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ADVANCED ENGINEERING TOOLS FOR EVALUATING RELAY PERFORMANCE AND TUNING RELAY SETTINGS

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Abstract: The needs for having advanced engineering tools when assessing the relay performance and tuning relay settings are addressed. It is pointed out that determining relay settings is a well-defined routine in most of the utilities. The approach may have to be re-examined in two specific situations: when the existing relays missoperate or when new relays are about to be purchased. In both instances, but for different reason, the relay settings may have to be re-evaluated and/or further tuned. Carrying out the mentioned tasks may require advanced engineering tools for facilitating the analysis and selecting the settings. An example of such tools and their use is discussed in this paper.

Keywords: Relay settings, digital simulators, electromagnetic transients, type tests, application tests

1. INTRODUCTION

The traditional approach in determining relay settings is well defined and supported by the existing engineering tools such as short circuit programs and relay setting coordination programs (1, 2). The approach is based on the knowledge about the relay setting options (described in the relay manuals) and assumptions about the worst case faults (obtained from a short circuit study). Such a practice may be adequate if there are no major problems with relay missoperations, or if there are no new purchases of relays. If either of the mentioned situations occurs, a different approach in selecting the settings may be required and new engineering tools may be needed.

Relay missioperations do occur and may be caused by a number of reasons (3). Relay engineers are responsible for setting and applying the relays, and hence their responsibility extends to the tasks of making sure that the relays do not missoperate, and if they do, that the causes are determined and the practice is corrected. For this purpose, the traditional approach is to have digital fault recorders (DFRs) that capture information about analog waveforms (currents and voltages), relay trip signals, circuit breaker status indications, relay communication channel signals, etc (4). This data is analyzed and conclusions about relay operations are reached. If the relay missoperations are detected and attributed to inadequate relay settings, than a way of using the recorded data in solving the problem needs to be defined.

Purchases of new relays are a very common situation since a number of utilities are trying to update their relays from the electromechanical to microprocessor-based variety. In doing so, the utilities are faced with quite a versatile set of options for selecting the relay settings. The question of the need for all the options and the selection of the most appropriate ones needs to be answered. If the practice of using the settings in the traditional way is not sufficient, or needs to be updated, than appropriate engineering tools may have to be used to achieve this (5).

This paper starts with a discussion of the needs for new approaches in selecting and verifying relay settings. The software tools aimed at automated analysis of recorded events and their replaying with a purpose of evaluating the relay responses with adjusted settings are presented. The tools for simulating actual fault transients to perform elaborate relay testing, and subsequently, tuning the relay settings, are described.

2. EVALUATING RELAY SETTINGS USING TRANSIENTS

Relay settings are determined based on a short circuit study, which allows computation of the worst case phasors of voltage and current representing various types of fault. In addition, required parameters for the power system components are computed and used in determining the settings. Once the settings are determined, they are entered into the relays and the relays are applied to the locations and power system configurations assumed when the settings were computed. The final outcome is that the settings are determined for the worst case scenarios, and the transient behavior of the fault signals is approximated using phasor representation. This approach has worked rather well in most situations in the past. Occasionally, the relays missoperate and the reason may be that the settings were not determined correctly or were not tuned appropriately.

Two applications deserve special attention: the transients cause relays to missoperate due to incorrect selection of the relay operating characteristic, or incorrect determination of relay settings; a selection of relay setting options in advanced microprocessor-based relays needs to be performed, and those options were not used earlier for the existing application. Both situations require careful analysis of relay applications to better understand what are the best choices for types of settings and their values. To perform such an analysis, one has to have access to advanced engineering tools that will assist with performing an elaborate task of evaluating relay performance under transients.

