The Use of Computer Relay Models to Teach Power System Protection in a Distance Education Setting

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Abstract

The specialized study of electric power system protection is a very detailed and abstract subject. However, problems with power system protection equipment can have visible, catastrophic results such as system blackouts. The authors used computer software models of protective relays to give both on-campus students and off-campus outreach students greater insight as to how relays behave under steady-state and transient conditions.

Specialized courses in system protection are of interest to engineers and students across the continent, but the enrollment on the originating campus may be only two or three students. Universities are using high technology solutions such as video tape and compressed video to offer courses to students in many locations. This paper discusses the experiences obtained in a graduate level power system protection course that used computer simulations to help teach the subject.

I. Introduction

High-voltage electric power systems are exposed to lightning strikes, insulation failure, and equipment failure. Faulted portions of the power grid must be isolated before a blackout occurs. The protective equipment of a modern power system is a complex collection of relays, instrument transformers and circuit breakers. Misoperation of the protective equipment affects the dependability and reliability of the power system. Relay misoperation can have disastrous effects, as evidenced by the major power blackouts in the Western U.S. on December 14, 1994, July 2, 1996, and August 10, 1996. Power system designers and researchers have been able to simulate the transient response of most system components, such as transmission lines, transformers, instrument transformers, a few protective relays, and other components. It is important that students in relay engineering courses learn how to test the steady-state and transient response of protective relays and verify relay settings.

The Electromagnetic Transients Program (EMTP) is a large time-domain simulation program that is a power industry-accepted method for studying the transient response of system components. EMTP simulations can be performed on personal computers, which are available to students and are an integral part of practicing engineer's equipment.

Several large utilities have built relay testing laboratories that subject commercial relays to transient waveforms [1,2,3]. Laboratory testing is accurate and complete, but the costs of these laboratories are high. Relay test laboratories are beyond the means of most universities, so a more cost effective method to teach relay testing is needed. This is even more important when many of the students enrolled in the class are distance education students viewing the course via videotape. A relay testing method based entirely on computer simulations provides a cost-effective solution, but it also must be both accurate and user-friendly to provide an effective

learning experience.

There are several methods that can be employed for steady-state, dynamic and transient testing of relays. For steady-state and dynamic testing, signal generators can be used to inject appropriate signals to the relay. A relay model implemented in EMTP can act to open and reclose circuit breaker models in a network, providing a closed-loop picture of the interaction between the relay control system and the modeled power system.

Experiences using the widely-available Alternative Transients Program (ATP) version of the EMTP in a graduate protective relay course will be presented. The objective of the course is to teach relaying, rather than proficiency with ATP. Therefore the students were given datafiles that were set up to be easily modified to observe the relay behavior. Experiences and challenges in using ATP with the remote students will be reported on.

II. Background

A. The Students

A limited number of electrical engineering departments at universities are specializing in power system engineering and offering graduate level courses in protective relaying. Engineers working at electric utilities or for consulting firms are enrolling in graduate courses offered via videotape along with graduate students at other universities.

These "distance education" students generally want a more applied course which they can use at their jobs or that contributes to their graduate education. The authors incorporated PC-based EMTP relay simulations as a means for the on-campus and distance students to "see" the response of protective relays to power system events.

B. Protective Relaying

Protective relaying is a specialized field within electric power engineering. Students must have completed several courses in power engineering before they start their study of relaying, hence this course is often offered in graduate programs. On the other hand, the course described in this paper is still considered an introduction to this vast field. The first author may offer more advanced courses in the future.

It is very important for students who work in relaying for an electric utility to be very exact and certain in their professional practice. A mistake in a relay setting or a false relay response can cause the entire electric power protective system to misoperate in one of two ways. The protective system may fail to detect an abnormal condition or may overreact when there are no problems. Either type of error can cause system outages which affect homes, hospitals, and commerce.

