Visualization and Animation of Protective Relay Operation

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Abstract: The evolution of software engineering, multitasking environment, object oriented programming and symbolically assisted simulation methods have enable the creation of interactive simulation environments that come close to providing a virtual experience of the actual system. These systems are useful for a variety of engineering and educational purposes. An important issue in power engineering is the understanding of protective relay operation and response to system disturbances. This paper focuses on protective relaying applications and the use of a virtual environment for the animation and visualization of protective relaying applications. The paper describes the virtual environment and the interaction of animation and visualization of protective relaying modules. The animation and visualization can be performed in the virtual environment or in an off-line environment where the system disturbance is captured into a COMTRADE file and “played back” into the animator/visualizer. Two examples of protective relay types are presented: (a) a modified mho relay and (b) a transformer differential relay. This tool is extremely valuable for educational purposes. Another potential application is digital relay testing.

Introduction

Relaying has always played a very important role in the security and reliability of electric power systems. Many events of outages and blackouts can be attributed to the misoperation of relaying schemes or inappropriate relaying settings. Traditionally, a two-step procedure is applied to minimize the possibility of such events. First, in the design phase, comprehensive analyses are utilized to determine the best relaying schemes and settings. Second, if such an event occurs, an exhaustive post mortem analysis is performed to reveal the root cause of the event and what “was missed” in the design phase. The post mortem analysis of these events is facilitated with disturbance recorders.

In this paper we propose a new approach to this old and perpetual problem. The proposed approach is driven by two factors: (a) recent developments in software engineering and computer graphics and (b) the new generation of power system digital-object oriented relays. Specifically, it is possible to integrate relay animated visualization objects within a virtual simulator of an electric power system. In this case, the relay visualization objects may contain a generic algorithm for a specific relay class, or alternatively, be interfaced to a specific digital relay algorithm (provided by a specific relay manufacturer). Using this approach, simulated system data can be used to study relay response, under any desired relay setting. This approach has been enabled by recent advances in software engineering that have made it possible to develop dynamic system simulators that operate in a multitasking environment. The additional graphical user interface tools and hardware accelerated graphics algorithms make the final product an indispensable tool to the understanding of the operation of the system.

This paper presents the new approach that is based on the virtual simulator. The paper presents a brief description of the virtual simulator, followed by detailed descriptions of specific relay visualization examples, including differential relays and distance (impedance) relays. Note that the presentation of the paper will be augmented with live demonstration of these examples.

Description of the Virtual Power System Environment

The internal structure of the Virtual Power System environment is illustrated in Figure 1. This architecture was developed with consideration on the minimal representation of system components and the requirements of a virtual environment. In the background is the network solver that is a time domain simulation program. The network solver is based on the representation of each system component with its algebraic companion form (ACF) [1]. The ACF is developed from the integro-differential equations of a component by numerical integration. The ACFs of all components in a system are related via the connectivity constraints. Application of the connectivity constraints yields
a quadratic network equation that is solved at the network solver.

The network solver is continuously executed providing the simultaneous solution of the entire system and determines the state of each component of the system. This information is passed back to the individual devices for animation and visualization of a specific component or groups of components. The Virtual Test Bed has been developed in a multitasking environment, thus allowing parameter changes and immediate system response observations.

The paper discusses a number of power system relaying virtual laboratory exercises. Each exercise uses visualization and animation to enhance the educational value of the exercise. Specific examples are:

2. Distance and Mho relay operation.

Each exercise can be demonstrated on a single PC. In the presentation of this paper, these examples will be demonstrated “live”. In subsequent paragraphs, brief descriptions of specific examples are given below.

Example 1: Distance and Mho Relay Operation

This example illustrates the visualization of the operation of the modified impedance relay (Mho Relay). The operation of this relay is based on the apparent impedance that the relay ‘sees’ and the trajectory of this impedance. The example system used for this exercise is illustrated in Figure 2. The system consists of a generator, a transmission line, a step-down transformer, a passive electric load, and an induction motor driving a fan. We focus on the relay operation visualization for the following two events:

(a) An induction motor start-up followed by a single-phase to ground fault on the Delta side bus of the transformer.

