DIGITAL SIMULATOR ACTIVITY WITHIN IEEE POWER SYSTEMS RELAYING COMMITTEE

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Abstract– This paper summarizes activities of two working groups formed within the IEEE Power Systems Relaying Committee to deal with issues related to the digital simulators for protective relay testing. Working Group F-8 is concerned with digital simulator performance requirements for relay testing while the Working Group F-10 investigates digital models for voltage and current transformers. Since the activities of both working groups are still in progress, this paper gives outlines of the working group assignments and examples of some preliminary results presently discussed by the working group members. The final reports of both working groups are expected in late 1996, early 1997 time frame.

Keywords: Digital Simulator, CT, CCVT, PT, EMTP, Instrument Transformer, Protective Relaying, Relay Testing

INTRODUCTION

The IEEE Power Systems Relaying Committee (PSRC) has been actively pursuing the issues in relay testing for a long time. Some of the recently completed reports are discussing some of the topics related to the existing practices [1] and future directions [2] in relay testing.

This paper has been presented at the First International Conference on Digital Power System Simulators - ICDS '95, College Station, Texas, U.S.A., April 5-7, 1995.

Recent advances in digital simulator developments [3–15], as well as current and voltage transformer modeling [16-24], specifically aimed at protective relay testing, prompted the PSRC to form two working groups to deal with various issues related to these topics.

Working Group F–8 "Digital Simulator Performance Requirements for Relay Testing" of the Relay Input Sources Subcommittee, Power System Relaying Committee, was formed in 1992 with the following assignment:

"Investigate performance characteristics of digital simulators when generating Electromagnetic Transient Program (EMTP) and Digital Fault Recorder (DFR) based relay test waveforms. Write performance requirements specifications and prepare an IEEE paper describing the importance of the simulator performance characteristics."

Working Group F–10 "Mathematical Models for Current Transformers (CTs) and voltage Transformers (VTs)" of the Relay Input Sources Subcommittee, Power Systems Relaying Committee, was formed in 1993 with the following assignment:

"Investigate mathematical models for CTs and VTs for use in Digital Simulation for Relay Performance Analysis. Prepare an IEEE paper summarizing the results."

The purpose of this paper is to inform the rest of the professional community about the working group on-going activities. Since the activities of the working groups are not yet completed, this paper summarizes only the activities that are presently in progress. This paper also discusses outlines of the final reports and gives some examples of the preliminary results. The goal of this paper is to make the working group activities known to as wide as possible range of professionals and solicit comments and inputs that will enhance and improve future working group activities.

The first part of the paper discusses efforts of the WG F–8. The second part of the paper is devoted to the WG F–10 activities. Contact addresses for the WG Chairman and Vice Chairman, as well as a list of the working group membership are given at the end.

WG F–8: DIGITAL SIMULATOR PERFORMANCE REQUIREMENTS

Preliminary Outline of the WG Final Report

The following are the topics presently considered for inclusion in the Final Report:

- Introduction
- Simulator Definitions
- Relay Test Requirements
- Power System Modeling
- Event Modeling
- Relay Characteristics
- Simulation Computer
- D/A Subsystem
- Power Amplifier Subsystem
- Conclusions
- References

The Introduction Section will concentrate on discussions related to the following topics: Limitations of analog simulators, EMTP based simulation, and history of digital simulator developments.

The Simulator Definitions Section will be aimed at clarifying various simulator operating modes and describing related hardware/software modules needed for the implementation. A typical digital simulator configuration shown in Figure 1 will be used as the starting point for definitions.

The Section on Relay Test Requirements will focus on some important issues related to relay

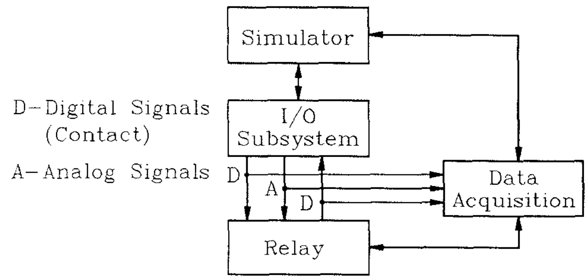

Figure 1. Typical Digital Simulator Configuration

testing such as: Interaction between the relay and the power system, testing requiring long simulation times, and interaction with the user.

The Power System Modeling Section will outline some of the issues in the digital modeling and simulation area that are not adequately covered by the existing programs and need future development.