Relay missoperation can be troubleshooted by replying recorded waveforms into the relay. This process may be repeated several times while changing the settings or even the operating characteristics. By such a process, one can perform a sensitivity study that indicates if the relay operation is susceptible to the changes in settings and/or operating characteristics. As a result, an optimal choice of settings for a selected relay operating characteristic may be determined. To carry out the mentioned activities, one has to be able to do the following tasks efficiently: analyzing each relay operation to locate the troublesome cases; replaying the waveforms that have caused relay to missoperate and assessing the performance under changing application constraints (settings and/or operating characteristics).

Selection of settings for newly purchased relays tends to be involved if the new relays have more versatile relay setting options than what is available in the relays already in service. In that case one has to decide if the provided types of settings are applicable, and if so, what should be the actual values for those settings. To accomplish this evaluation task, one may have to experiment with relay transients produced for some specific fault cases that may be found in the system of interest. This experimentation may require an ability to generate a large number of fault and no-fault cases resembling closely the actual events that may occur in the network. One way of doing this is by using and advanced electromagnetic transient program (6) as well as state of the art relay test systems capable of reproducing simulated waveforms (7).

The next two sections are devoted to discussion of the engineering tools that may be very useful when evaluating relays and tuning the settings for the mentioned situations.

3. PERFORMING AUTOMATED FAULT ANALYSIS

The tools for performing automated fault analysis offer an automated analysis and archival of fault recordings with integrated fault location calculation. The main benefits of the solution are:

- Reduces time spent on handling and analyzing of DFR records.
- Integrates archival and viewing of DFR data from different types of DFRs.
- Disseminates recorded data and results of the analysis over your corporate Intranet.

3.1. Design

An example of the system for automated fault analysis is a distributed system using client/server paradigm. The main elements of this system, called DFR Assistant, are indicated in Fig 1 (8).

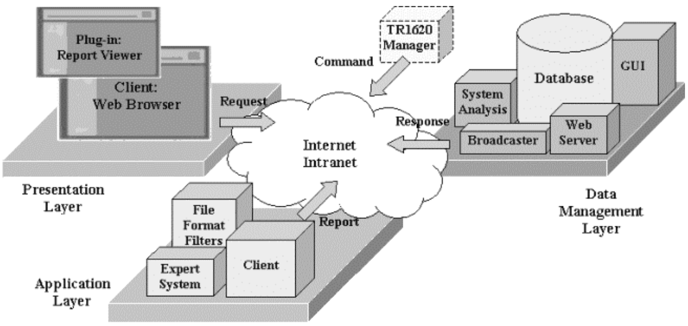

Fig. 1. Three layers of the system for automated fault analysis

Considering the most complex *DFR Assistant* configuration, there can be three major system layers:

- Application Layer
- Data Management Layer
- Presentation Layer

Considering the major elements of these system layers, they can be associated with the following:

- *Client*
- *Server*
- *Report Viewer*

A large flexibility and independence of its modules characterize the architecture of DFR Assistant. Various system configurations can be achieved through the virtually unlimited combining of these building blocks.

Three major types of configurations are:

- Autonomous installation
- Distributed installation
- Centralized installation

The subsequent sections will identify and describe system modules as well as indicate some of their possible combinations.

3.2. Application Layer

Application layer of *DFR Assistant* is composed of the modules implementing core functionality of DFR Assistant (see figure bellow).

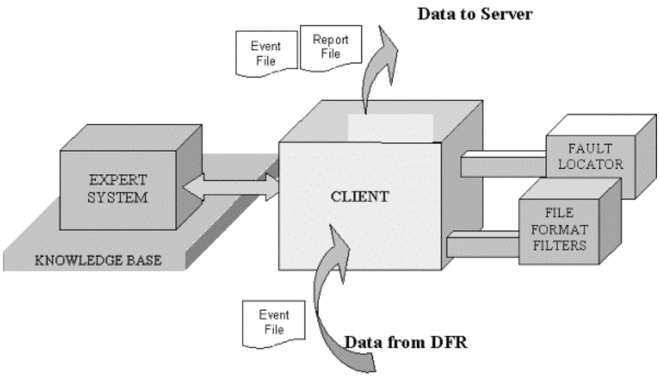

Fig. 2. The architecture of the application layer

The following functional modules can be distinguished:

