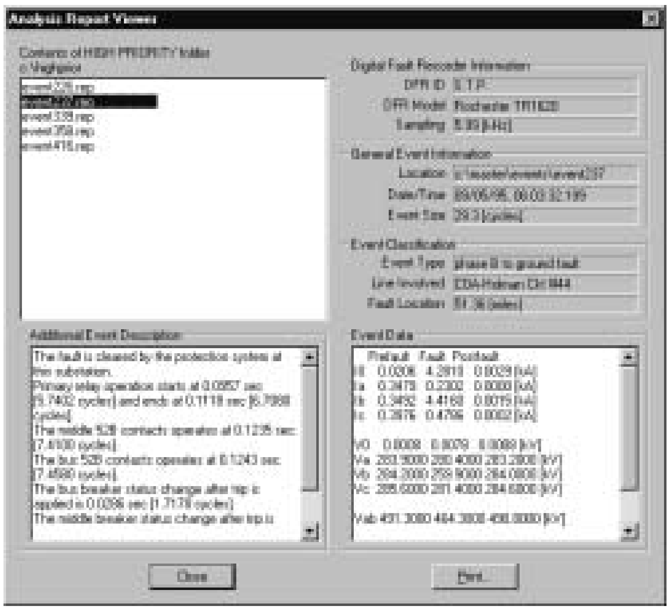

Figure 5. DFR Assistant's analysis report view

V. Further Developments

This section briefly describes some of the work presently being done on the enhancements to the existing software for automated analysis.

A. Fault Detection and Classification

As described in previous sections, the knowledge base implemented in the automated analysis system performs the following steps in order to process each data file:

- fault detection and classification,
- determining expected protection system operation,
- extracting actual operation of the protection system,
- comparing expected and actual protection system operation,
- assessing protection system performance based on the results of the comparison.

It has been noticed that, potentially it may be difficult to select generalized settings of such a system. Namely, as in every rule-based system, certain thresholds (i.e., the knowledge) have to be specified in the rules. These thresholds are used to determine the relationship between the analog values (e.g., the phase currents and voltages) for different events or faults that can happen in the transmission system. The problem arises because of the dynamics present in a power system. The load and generation are constantly changing, as well as the transmission grid configuration. Fine tuning the thresholds in the rules may be needed as the system conditions dramatically change.

Also, the conventional rule-based analysis systems may be too slow to be applied in real-time environments since under certain conditions they require time-consuming process of rule- and knowledge-base search. The size of the rule- and knowledge-base is a limiting factor for these systems. The speed of diagnosis is inversely proportional to the rule-base size, because the inference process is sequential in nature (i.e., rule-based system sequentially searches for the solution by pattern matching to the hypothesis).

Due to the mentioned potential limitations of the rule-based system solution, a study of the neural net application to fault detection and classification was initiated [3, 4].

Enhancements to the expert systems can be achieved by using the neural networks [5, 6]. Neural nets have strong generalization capabilities, and an easy way to automatically improve its performance by additional learning (often, without a need for a human intervention). Also, since the neural nets are parallel in nature, they can be used for real-time processing. Figure 6 (representing existing rule-based system) and Figure 7 (representing combination of neural net and rule-based system) show how the two solutions differ from one another.

Figure 7 shows a hybrid system that contains neural nets for disturbance detection and classification, and rule-based analysis system for evaluation of the protection system performance. A separate neural net is trained for every transmission line in the substation. An automated training can be implemented using advanced digital simulator software [7]. Trained net is, then, used for fast disturbance detection and classification [4]. The results of this classification are used together with the digital contacts data (e.g., relays, communication channels, breakers, etc.) in the expert system part to assess the performance of the substation protection system.

This system can be used in two different modes of operation:

- event processing based on a data "snapshot",
- event processing based on a "continuous" data flow.

The first mode of operation is a conventional approach, where digital fault recorder, based on its internal triggers, records the event. The event is then transferred to the neural net/expert system for automatic processing.

The second mode of operation assumes continuous data flow from digital fault recorder (or, any other data acquisition device). In this case, the neural network "triggers" the analysis based on its detection capabilities.

