

PC BASED DYNAMIC RELAY TEST BENCH-STATE OF THE ART

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Abstract – This paper describes Relay Assistant, a new Win95/NT software for automated open-loop transient testing of protective relays. The software is designed to complement and improve widely accepted methods and practices of the relay testing. By using Relay Assistant users will be able to combine portability of universal relay test sets with transient testing capabilities of modern power system simulators at a price comparable to the price of conventional test sets. The software can use several different I/O hardware platforms enabling the users to match simulator configuration with their testing requirements. To offer greater flexibility, the software can load and replay transient files in a variety of file formats ranging from various DFR native formats to EMTP/ATP output file formats. Test files in COMTRADE format can also be used. Relay Assistant comes with full-blown graphical user interface. The user can create and reuse test objects of various levels of complexity to speed up the test preparation. Comprehensive set of signal processing and data handling functions is available to further increase efficiency of the testing.

I. INTRODUCTION

The existing practice for relay testing is related to the use of phasors to perform design testing verifying the operating characteristic and calibrating relay settings. The future relay testing practice may include extensive application testing using transients verifying relay performance under actual fault scenarios and conditions.

Recent development of digital simulator technology has provided an opportunity for using digital simulators in testing protective relays both in closed-loop and open-loop modes [1]. As prospective users are becoming more exposed to the simulator technology, application of the simulators is gaining an increasing interest in the power industry. However, a wide acceptance is contingent upon this new technology being affordable. In most of the relay test applications this leads to a requirement that the total simulator cost does not exceed an investment required for the standard test sets. Also, some utilization of the investments made in the past into the standard test sets is desirable. This can be translated into a requirement that new digital simulators designs should be

flexible to enable users to select hardware and software that fit their application requirements. According to the requirements outlined here, it is expected that most of the new simulator designs will be centered around a standard PC.

This paper describes a new digital simulator design that meets the requirements outlined above. The simulator is PC-based, yet it has the functionality of a full-blown digital simulator. This has been achieved by developing and utilizing new software for user interfacing, test signal processing and waveform replaying. To reduce the overall cost, this software does not rely on the use of external software packages, such as MATLAB, for realization of certain functions. In addition, the software is written in such a way that either the existing test sets or custom-designed, high-precision hardware can be selected as the I/O hardware. In the latter case, the additional flexibility is provided in selecting the power amplifier subsystem where either amplifiers from the standard relay test sets or high power amplifiers can be used.

As an especially attractive feature, Relay Assistant enables users to exploit the power of the electromagnetic transient simulation programs in relay testing. Output files of the industry-standard EMTP/ATP files can be directly loaded thanks to the existence of an embedded conversion filter. This feature can significantly reduce the overall cost of the simulator, since some of the most popular electromagnetic transient programs (ATP) and their graphical user interfaces (ATPDraw) are available either for free or for only a small registration fee. For users of ATP and ATPDraw, Relay Assistant comes with a supplemental library of some models of the most frequently used power system elements.

II. EXISTING TESTING APPROACHES

A traditional way of relay testing has been the phasor-based testing using conventional test sets. The simplicity of the test methods used and flexibility for testing applications involving relay operating characteristic as well as the portability and relatively low price of the test sets make this testing approach especially attractive. Testing with relay test sets may suit well those users that perform a lot of periodic relay tests aimed at verifying relay setting without performing extensive evaluation of the transient performance.

While this approach may be entirely sufficient for many applications and users, there may be cases that require a more thorough relay evaluation. The examples include cases when: the suitability of a particular relay to a specific application is studied; the design characteristics of a new relay design are being checked; the relay misoperations are being analyzed. The existing relay test sets can not meet these requirements and digital simulators for relay testing are used instead. Today, some manufacturers of digital simulators are offering solutions for such applications [2].

Existing simulator designs can be divided into two main categories: open-loop and closed-loop. The difference is in the way the relay under test interacts with the simulator and model of the simulated power system. With open-loop simulators, the users test relays by applying appropriate test waveforms to the relays and verifying that the relay operates in accordance with the expectations [3, 4]. The test signals are either simulated or recorded in advance. Therefore, there is no feedback from the relay to the simulation model. With this type of the simulator one can test relay operations under a variety of operating conditions including transients. On the other hand, test signals that closed-loop simulators apply to the relay under test are calculated in an on-line simulation [5-7]. The simulator can recognize a trip command issued by the relay under test and use it to immediately change the network topology of the model by opening or closing associated circuit breaker. Since the transient simulation is going on as the relay testing progresses, these simulators are also called real-time simulators. This type of simulators enables users to study more closely the relay interactions with the power system elements. Majority of today's simulators belongs to one of these two groups, but there are also some designs that combine the features of both simulator types [8].