The modeling of faults, autoreclosing sequences, geomagnetically induced currents, and out–of–step conditions are the topics selected for more detailed discussion to be included in the section on Event Modeling.

The most important considerations to be covered in the Relay Characteristics Section are related to the nominal and operating currents and voltages needed to drive a given relay. The way these considerations affect the requirements for power amplifiers is also discussed in this section.

The D/A and Power Amplifier Subsystem Sections will outline detailed requirements for the interfaces between the digital simulator and relay under test.

Examples of Some WG Topics Presently Discussed

One of the topics that may be most important for the users of digital simulators is the I/O interfacing between the simulator and the relay under test. The following discussion will give an example of the preliminary results of the working group discussions on two major issues of the interfacing problem: nominal currents and voltages as well as operational currents and voltages.

Table I. Examples of Typical Relay Characteristics

Relay Type	Rated Current	Rated Voltage	Setting Range	Burden
Induction Disk Time Over Current Relay	5	NA	0.5–16A	Min Tap 21Ω @ 0.26pf Max Tap 0.35Ω @ 0.29 pf
Induction Disk Time Over Voltage Relay	NA	67–345	10–40%	Min Tap 35VA @ 0.35 pf Max Tap 15 VA @ 0.95 pf
Plunger Type Instantaneous Over Current Relay	25 1.5	NA NA	40–160A 0.5–2.0A	0.025 VA @ 0.95 pf 165 VA @ 0.40 pf
Plunger Type Instantaneous Over Voltage Relay	NA	115–460	60–140%	9 VA @ 0.5 pf
Transformer Percentage	5	NA	2.9–8.7A	2.9 A Tap Op: 0.128Ω Rest: 0.052Ω 8.7 A Tap Op: 0.028Ω Rest: 0.020Ω
Current Differential Relay	5	NA		1 X PU : 58Ω 25 X PU : 5.4Ω
Solid State Frequency Relay	NA	120	44–61 Hz	AC Powered: 11.7 VA @ 0.85 pf DC Powered: 1.3 VA @ 0.98 pf
Bus Differential Relay (Voltage)				Current Burden @ 5 A 1678Ω @ –24°
Cup Type Distance Relay	5	120	0.75–30Ω	I : 0.3Ω @ 0.98 pf V : 340Ω @ 0.99 pf
State (Hybrid Analog–Digital) Distance Scheme	5	120	0.10–50Ω	I : 0.03Ω @ 5° V : 0.2 VA @ 50°
Numeric Digital Relay	5	120	0.10–50Ω	I : 0.02Ω @ 5° V : 0.15 VA @ 50°

The following data is indeed preliminary and is meant only to illustrate the working group discussions rather than to be conclusive in any way. The final results and conclusions will be published in the working group final report to be released in late 1996.

Nominal Currents and Voltages

Protective relays are used to protect a wide variety of power system elements; and thus vary greatly in design. The relay hardware may range from electro–mechanical to microprocessor.

The current and voltage signals used in simulation testing must, therefore, be capable of wide range of magnitude, frequency, and power level.

In general, the nominal voltage and current ratings of a relay will fall in the following range:

Voltage:	100 to 120 VRMS phase to phase (57 to 69 VRMS phase to ground)
Current:	1 or 5 Amperes
Frequency:	50 or 60 Hz

Operational Currents and Voltages

The dynamic operational range of the input signals will vary greatly from the nominal ratings, depending upon the type of relay being considered. In order to illustrate this, some examples of typical relays are shown in Table I.

An additional variable on some relays is the addition of surge capacitors to the current and voltage inputs. These surge capacitors are often required to meet the applicable Surge Withstand tests. On low burden relays, the impedance of the capacitor may become a major component in the relay burden; and may, in some cases, cause the burden to become capacitive. This may affect the amplifier requirements.

As can be seen by the above relays, a simulation system must be capable of supplying a wide range of current and voltage signals to a protective relay. For single function relays (time over current, etc.), it may be easy to establish a range of inputs based on a particular setting. A distance relay, on the other hand, is very dependent upon its application in the power system to establish the range of currents and voltages which will be seen in service. For a relay system which typically will include many individual relay elements, it is extremely difficult to specify a limited set of currents and voltages.

Effect on Amplifier Requirements

The amplifiers used to supply currents and voltages to a protective relay in a test system, must not only be able to deliver the signal magnitude required, but also to deliver it into the burden of the relay under test. If it is a requirement to test electro–mechanical relays, a higher output VA rating and a higher compliance voltage are needed than if only solid state/digital systems are to be tested.