- Client
- Expert System
- File Format Filters
- Fault Locator

These modules work together implementing the main function of the application: classification of the DFR event files. The following scenario is usually seen:

- Client constantly monitors incoming folders for new events;
- Optionally, Client periodically interrogates attached digital fault recorder (DFR) for new events;
- When a new fault record is detected, Client reads it and prepares for the analysis;
- Client uses embedded file format filters to extract event data from DFR files;
- Client does signal processing to extract representative parameters of an event;
- Expert system uses calculated event parameters to classify/analyze the event;
- If the event is classified as the fault, Fault Locator calculates fault location;
- Expert system report and the event files are passed to Data

3.3. Data Management Layer

The main building blocks of Data Management Layer architecture are shown in the following figure:

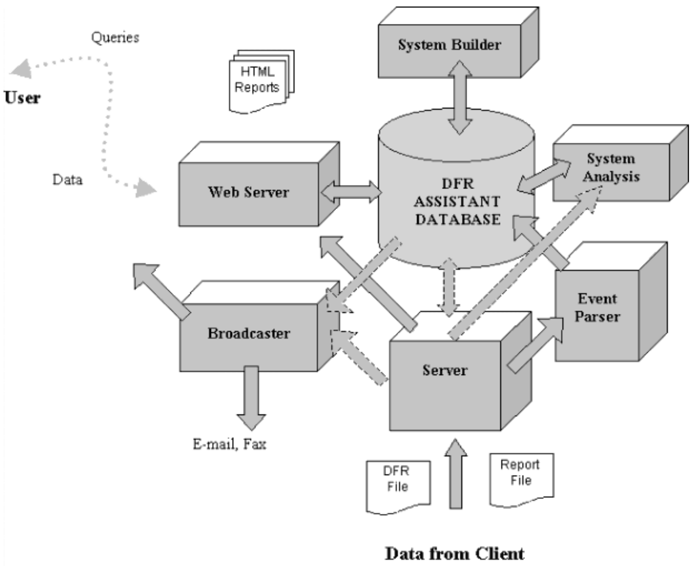

Fig. 3. The architecture of the data management layer

The functionality for each of the main elements is as listed:

- *Server Manager* constantly monitors incoming folders for new event reports and files,
- *Event Parser* parses the event report and archives pertinent data into the database,
- *System Analysis* is optionally conducted for related substation objects and system events,
- *GUI* is used for setting up the system database and generating client configuration files,
- *Web Server* responds to users' queries by retrieving and preparing requested data,
- *Broadcaster* sends data (files, reports, pages) to users registered to receive them.

3.4. Data Presentation Layer

Data Presentation Layer is shown in figure bellow.

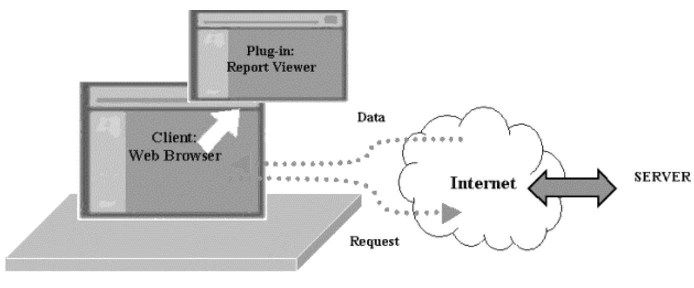

Fig. 4. The architecture of the data presentation layer

The main details of this architecture are listed underneath:

- User gets notified via e-mail, fax, or pager that the new event has occurred in the system;
- User visits DFR Assistant Web site and views the event page using standard Web browser;
- User browses database and inspects the event and related system records in more details;

- 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.

3.5. Implementation

A system for automated fault analysis can be configured in several different ways to match various system architectures and to serve the needs of different users. Typical configurations are illustrated in following sections (9).