The computer hardware used to realize simulator designs described above varies greatly [1]. Basically, one can recognize three approaches: simulators based on custom-designed computer, workstation based simulators, and PC-based simulators. Generally, the choice of the simulator computer is linked with a degree of testing functionality one wants to implement. Today, closed-loop simulators are based either on workstations or on custom-designed computers. The open-loop simulator designs are based on workstations and PCs. Having in mind the current pace of the advancements of the microprocessor technology one will see future simulator designs gravitating toward PCs.

The output hardware used to apply calculated or recorded test signals to the relay under test is also very diverse. Analog-to-digital converter subsystems are mostly custom-designed with an accent being put on the high vertical resolution and wide sampling frequency range. On the other hand, the amplifier subsystems are generally selected among various commercially available products. Their common

characteristics, a high output power and wide frequency bandwidth, fit very well high-demanding relay testing applications. One possible disadvantage of this, however, is that the users that perform less-demanding applications may end up with amplifiers with broader specifications and higher prices than necessary.

As stated above, the power industry today demands more versatile and less expensive simulators. New designs are attempting to meet these demands by increasing the flexibility of the simulator output hardware and in turn widening its range of test applications.

III. NEW REQUIREMENTS

In order to meet the future relay testing requirements at a minimal cost and overcome limitations of the existing simulator designs, the following set of general design requirements was defined:

- Simulator computer should be a personal computer (PC) since the majority of test set users is familiar with this technology. Since many users already possess PCs, total investment in the simulator hardware is reduced.
- Simulator input/output hardware should be available "off the shelf" with a strong emphasis on the use of existing test sets. The additional possibility of using other high-performance output platforms is recommended.
- Simulator system software should be based on the commercially available platforms. The investment in this software segment should be at the lowest possible extent.
- Simulator application software should be written in a high level programming language. The horizontal and vertical portability across different platforms and within future upgrades of a given platform respectively must be on the top of the design requirement list.
- Simulator should have a simple Graphical User Interface implemented using standard graphical tools.

On the other hand, a set of the simulator design requirements related to the specifics of the relay test applications can be defined as follows:

- The simulator should operate in an open-loop mode, but future extension should also include real-time mode of operation.
- The testing of relays should be possible by applying either recorded or simulated waveforms. Most probable sources of the test waveform files are either digital fault recorders (DFRs) or transient simulation programs. The simulator software must be able to replay these files.
- If the test waveform files are not readily available, the simulator should provide means for their generation. The use of internal or external transient simulation programs (such as ATP/EMTP) should be a standard feature.

- An easy-to-use user interface for the test waveform file processing must be provided. This is needed since the recorded or calculated waveforms often can not be used without further processing to fit the characteristics of the particular test application.

The main emphasis in development of the Relay Assistant was on meeting these requirements.

IV. DESIGN

This section describes the elements of the new simulator design. Only main aspects of the hardware and software architecture are elaborated while the software is described in detail in the following sections.

A. 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. 1.

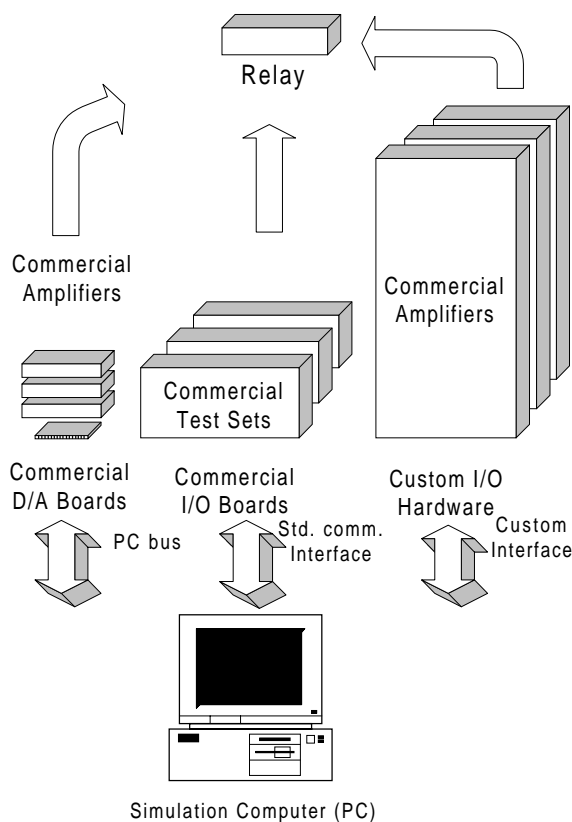


Fig. 1. The hardware architecture of the simulator

Simulator Computer

Generally, any PC equal or better than 80836 is acceptable, but recent Pentium models are recommended to achieve fast graphical user interface operations. As for the operating system, Windows 95/NT is required. Additional factors to have in mind are the number 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 (AT or PCI bus). 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.

B. Software Architecture

The simulator software architecture is shown in Fig 2. The main elements of the architecture are described below, while some examples of the software implementation are left for the subsequent section.

