New Test Approach for Microprocessor-Based Power System Automation Equipment

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ABSTRACT

This paper describes a new dynamic test approach used for power system protection and control equipment. Digital simulator has been implemented to generate desired test waveforms. A description of the simulator design as well as discussion of the test approach are provided.

INTRODUCTION

Present test practice in the electric power utilities assumes use of conventional steady state test equipment for testing automation devices and systems. This equipment is lately enhanced by computer designs which enable additional flexibility and improved test performance [1,2,3]. The utility personnel have been able to utilize this equipment in performing quite elaborate test procedures that require dynamic change of the steady state quantities [4,5].

Introduction of microprocessor-based power automation equipment such as protection relays, transient recorders and fault locators, has presented a problem of evaluating the new designs versus the existing electromechanical and solid state equipment. Further more, a great variety of microprocessor-based equipment designs has been available on the market for a given automation function. Therefore a need to compare different designs in order to select the "best" one has been identified. The existing test equipment and practice are shown to be limiting for elaborate tasks such as the acceptance and the commissioning tests.

Some of the recent studies of digital protection relay algorithms and of transient nature of the fault phenomena have indicated that dynamic testing may be the only appropriate approach to accurate relay performance evaluation [6,7]. This concept is well supported by development of new digital simulators to be used for the test task [8,9,10,11]. This paper gives description of a new approach to digital simulator implementation using advanced computer techniques.

The first part of the paper is devoted to discussion of the new test approach. An analysis of the signal sources which produce either simulated or field recorded test signals is given next. The subsystem needed to convert signal sample outputs, generated by the simulator, into analog signal test waveforms is also discussed. Conclusions and references are given at the end.

NEW TEST APPROACH

The new test approach discussed in this paper promotes two unique features. One is dynamic nature of proposed tests and the other one is digital implementation of the test equipment.

Dynamic Test Requirements

A careful analysis of the new microprocessor based equipment for power system automation indicates that digital algorithms for signal measurements, used in the equipment designs, can properly be evaluated only if the transient nature of the power system events is taken into account [6,7]. This is unavoidable if a new design is to be evaluated for acceptance purposes [12,13]. However, this requirement can easily be extended to other engineering and equipment servicing situations such as application, functional type, maintenance and trouble shooting tests [8].

The need for dynamic testing of power automation equipment has not only been recognized as an interesting problem, but there are also efforts underway in the professional community to establish recommendations for future practice in this area [14]. This paper assumes that this practice will be expanding in the near future. Digital test equipment for this purpose has been developed and its description is given next.

Test System Functions

Summary of the functions that need to be supported by the test system are given in Table I. Purpose of using each of the functions in the test methodology is outlined.

Test System Architecture

The system architecture is shown in Fig. 1. Allocation of test functions is distributed among different computers connected to the Local Area Network (LAN). Several computers are used

Table I. Test Equipment Functions

Functions	Purpose
Simulation of faults	Production of test signals
Recording of faults	Acquisition of test signals
Digital signal processing (Filtering, FFT, Decimation/ Interpolation)	Analysis of test signals Preprocesing of test signals
Digital to analog conversion Analog filtering	Generation of test signals in analog form
Signal amplification Galvanic isolation	Preparation of the required energy level for test signals
Digital I/O Galvanic isolation	Interaction with relay contacts
Graphic interfaces	Selection and initiation of test sequences
Expert system for testing	Display of test waveforms and faults

to run EMTP programs used for fault simulation (VAX, SUN workstation, HP PC). One of the computers (HP PC) is also used for interfacing to Digital Fault Recorders (DFR's). Test signals, generated either by the simulation or by the DFR sources, are downloaded to the MASSCOMP computer. This computer controls D/A converters, which are used to generate analog test signals. Signal power is increased to the required level using power amplifiers. These signals are subjected to relays for testing.

SIGNAL SOURCES

Test signals for automation device testing are generated by a simulator, or from a field-recorded file. The following discussion gives details regarding each of the test signal sources.