Autonomous System

This is the simplest configuration. It is characterized by the absence of the system database and centralized data distribution services. In this case, a system is usually reduced to the Application Layer only. This configuration is implemented for a small number of recording devices. Figure bellow illustrates the architecture of this type of the system.

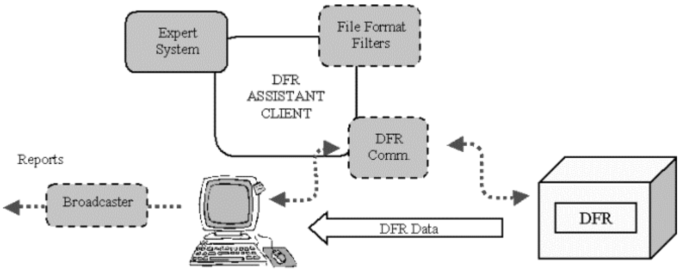

Fig. 5. Configuration of the Autonomous System

In this case, a system is installed either on the computer next to a recording device (e.g. DFR) or on another computer where recorded fault data are transferred by some means. This simplest configuration includes *Client*, *Expert System* and *Fault Locator*.

This type of the system is characterized by the analysis centered on the faulted transmission line in monitored substation. Event files must be in COMTRADE format (10). System-wide analysis is not possible nor is the centralized data archival and dissemination. Event reports and data are copied to selected folders on the local computer only.
Adding Communication module, File Format Filter modules and Broadcaster module can upgrade the configuration discussed above. This provides direct link between the analysis system and the recording device, direct importing of files in native formats of the recording device, and transmission of the analysis reports to registered users.

Centralized System

This is a more complex version of *DFR Assistant* and all three system layers are present in this case. The system is characterized by the centralization of all system functions. This configuration is normally implemented for systems consisting of multiple DFRs. Computer hosting *DFR Assistant* is usually a dedicated one and data downloading is done using separate computers (MS computers). This configuration can be implemented with the single computer, too. Figure bellow illustrates the architecture of this type of the system.

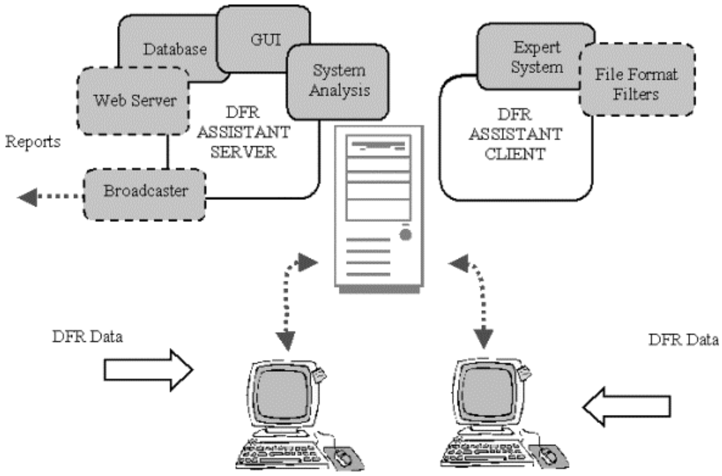

Fig. 6. Architecture of the Centralized Configuration

In this system, all *DFR Assistant* modules are installed on the computer at the central location (e.g. in the central office). DFR event files are transferred to *DFR Assistant* computer by some means (e.g. using DFR Master Station software). Therefore, only an indirect link between *DFR Assistant* and DFR exists. Event files can be in COMTRADE format or in native DFR format if optional modules are added. *DFR Assistant* modules can be configured according to the user's preferences, but some modules must come together.

This type of the system is characterized by the two-tier analysis. First, the Expert System module carries out the analysis centered on the faulted transmission line in a substation. Second, the System Analysis module performs more elaborate, substation- and system-wide analysis.

Centralized data archival (of event reports and event data) is an inherent feature of this system. The addition of optional *Web Server*, *Broadcaster* and *Report Viewer* will provide for sophisticated and user-friendly data dissemination.