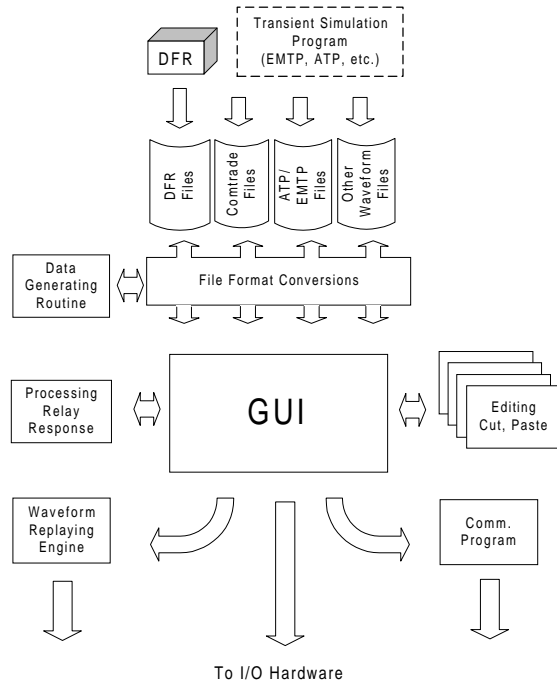


Fig. 2. The software architecture of the simulator

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.

Data 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 implementation 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.

Data 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.

V. IMPLEMENTATION

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

A. 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. 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 I.

Table I. I/O HARDWARE CHARACTERISTICS

Characteristic	Hardware option I	Hardware option II
Comm. interface	GPIB	Custom
Vertical resolution	13 bits	16 bits
Sampling freq.	50 μ Hz - 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

B. 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.

VI. EXAMPLES OF GUI DIALOGS

Several figures showing examples of the main Relay Assistant graphical user interface dialogs are given in the appendix. They illustrate both the simulator design and its usage. Short explanations that accompany each figure further clarify transient relay testing philosophy that lies behind the Relay Assistant design.

VI. CONCLUSIONS

Digital simulators for relay testing meet most of the requirements encountered in relay test applications. A variety of existing simulator designs enables the users to select a simulator that matches their exact needs. However, to gain wider acceptance, simulators must become more affordable.

A common practice in the utilities today is to perform the routine relay testing using conventional relay test sets. The utilities expect that any new testing technology be comparably affordable. In the past the large investments have been made into relay test sets. The requirements of the utilities is that these sets must be utilized.

This paper presents a simulator design the meets above-stated requirements. Its Relay Assistant software for transient relay testing brings greater hardware flexibility and less expensive implementation platforms. Thanks to Relay Assistant, this simulator can utilize both the existing test sets and customized interface as its output hardware. The simulator software is designed and implemented using an object-oriented approach with the use of modern tools for the rapid software development.

The main benefits that simulator design described in this paper brings to the users are: the use of the existing relay test equipment and the possibility for a gradual investment.

VII. REFERENCES

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M. Kezunovic (S'77, M'80, SM'85) received his Dipl. Ing. degree in electrical engineering in 1974, as well as the M.Sc. and Ph.D. degrees from the University of Kansas, both in electrical engineering in 1977 and 1980 respectively. His prior industrial experience is with Westinghouse Electric Corporation in the U.S.A., and the Energoinvest Company in Sarajevo. His academic experience is with the University of Sarajevo and Washington State University. He has been with Texas A&M University since 1987 where he is a Professor and a Director of EPPEI institute. He is member of the IEEE PSRC, member of CIGRE and a registered Professional Engineer in the State of Texas. Dr. Kezunovic was the chairman of the PSRC working group F-8 on "Digital Simulator Performance Requirements".