C. Transient Relay Testing and Simulation

Industry standard practice uses specialized and expensive electronic equipment, called relay test sets, to verify relay steady-state responses. A relay field engineer or a relay technician would use test sets to test relays in the electrical power plant or substation. The test set supplies phasor voltages and currents to physical relays to verify operating characteristics.

The objective of steady-state testing of a mho relay is to obtain a circular characteristic when the

data are plotted on a complex plane of resistance vs. reactance (R-X) plane, as shown in Fig. 1.

One common testing technique is to hold the angle between the sinusoidal voltage and current signals constant. The voltage is fixed and the current is increased in steps until the relay measuring unit trips or a maximum value is exceeded. The angle between the signals is then varied and the process repeated. A variation is to hold the current constant and decrease the voltage until the measuring unit trips or a minimum is exceeded.

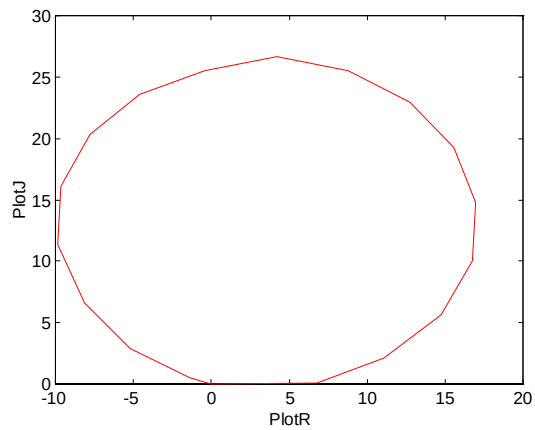

Fig. 1: Mho circle generated by EMTP simulation.

To mimic this process, an EMTP model called TESTSETV.DAT was developed. This model "stands alone" as there is no direct transient signal input from the EMTP program. Phasor values are generated by using resident sine and cosine functions. The test set program uses two IF-THEN-ELSE logical loops to mimic commercial equipment. The first, or inner loop, holds one signal constant and varies the other signal. After a set waiting time, the program decreases the voltage (increases the current) and waits for a measuring unit response. This process continues until the output trip signal from the measuring unit model changes from zero to one or an extreme value is reached.

A second, or outer loop, controls the angle between sources. When the model trips, the phasor impedance is calculated. The angle between the signals is next incremented by a set amount, variables are reinitialized, and the process continues. The outer angle loop ends when a preset maximum angle is reached or the EMTP simulation time is reached.

The real and imaginary parts of a phasor are stored as arrays (vectors). The voltage and current values calculated by TESTSETV are passed to the relay simulations. Rectangular components of the impedance are written to a computer file for plotting. On-screen plotting can be done with an auxiliary plotting program available with the version of EMTP, or by exporting the data to a general purpose program such as MATLAB. Fig. 1 shows the output an example of the output generated.

III. Applying EMTP in the Classroom

There are many benefits of including computer simulations in an abstract course with on-campus and remote students. As discussed earlier, the University of Idaho cannot afford a $500,000 relay testing laboratory. Computer simulations give both on-campus and remote students some "hands on" experience. The students can simulate short-circuit faults on the power system and see how

the protective relay responds (or does not respond). Students are introduced to the different levels of relay testing: steady-state, dynamic and transient. This gives them a chance to observe the behavior of the basic relay algorithms covered in the balance of the course.

A. The Alternate Transients Program

There are several versions of EMTP: ATP [4], Electric Power Research Institute EMTP Development Coordination Group (EPRI-DCG) [5], and Manitoba HVDC Research Centre [3]. The ATP version of EMTP was used in the course for several reasons. ATP is free to most users, the licensing is easy to obtain, and shipping costs are low. The first author installed ATP in the University of Idaho EE computer lab. Off-campus students had no trouble obtaining ATP for their PCs as well. However, ATP is also rather difficult to install, and some students experienced installation problems, as described below. In addition, the relay models developed by the second author were written in the MODELS simulation language which is only supported by the ATP version or EMTP.