Distributed System

This configuration is characterized by the centralized data archival and distribution (*Server*) on one side and distributed event analysis (*Client*) on the other side. This configuration is normally implemented for systems consisting of large number of DFRs (11). Faster time response is an additional reason for the selection of such a system. Computer hosting *Server* is usually very distant from *Client* computers(s). Event data transfer from DFRs to local PCs can be done using separate computers (MS computers) or directly using DFR Communication module. Fig. 7 illustrates the architecture of this type of the system.

The system is also characterized by the two-tier analysis. First, the Expert System modules on local computers carry out the analysis centered on the faulted transmission line in a substation. Second, more elaborate, substation- and system-wide analysis can be performed by the *System Analysis* module (part of the *Server*).

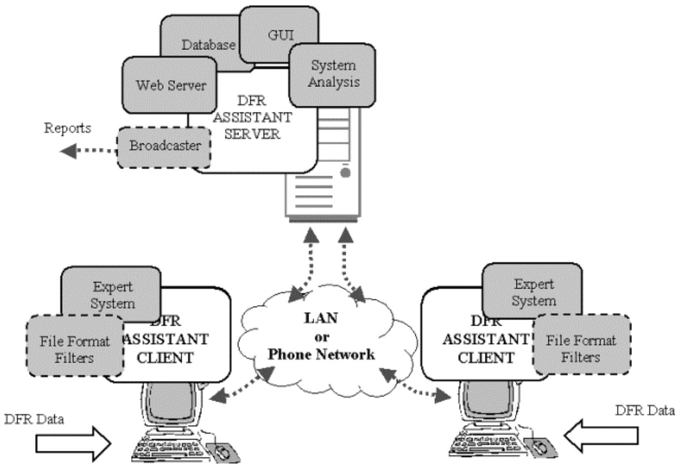

Fig. 7. Architecture of the Distributed Configuration

Centralized data archival (of event reports and event data) is an inherent feature of this system. As before, the existence of *Web Server* and *Broadcaster* provide for sophisticated and user-friendly data dissemination.

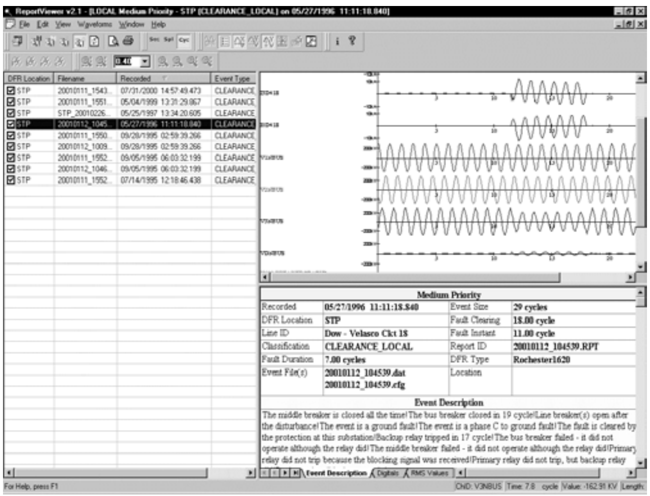

Fig. 8. Report Viewer – Universal Solution for Viewing Reports and Data

Reports and fault recordings (waveforms) can be viewed and further inspected using universal report viewer (Fig. 8). The viewer is designed for viewing both COMTRADE format files and analysis report packages containing report file and fault data.

4. TESTING RELAYS USING TRANSIENTS

An automated transient testing of protective relays with integrated test result analysis and archival is a desirable feature when assessing and/or tuning the relay settings (12). The main benefits of a tool that allows automated transient testing are:

- Testing relays with simulated and/or field recorded transients automatically.
- Evaluating a sample of a new relay for an existing application before purchasing a batch of a new relays.
- Troubleshooting relay miss-operations for specific power network conditions.