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APPENDIX

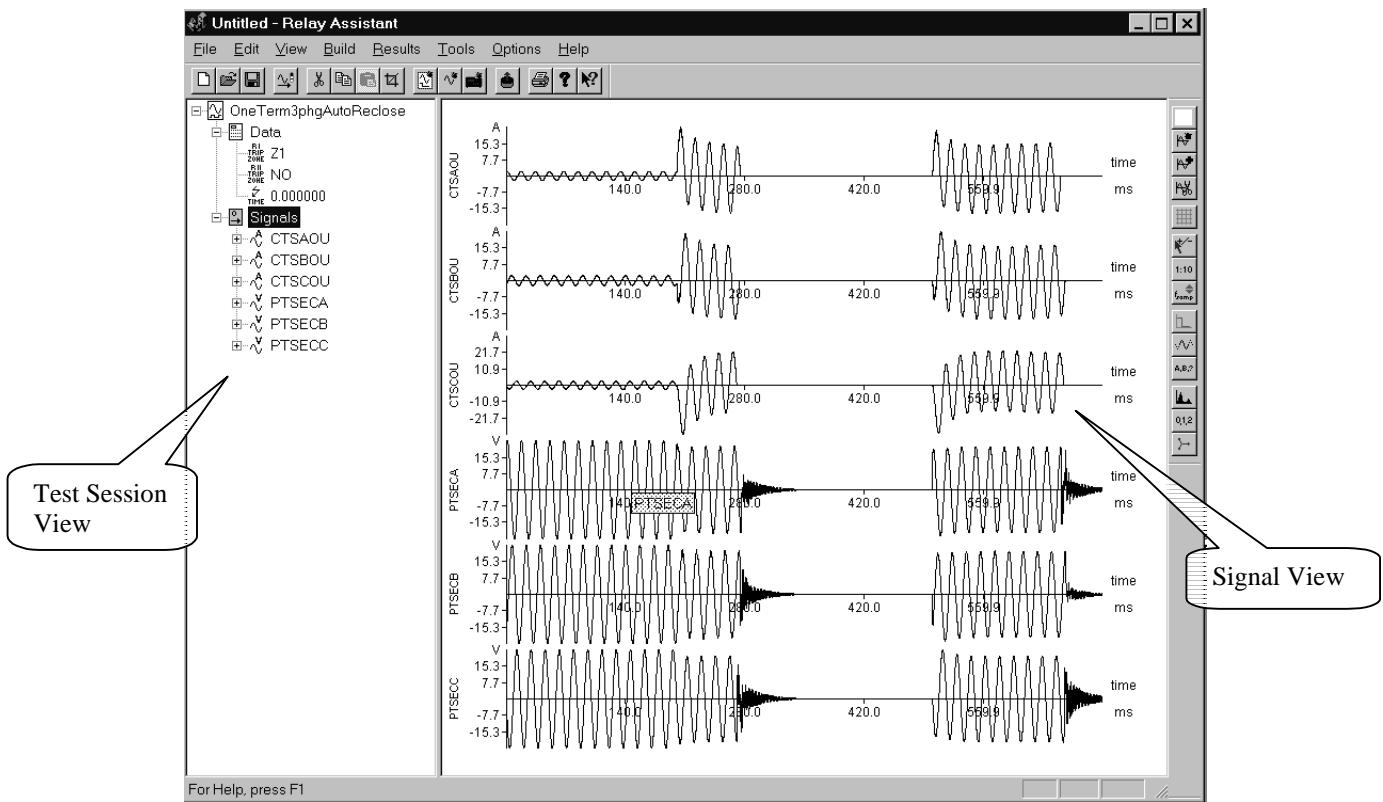


Figure A1. The main window of the Relay Assistant has two panes: Test Session View and Signal View.