B. System Wide Analysis

Other enhancements to the existing automated analysis system are currently under way in the area of system wide analysis. A development effort is under way to implement an analysis approach where the overall power system condition after occurrence of a fault is assessed to determine if the system stability is maintained and what are the possible restoration actions that may be required.

The other effort is aimed at developing an analysis system capable of utilizing data coming to the central location not only from DFRs but also from sequence of events recorders (SERs), advanced microprocessor based relays and other digital equipment installed in the field. This approach would enable comprehensive analysis of a given event (fault) in the system providing detailed description in very short period of time after disturbance. This would also help system dispatchers to make reliable decision regarding system restoration, and give protection engineers powerful tools to better assess condition and maintain protective relaying system.

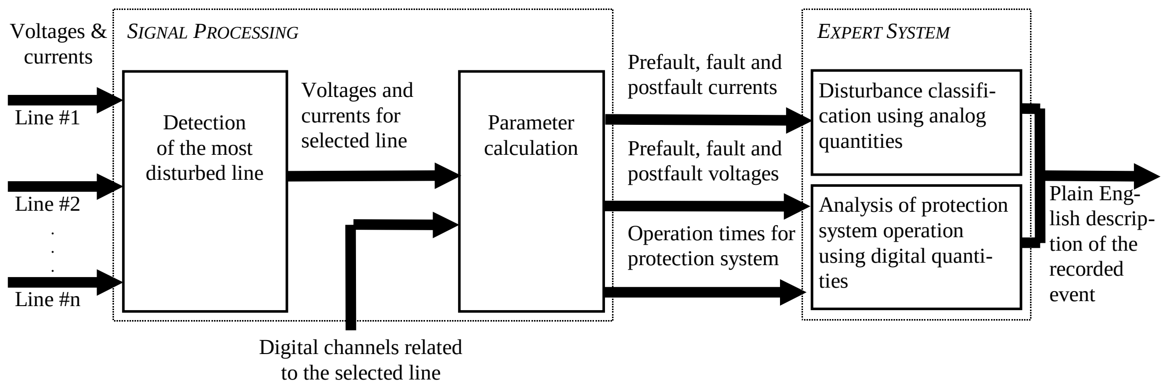

Figure 6. Data flow diagram of the rule-based analysis system

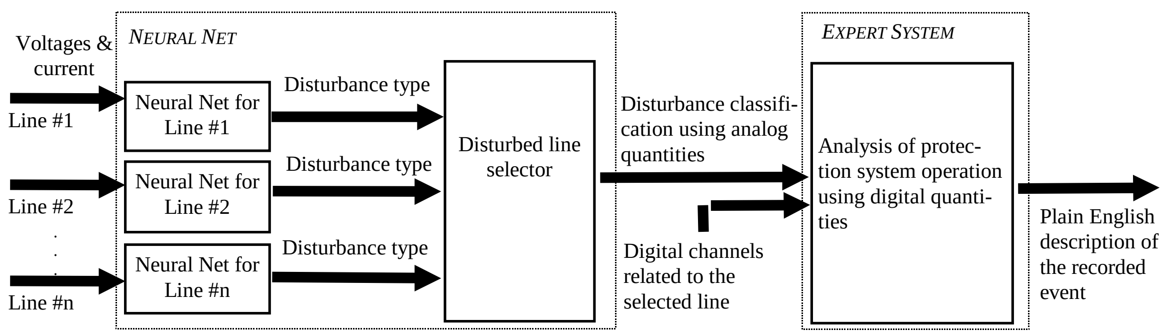

Figure 7. Combined neural net and rule-based analysis system

VI. Conclusions

Development efforts reported in this paper indicate that:

- Automated analysis of DFR records is feasible and cost effective solutions are commercially available.
- Several system solutions for the automated analysis are possible and the final choice depends on the intended uses of the analysis results.
- Future automated analysis enhancements using neural nets are quite promising but do require tools for neural net training.
- Future directions in the system wide analysis include automated correlation of the substation analysis results as well as addition of the results obtained by performing automated analysis of the data coming from SERs, protective relays and other digital equipment.

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