4.1. Design

This section describes the elements of the new simulator design. Only the main aspects of the hardware and software architecture are elaborated while the software, called Relay Assistant, is described in detail in the following sections (13).

Hardware Architecture

In accordance with the simulator design requirements, the major hardware building blocks of the simulator architecture can be represented as given in Fig. 9.

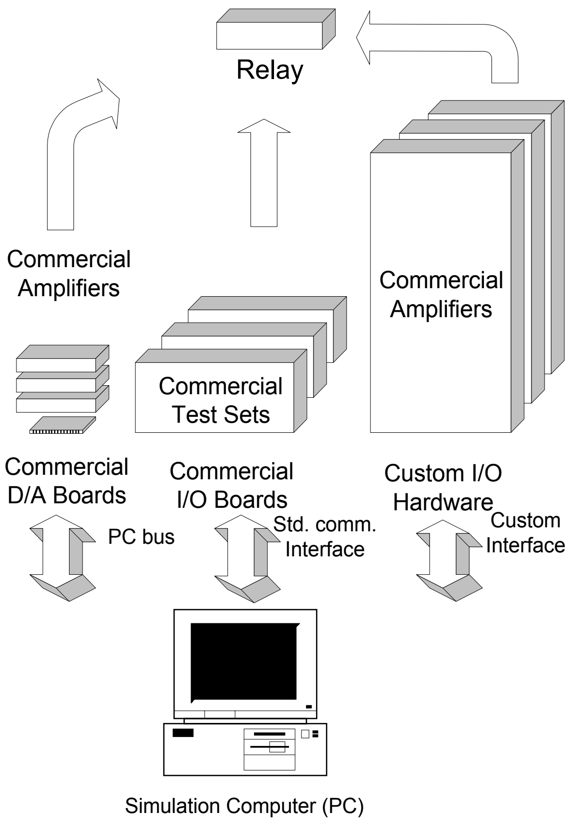

Fig. 9. The hardware architecture of the simulator

More details on hardware components are given in the following sections.

Simulator Computer

General recommendation is a PC based on Pentium III running Windows NT Workstation operating system. Additional factors to have in mind are the size and speed of the hard drive, number and types of the extension slots needed for interface cards and memory size.

Communication Interface

Depending on the choice of the output hardware for a particular simulator implementation, the simulator design may include either a custom-designed or standard communication interface.

If commercial plug-in D/A boards are used, there is no need for special communication interface since the boards are plugged directly into the PC (ISA, PCI, USB etc.). On the other hand, with commercial relay test sets additional interface must be used. Typically, the choice is between GPIB and RS-232 interfaces. Choosing the custom-designed I/O hardware usually means that a custom-designed communication interface is also needed. The communication protocols are defined accordingly.

Output Hardware

The standard test sets may prove to be the most attractive option for the majority of the test set users. The reason for that is an investment that has already been made as well as the familiarity to the majority of the users. Most relay test sets can be controlled through software allowing the developers to come up with customized software solutions. Further appeal of this option is the existence of embedded test set functions that can be utilized by the new software.

Due to the fact that the simulator hardware specifications are defined by the intended applications, custom I/O hardware may offer the best testing characteristics. The vertical resolution of a custom I/O hardware is usually higher (16 bits) than for most of the relay test sets and D/A boards (12 bits). The sampling rates are also higher and signal reconstruction more sophisticated. Commercially available amplifiers as well as the test sets accepting analog inputs can be used to amplify test signals.

Data acquisition manufacturers offer a great number of digital-analog conversion boards. Some of these boards fit very well the relay testing requirements. Even 16-bit D/A cards with a sophisticated signal reconstruction are available at an affordable price. When used with commercial power amplifiers, they offer an opportunity for building powerful and inexpensive relay test system hardware.

In some applications, the number of relays that can be tested simultaneously can be an issue too. At least two-terminal test configuration should be possible. There are solutions supporting even three-terminal setup (13).