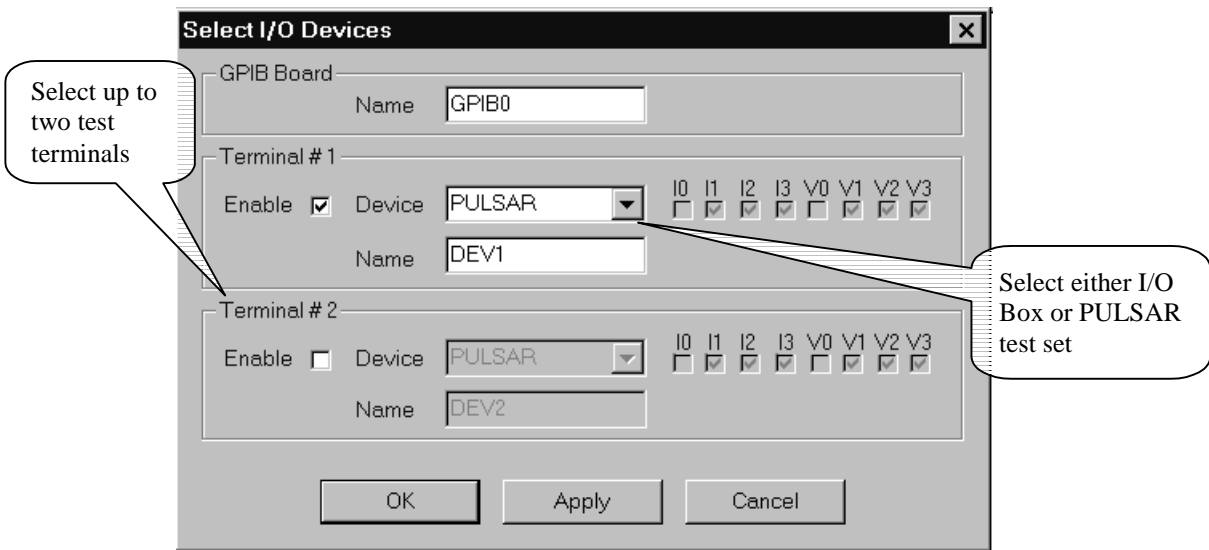


Figure A2. Appropriate hardware platform is selected in this dialog

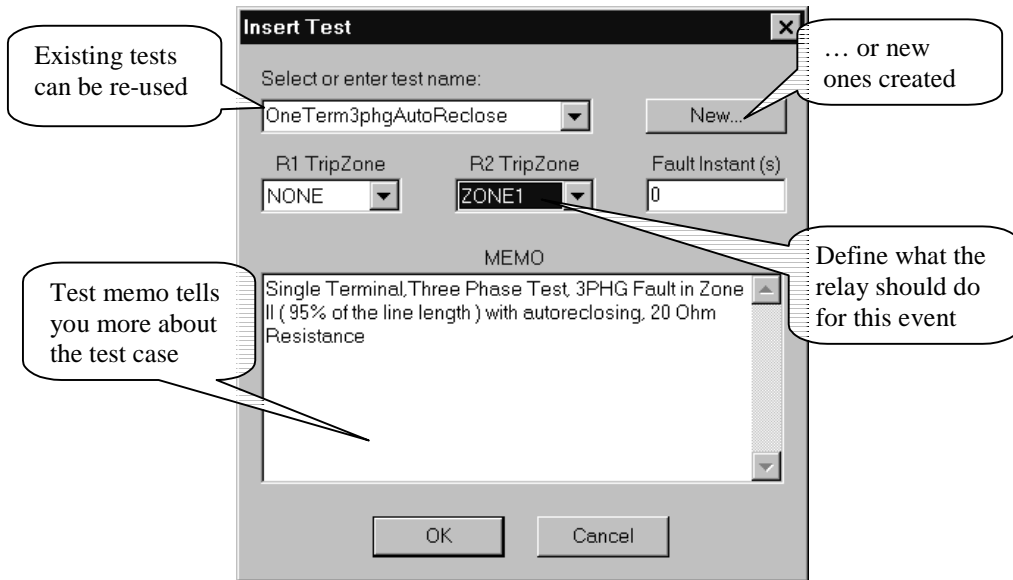


Figure A3. Existing test can be reused or new ones created easily

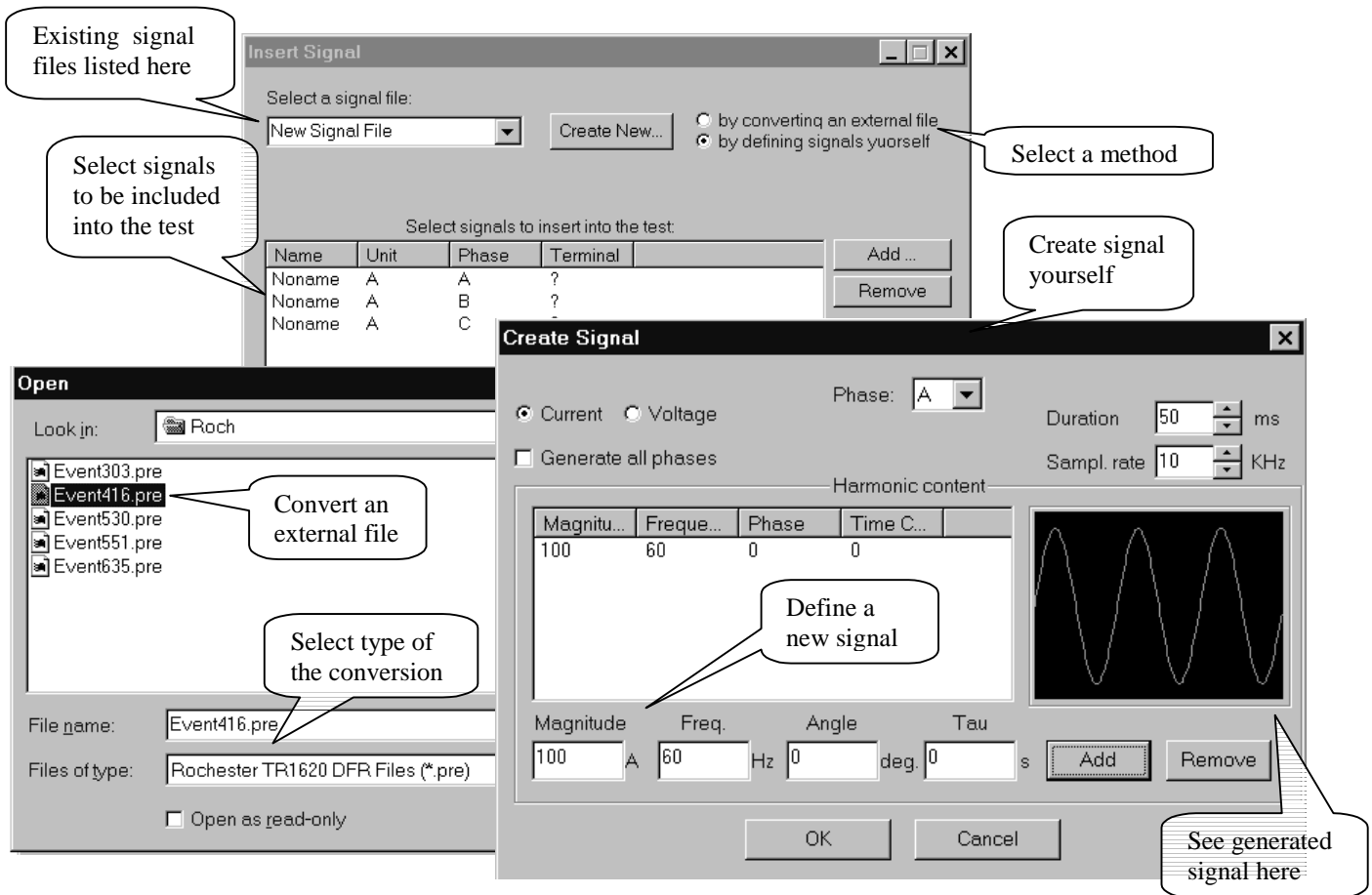


Figure A4. Test signals can be generated by converting external files or by defining signal harmonic content