WG F–10: MATHEMATICAL MODELS FOR CURRENT AND VOLTAGE TRANSFORMERS

Preliminary Outline of the Working Group Final Report

The following are the topics presently considered for inclusion in the final report:

- Introduction
- CT Models
- CCVT Models
- PT Models
- Conclusions
- References
- Appendices

The introduction section will concentrate on discussions related to the following topics: Transient errors produced by the instrument transformers and their impact on the dependability and security of protective relays, factors which influence the transient performance of CTs, CCVTs and PTs, and the need to test relaying systems utilizing transient data that have been generated by electromagnetic transient programs such as EMTP in which instrument transformer have been modeled adequately in order to access the performance and applicability of relaying systems.

The sections on CT, CCVT and PT models will provide guidelines on how to adequately model the instrument transformers, discuss which elements of the physical devices are important to model in transient relaying studies, and which elements could be ignored without sacrificing the accuracy of the results. In addition, each section will compare the transient response of CTs and CCVTs as was record in the laboratory or during staged fault tests with computer simulations using different mathematical models of the core.

The appendices will cover the different mathematical models investigated by the working group as well as provide the EMTP data files used to generate the instrument transformer models.

Examples of Some of the WG Topics Presently Discussed

The major problem, from a simulation point of view, is the representation of the non–linear elements in the magnetizing branch of an instrument transformer equivalent circuit (L_m and its parallel resistance). They both vary with the different states of core excitation. Some authors have used non–linear elements available in EMTP [22] to model the core non–linearities, while others have used custom current source circuits which fit very well into the Dommel algorithms [18]. The later are particularly suitable for real–time simulations where there is no time for iterations.

Details of the model algorithms will not be discussed here. However, a comparison of laboratory current transformer saturation test and an EMTP simulation is shown in Figure 2. Figure 2 indicates that the comparisons will provide confidence to protection engineers to utilize electromagnetic transient programs, or real-time digital simulators to transiently test relaying systems to assess their performance.

The working group is in agreement that CCVT models must be able to represent adequately the frequency response of the device for frequencies ranging from as low as a few Hz to several kHz. In addition, users should model all elements including the iron. The core model should be capable of accepting at least initial remanence if it does not include hysteresis. Stray capacitances of other elements such as the compensating inductor and the PT primary winding must be incorporated when the bandwidth of the relay under test extends beyond the rejection cusp frequency of the CCVT (typically > 500 Hz). Proper modeling of voltage limiting elements is also necessary.

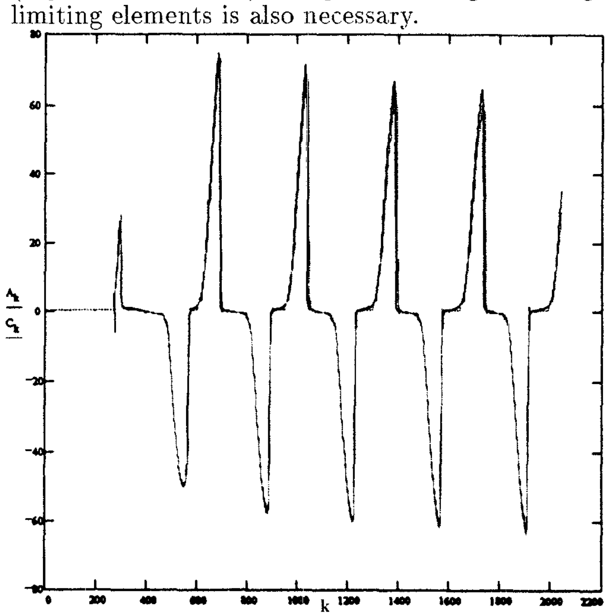

Figure 2. CT Responses Obtained Through EMTP Simulation and High Power Laboratory Tests (The Curves are Overlapping)

The above comments are indeed preliminary and were meant only to illustrate the working group discussions rather than to be conclusive in any way. Final results will be published in late 1996.

CONCLUSIONS

The main conclusions of this paper are as follows:

- IEEE PSRC has on-going activities and interests in the digital simulator area.
- WG F-8 is pursuing definition of digital simulator performance requirements.
- WG F-10 is specifying models of voltage and current transformers.
- Any inputs and comments to these working groups are welcome to make the final reports as complete as possible.

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The authors would also like to acknowledge contributions to the working group activities by its members.

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