4.2. Software Architecture

The simulator software architecture is shown in Fig 10. The main elements of the architecture are described below.

Data Generating

The waveform files used for testing usually originate either from DFRs or from transient simulation programs. A great variety of file formats is used and the simulator software must include a file format conversion layer to facilitate the use of the most commonly found file formats. In any case, the COMTRADE format should be a standard feature (10). Other formats supported are ATP/EMTP, native DFR formats (Rochester, Hathaway), MATLAB and ASCII.

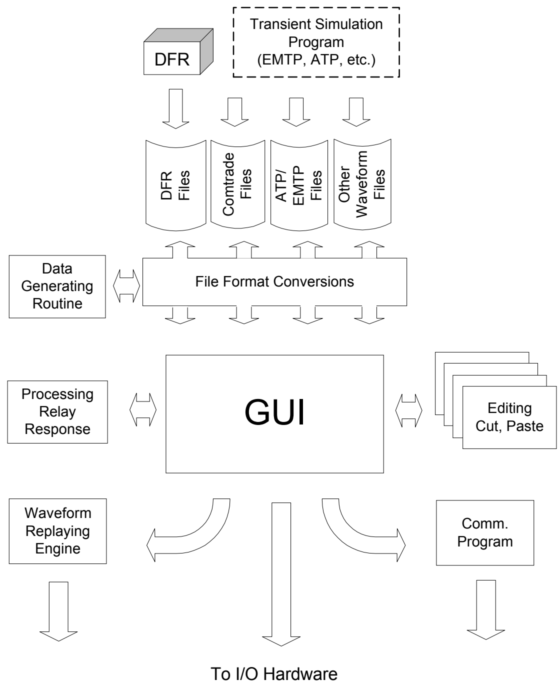

Fig. 10. The software architecture of the simulator

Signal Processing

The waveform files generated by the transient simulation programs or recorded by DFR usually require certain processing in order to be actually used for the testing. The signal editing and processing functions such as cut, paste, insert, resample, rescale, invert, and filter are examples of the functions supported by Relay Assistant.

User Interfacing

The graphical user interface (GUI) is the single most important element of the overall Relay Assistant design. Its functions for test and waveform handling as well as, signal processing and displaying affect the productivity of the simulator user tremendously. In addition, GUI provides the required software/hardware transparency.

Data Replaying

Prepared waveform files need to be played back to the relay under test through a digital to analog conversion system. Depending on the selection of the I/O hardware, various implementations of the replaying engines are available for Relay Assistant. Replaying engines accompanying custom-designed hardware exhibit greater flexibility, but they are the most complex and expensive.

Results Processing

After replaying the waveform file, the software must assist the user in the processing of the relay response. Processing has to extract as much information as possible from the raw relay trip data. The results obtained through the processing must be suitable both for immediate and for further analysis with independent software packages. To facilitate this, the test results along with the most important test data can be printed or saved in the form of a test report or exported in a form suitable to be loaded into an external database.

4.3 Implementation

Main implementation details of the simulator design are presented in this section.

Hardware

Current PC-based open-loop simulator implementation supports two output hardware platform options:

- Option I - AVO universal test set PULSAR as the output hardware (14). Two-set, three-phase simulator is available for applications requiring back-to-back testing with standard output power.
- Option II - TLI I/O interface system and user-selected commercial high-power amplifiers as the output hardware. Two-terminal, three- and four-phase simulators are available for applications demanding more output power.

The main characteristics of the I/O hardware for both simulator versions are listed in the Table 1.