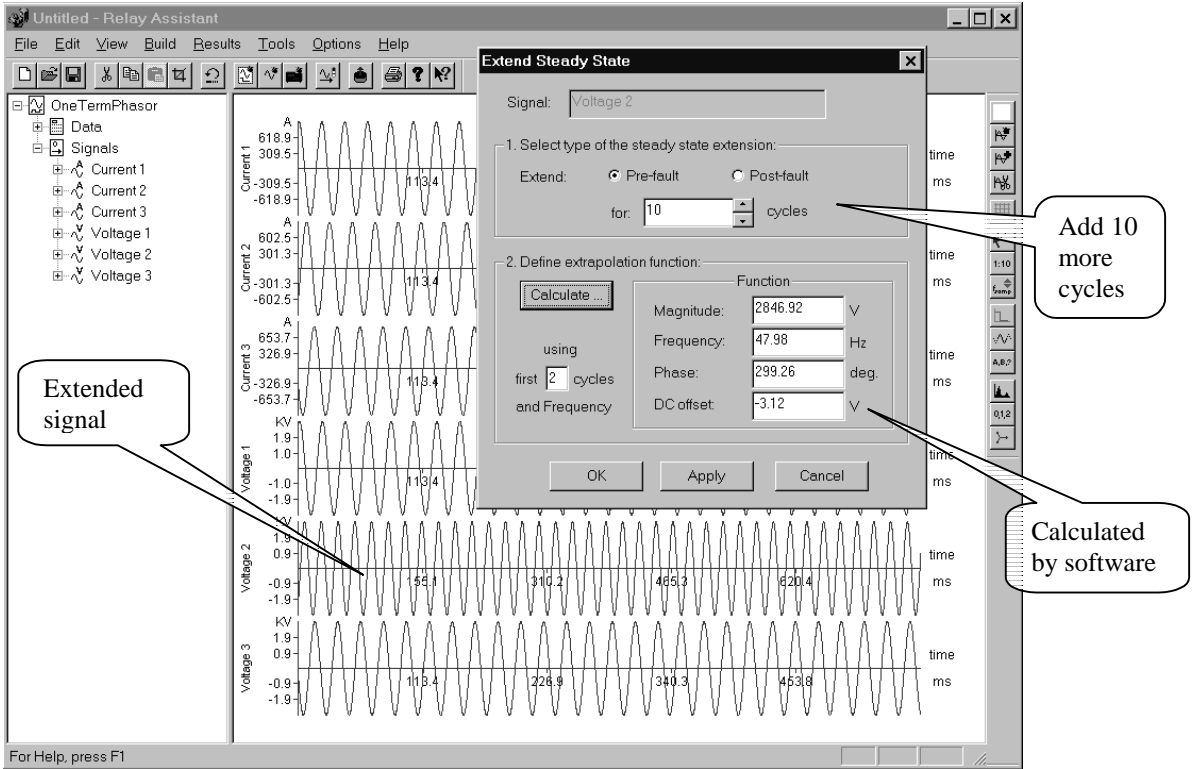


Figure A5. Steady state period of the signal can be extended automatically

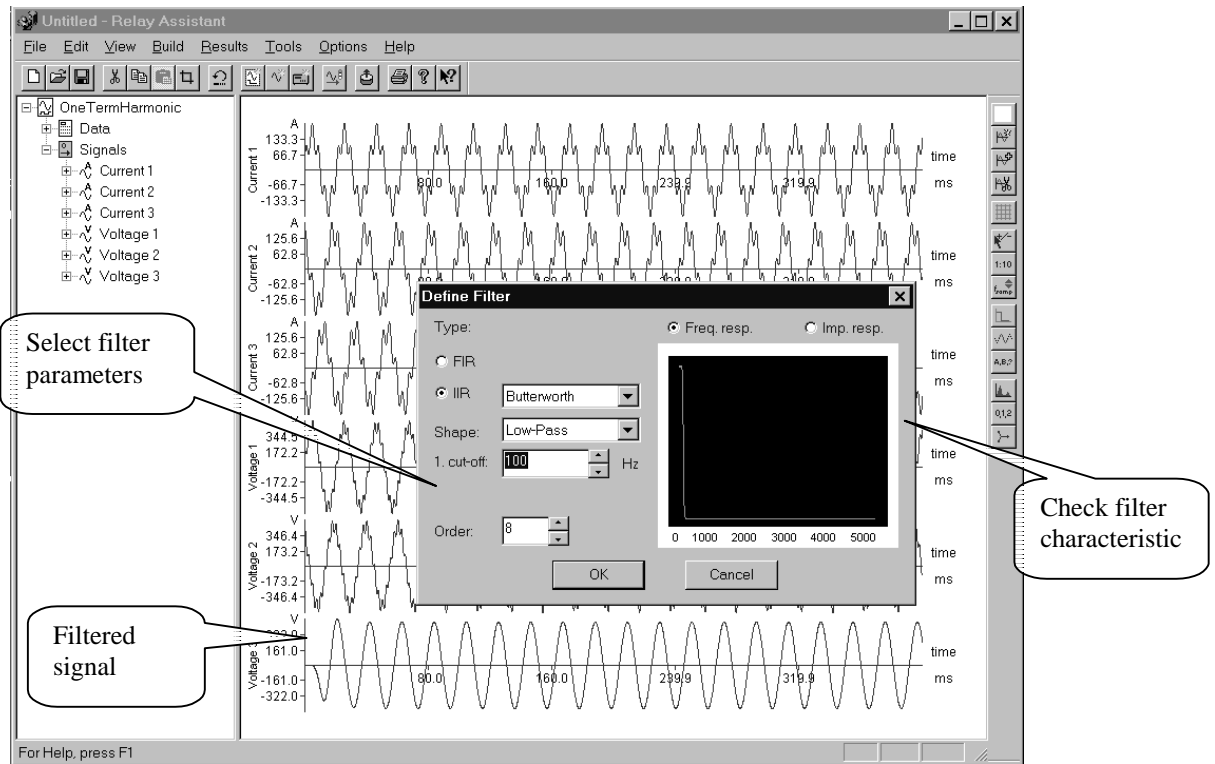