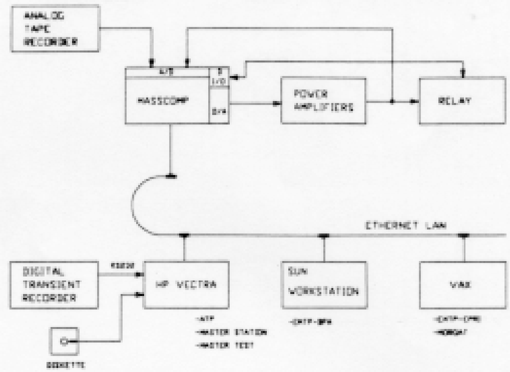

Fig. 1. Test System Architecture

System Modeling Using EMTP

Digital simulation of voltage and current waveforms, which will be used to test the power system automation equipment, is done using the Electromagnetic Transient Program (EMTP). The procedure involves two steps: (1) Modeling the study system, (2) Carrying out simulations using the developed system model.

Our study of interest focused on a small section of the Houston Lighting and Power (HL&P) Company's high voltage (345 KV) system. Power frequency Thevenin short circuit equivalents are calculated and attached at the boundary buses between the subsystem under study and the rest of the system. This resulted in a 6 bus reduced system whose one line diagram is given in Fig. 2. The reduced system is modeled in detail by

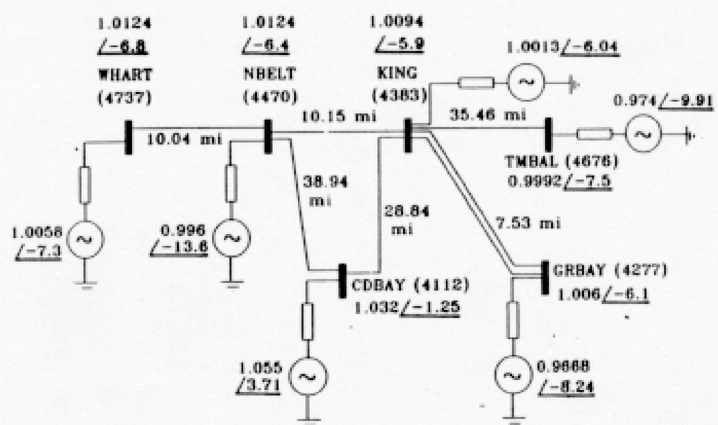

Fig. 2. Model of an HL&P system section

first using distributed, constant-parameter line models. Then the same lines are modeled using the frequency-dependent line models. The simulation results of these two cases are shown in Fig. 3 and 4 respectively. They show the phase-a voltage transients at bus KING when a phase-a to ground fault occurs at the neighboring bus NBELT. This is the signal on the line (primary) side of the Potential Transformer (PT) and Capacitor-Coupled Voltage Transformer (CVT) connected to bus KING. In order to verify the validity of the results, they are compared with the Digital Fault Recorder (DFR) output which was recorded when such a fault occurred in the actual system. The recordings were made simultaneously by two separate channels which were fed signals from the PT and CVT secondary; Fig. 5 and 6 show the two recorded signals respectively. The difference in the frequency response of these instrument transformers is reflected in the recordings. The PT reproduced the applied signal quite faithfully, while the CVT filtered most of the higher frequency components present in the original signal. However, since the DFR uses a sampling-frequency of 6 kHz and a suitable low-pass filter (to prevent aliasing), the recorded signals are a filtered version of the actual PT/CVT secondary signals.