Table 1. I/O HARDWARE CHARACTERISTICS

Characteristic	Hardware option I	Hardware option II
Comm. interface	GPIB	Custom
Vertical resolution	13 bits	16 bits
Sampling freq.	50 μHz - 20 kHz	5 Hz - 40 kHz
Over-sampling	No	Yes
Current output	30 A rms., 150 VA	180 A peak, 1550 W
Voltage output	300 V (rms.)	120 or 300 V (rms.)
Configuration	1-, 2- or 3-channel	1-, 2-, 3- or 4-channel

Software

The simulator software consists of four layers:

Layer I - Software modules for test case creation. These modules provide the capability of reading, processing and replaying the following waveform files: COMTRADE, ATP/EMTP, MATLAB, and native DFR files (Rochester, Hathaway). Another module generates the test waveforms with specified harmonic content. For users using popular ATPDraw and ATP to generate transient files libraries of the customized ATPDraw power system elements tailored for relay test applications are also included.

Layer II - Software modules for waveform processing. These modules provide test waveform editing and processing capabilities such as: cut waveform segment (e.g. to eliminate noisy part of a signal), insert waveform segment (e.g. to build the waveform from multiple segments), waveform rescaling (e.g. to decrease signal levels of replayed waveforms), waveform resampling (e.g. to decrease waveform sampling rate for EMTP/ATP generated files), waveform polarity change (e.g. to rectify wrong measuring connection), automatic pre-fault and post-fault extension (e.g. to increase the length of a DFR record), etc.

Layer III - Graphical user interface software modules. These modules provide facilities for the test case creating, editing and storing. The functions implemented here enable the users to visually inspect and select desired waveforms from a waveform file and save them in a test file for later replay. All processing functions mentioned earlier also have the corresponding outlets in the user interface. In addition, the modules that collect, process and store the information about relay response are also controlled from here.

Layer IV - Software modules for waveform replaying. This layer includes software communication modules for two possible I/O hardware platforms. First module communicates with AVO PULSAR test set using GPIB interface. Second one, communicates with TLI I/O hardware using custom-designed interface.

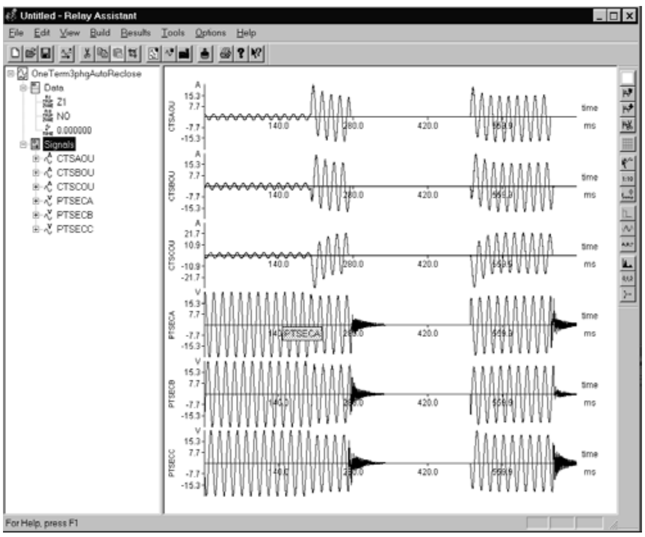

Fig. 11. Relay Assistant – Software for Automated Transient Relay Testing

All four software layers are integrated in a single Windows application called *Relay Assistant* (Fig. 11). Additional plug-in applications for generating test cases are available for special needs. Examples are TFAA module for simulating faults in transformers and BGEN module for generating batch of test cases by simulating faults in existing models (15,16).

5. CONCLUSION

This paper introduces several engineering tools aimed at evaluating relay performance, for given settings, using fault transients. The tools are quite flexible and facilitate the following tasks related to selection and tuning of relay settings:

1. Automate analysis of relay operations to identify relay missoperations
2. Investigate missoperations by replaying recorded waveforms and changing relay settings until optimal settings/operating characteristic are selected
3. Apply similar approach to newly purchased relays by evaluating relay performance under various fault transients and selections of different setting features
4. Perform a large number of simulations to generate the fault events automatically for the application in question and execute the tests by replaying the events automatically into the relay of interest
5. Tune the relay settings by replaying a number of transients that correspond to different fault characteristics related to a selected power system element

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