Figure A6. Noisy signals can be filtered easily using digital filtering

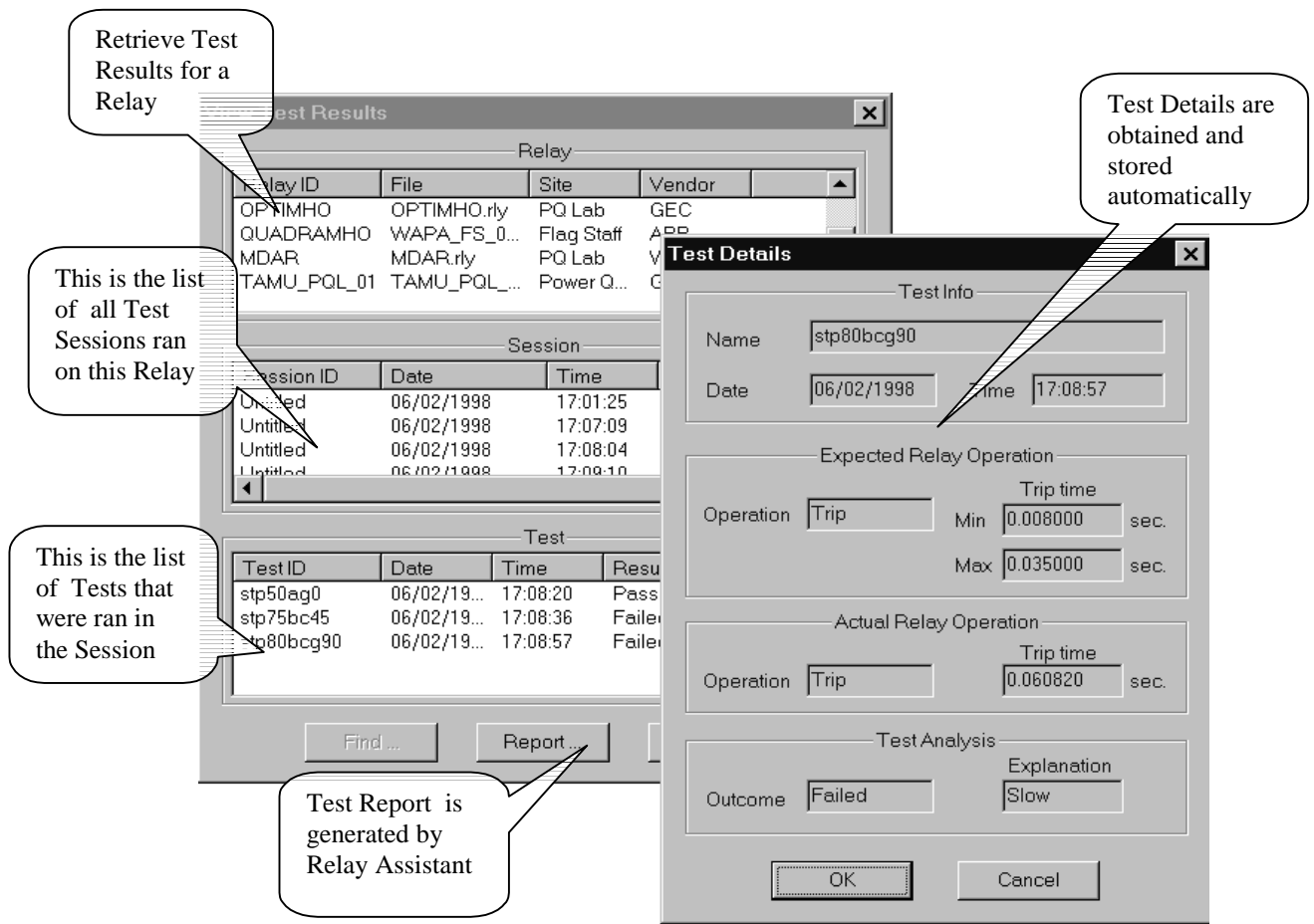