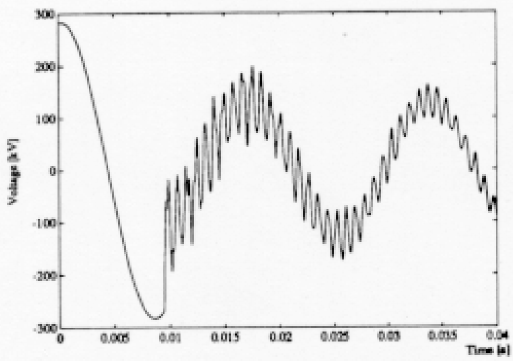

Fig. 3. Simulated Voltage Transient Using CP Line Model

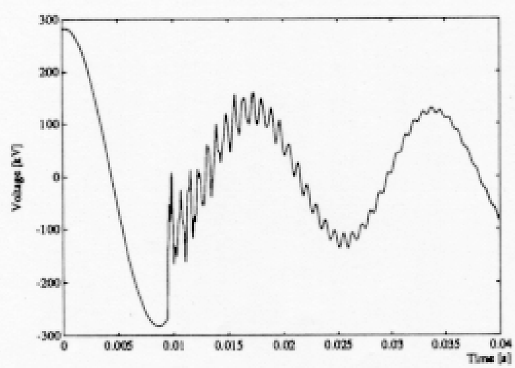

Fig. 4. Simulated Voltage Transient Using FD Line Model

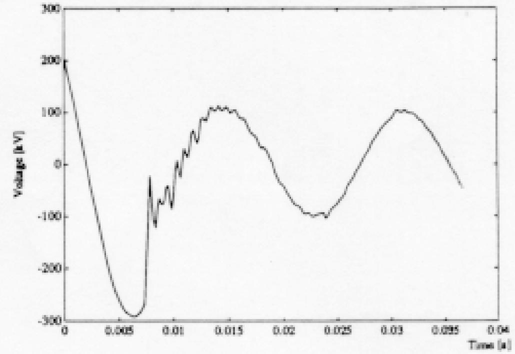

Fig. 5. Recorded Voltage Transient Using PT

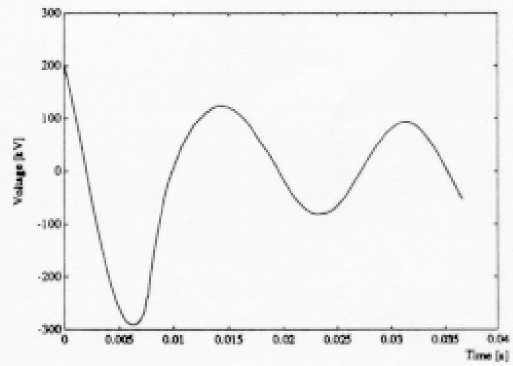

Fig. 6. Recorded Voltage Transient Using CVT

Based on these simulation results, the following general guidelines can be recommended for modeling power systems: Use a short-circuit equivalent for the parts of the system at least one bus away from the point of fault and represent the transmission lines within the retained subsystem by frequency-dependent, distributed line models. The close agreement between the voltage transients shown in Fig. 4 (EMTP simulation results using frequency-dependent line models) and 5 (DFR recording via PT) supports this conclusion.

Transient recorder interfaces

Digital fault recorders (DFR's) present the primary source of field recorded test signals. These instruments, often located in remote substations, provide continuous monitoring of power system signals. In the case of an extraneous event, a snap shoot recording is made and automatically stored for later analysis.

Typical DFR's provide 16 to 48 analog channels, with 12 bit resolution, and up to 32 digital channels. Sampling frequency varies among different models and manufacturers, with 6 to 12 kHz being the typical value.

Up to date there is no widely accepted standard for transient data storage and communication with remote DFR's, resulting in the number of proprietary solutions supported by different manufacturers. Most of the systems are organised around IBM-PC based computers providing the communications and waveform data base management.

In the described test system the interfacing with DFR's is provided by means of the IBM-PC compatible computer connected with the MASSCOMP system controller over the network (ETHERNET). Additional software is provided for data format conversion and signal editing. All of the incoming data is converted into one of two adopted output formats: (1) IEEE/COMTRADE common format for transient data exchange [15], (2) MASSCOMP LWB binary data format [16]. Provisions are made for data conversions to several commercially available signal analysis packages.

SIGNAL RECONSTRUCTION

The dynamic relay test application requires a minimum of 6 analog signals being generated simultaneously (3 currents and 3 voltages), along with the generation and monitoring of various signaling contacts. This task is performed by a dedicated computer - system controller. This machine provides the necessary input data file processing, sampling frequency and D/A conversion. It is followed up by the analog reconstruction filter hardware and high power amplifiers required to boost up the signals to appropriate power levels. Galvanically isolated digital inputs/outputs are also provided.