III. ATP Assignments and Objectives

The first author offered a course at the University of Idaho during the Fall semester of 1996. Three students attended the on-campus lectures and twelve students enrolled via the outreach program. ATP was introduced mid-semester. The second author was a relay field engineer for ten years before graduate study at the University of Idaho. He came to the Moscow, Idaho campus to give a series of guest lectures on current industry standards for relay testing, relay simulations, and EMTP relay modeling. He developed the relay models and TESTSETV program in previous research [6,7].

The original intent of the course was to introduce students to the general concepts of protective relay systems. To supplement this, the students simulated power system faults on the different parts of the power network and investigate how the relay models responded. The power network modeled a portion of the Bonneville Power Administration (BPA) system. The students simulated Zone 1 faults (within the protected transmission line section), Zone 2 faults (beyond the protected line section, the relay should respond after a delay), and reverse faults (which the relay should not respond to). Due to course time spent in making the ATP software work, there was not sufficient time for the students to do the above work. This work was offered as extra credit (see below).

IV. Results and Assessment

The results of using ATP for class assignments were mixed. The students had little difficulty acquiring ATP licenses for home use. However, many of the students had difficulty installing ATP. Some of the problems were fairly simple to solve by E-mail or over the telephone. The most common problem was failing to reboot their computers after modifying the “config.sys” to support the DOS extender required to run ATP.

However, the DOS extender, Salford DBOS, caused more installation problems for several students. One student had a problem installing and running ATP on a computer at work until the computer was rebooted without the network software running. Several students had problems running the plotting program distributed with ATP, called TPPlot. The version of DBOS distributed with ATP, does not support very many high resolution video drivers. As a result, the

students were unable to view plots of their results. One of the students posted the problem on the ATP E-mail listserver. The proposed fix was a public domain program available by anonymous FTP. This solved the problem for many of the students. However, one student had a video driver that wasn't supported this way either. The first author helped the student export the data in a format that could be read into a spreadsheet or to MATLAB.

Another student had access to a newer version of DBOS, which does not suffer from the problem with high resolution video drivers. This student also convinced the parties distributing ATP to begin to move toward upgrading the version of DBOS used for the general distribution.

Once the students had ATP installed, they all did quite well on the first assignment, which was to run TESTSETV to determine the mho circle for a distance relay and then vary settings to see how the mho characteristic changes.

However, there was not sufficient time to assign the application of the same distance relay in a power system to observe dynamic and transient responses. The problem was instead given as an extra credit assignment. This assignment also included EMTP data files demonstrating digital filtering techniques for microprocessor relays, and exposing some pitfalls one can find when simulating digital relays in EMTP [8]. Roughly half of the off-campus students did the extra credit assignment, and most of them did quite well.

V. Considerations for the Future

With the experience gained in this first use of relay models, this approach may be better suited to a second graduate level course. There would then be more time available to simulate relays for protecting transformers, generators, and other apparatus.

This semester the first author and the students spent too much time installing the software. The EMTP files were too complicated for many students to easily find the key parameters and change those parameters. Next time this course is offered more time will be spent developing models of relays and explaining the relay model file in more detail so students can more easily modify relay parameters.

One of the courses offered (on-campus and remotely) in the University of Idaho graduate power program is Power System Transients. This course teaches and uses EMTP to study the causes and effects of high-voltage transients on transmission lines, power transformers, and other equipment. The first author will definitely use ATP in the transients course. EMTP relay models will be demonstrated to students in an introductory power systems course and in the first relay course. Student manipulation and use of relay models would be saved for a second course in relaying.

VI. Conclusions

The combination of power system simulations generated by EMTP and models of protective relays have been a valuable addition to the graduate course on power system protection. Relay simulations demonstrate relay performance in a cost-effective manner, avoiding the cost of setting up a relay testing laboratory. Computer simulation also allows remote students to have the same laboratory experience as on-campus students using industry standard software.

VI. References

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