Figure A7. Test history is available and easily accessible for any relay

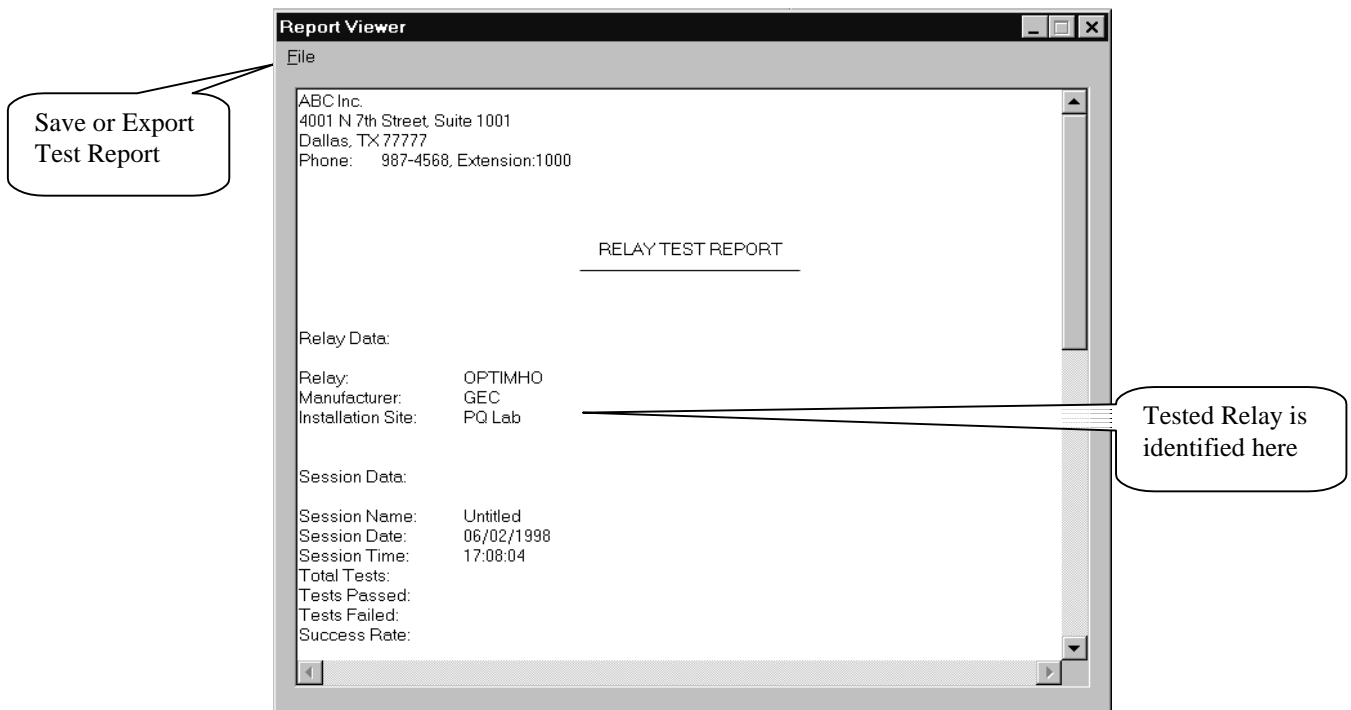


Figure A8. Test report is generated automatically