Controller Hardware/Software

The system controller is based around the MASSCOMP computer, equipped with required D/A and digital I/O interfaces as shown in Fig. 7. This machine also provides A/D conversion capability, used for digitizing the transients reproduced from AMPEX PR2200 tape recorder. Running under the REAL TIME UNIX operating system the controller provides the power necessary for fast direct disc transfer of transient data to the D/A converters.

The system software organization is shown in Fig. 8. There are three main modules: (1) data file format conversion utilities, (2) signal editing and analysis support, (3) D/A converter drivers, controlled by a common graphic user interface.

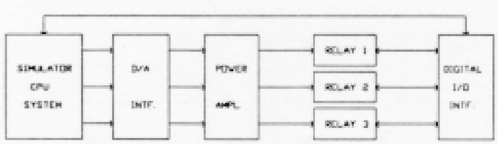

Fig. 7. Architecture of the Controller

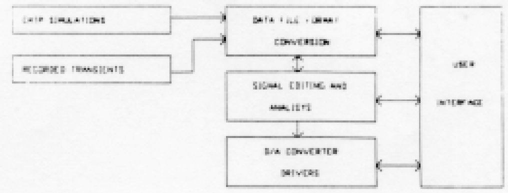

Fig. 8. System Controller Software Organization

D/A Conversion Subsystem

Signal reconstruction subsystem block diagram is shown in Fig. 9. It is built around DA08F standard 8 channel, 12 bit D/A converter board housed inside the MASSCOMP system controller.

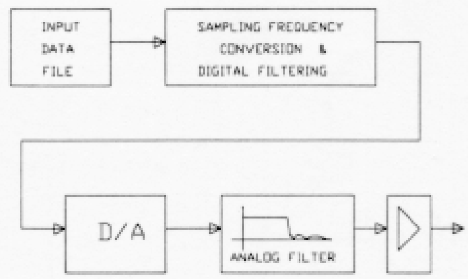

Fig. 9. D/A Conversion Subsystem Block Diagram

The reconstruction filters are to be provided externally. The sampling frequency is fixed at 16 kHz, enabling the use of standard filters intended for commercial audio applications. The chosen frequency ensures the 7 kHz usable system bandwidth, and is consistent with guidelines for sampling frequency conversion as described in [15].

Power Amplifiers

Although at first sight the task of signal amplification to the power level required by the relaying equipment might seem trivial, it is one of the main obstacles on the way to the highly accurate dynamic test system. The main problem lies with the limited accuracy of the current amplifiers. Regardless of design those amplifiers are faced with severe operating demands: (1) high output currents, (2) broad frequency range, (3) high voltage compliance required to drive inductive loads at high frequencies, (4) high accuracy, (5) capability of operating with highly non linear loads. Voltage amplifiers do not pose any major problems.

A number of commercially available power amplifiers is being evaluated by the authors at this time. The minimum requirements requested on both voltage, and current amplifiers are given in Table II.

Considering the fact that the D/A and reconstruction filter sub systems provide the full 12 bit precision (72 dB dynamic range), the main emphasis is put on evaluating the amplifier limitations, and devising the methods for final system performance verification/commissioning.

Table II. Power Amplifier Requirements

	VOLTAGE AMPLIFIERS	CURRENT AMPLIFIERS
OUTPUT VOLTAGE	> 200 V	60 V
OUTPUT CURRENT	-	140 A
POWER DISIPATION (CONTINIOUS)	> 15 W	400 W
POWER DISIPATION (200 mS MIN)	> 15 W	4000 W
FREQUENCY RESPONSE	> 10 kHz	> 10 kHz
TOTAL HARMONIC DISTORTION	< 0.2%	< 1%

CONCLUSION

The new test approach described in this paper is expected to become part of the utility test practice in the future. Digital simulators similar to the one developed by Texas A&M University are also expected to become commercially available in the near future. Some major parts of the simulator such as power amplifiers, controllers and input sources are already available at an affordable price. Implementation of the new test approach using digital simulators will in our judgment represent major step forward in evaluating and maintaining new microprocessor - based power system automation devices and systems.

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