(b) An induction motor start-up followed by a three-phase fault on the Wye side bus of the transformer.

The relay visualization object (illustrated in Figures 3 and 4) accesses the three phase voltage and current waveforms from the virtual simulation program. Subsequently, it computes the phasors of the voltages and currents as well as the sequence components of these voltages and currents. From this information, the apparent impedance seen by the relay is computed and displayed.
There are many ways to visualize the operation of this relay. Figures 3 and 4 illustrate one of the options. Specifically, the voltage and current phasor magnitudes are displayed as bar graphs on the left side of the visualization object window. The impedance trajectory is displayed over a complex impedance plot, (real/imaginary components), which also includes the relay setting zones (gray circles, see Figure 3).

Figure 3 shows the relay operation for event a (induction motor start-up and high side single-phase to ground fault). In this case the impedance trajectory does not visit the trip “region” of the relay. Figure 4 shows the relay operation for event b (induction motor start-up and low side three-phase fault). In this case the impedance trajectory visits the trip “region” of the relay.

It is important to note that the user may select what phasors to display, i.e. phase voltages or currents or any of the sequence components of the voltages or currents. In this example, the positive sequence phasors of the voltage and current as well as the positive sequence of the apparent impedance is displayed. Figure 5 shows the visualization object parameter setup window, which allows the user to select relay parameters, display options, as well as assign the recorded waveforms to the appropriate relay inputs.

Figure 5. Mho Relay Setup Window

Example 2: Transformer Differential Relay

Another important protective relaying example is the differential relay. In this example we present the visualization of a differential relay scheme for a delta-wye connected transformer with tap changing under load. The system may operate under steady state, or under transient conditions. The effects of tap changing on the operation of the relay as well as the effects of transformer inrush currents can be demonstrated. The example system is shown in Figure 6. It consists of an equivalent source, a transmission line, a 30 MVA delta-wye connected transformer, a distribution line and an electric load. The differential relay receives as input the transformer terminal currents.

Figure 6. Example Test System For Transformer Differential Relay Animation

Again, there are many ways to “visualize” the operation of this relay. Her one such way is described. Specifically, the differential relay visualization object window is illustrated in
Figure 7. It is based on the electromechanical equivalent of a differential relay. It contains RMS bar-graph and phasor displays of the differential relay restrain and operating coils, as well as a bar-graph of the net force applied on the relay trip switch arm. Restrained coil current displays are in red, operating coil current displays are in green, and the switch force display is in blue color.

All displayed quantities provide the state of the relay at a time instant corresponding to the simulation present time. As the simulation time progresses, the relay visualization window is dynamically updated providing an animation effect.

The importance of this visualization object is that one can study the effects of various parameters and phenomena on the operation of the relay. Relays can be tested for various sets of recorder or simulated waveforms. For example, a relay can be tested for various tap settings of the monitored transformer in order to determine the optimal level of percent restraint for the relay. Another example is testing the relay operation during transformer energization. Using recorded or simulated inrush currents for various types of breaker closing schemes, the optimal relay settings can be determined by observing the relay operation. Note that the user can select the relay restrain and trip settings, the ratios of the CT’s feeding the relay as well as the CT connection (Wye/Delta) using the parameter setup window illustrated in Figure 8.

Figure 8. Transformer Differential Relay Parameter Setup Window

Interfacing With Digital Relays

The Virtual Power System program uses a flexible open architecture. Plug-In tools such as the presented relay visualization examples can be easily added. These tools can be directly linked with the program or attached in run-time as “Dynamic Link Libraries”. We propose that the natural extension of the work reported in this paper is to use this feature to interface with commercially available digital “relays” from any manufacturer. The word “relay” is in quotation marks to indicate that the relay is simply a digital program that takes inputs of voltages and currents, performs an analysis of this data, applies logic and issues a decision. This program can be packaged into a Dynamic Link Library.

If this DLL is “linked” with the virtual test bed, in the sense that the inputs come from the virtual test bed, then the specific relay can be evaluated within the virtual test bed environment. The paper proposes an interfacing procedure. This procedure consists of modeling in the virtual test bed the instrumentation channel (i.e. instrument transformers, control cable, attenuators, etc.) and the output of the instrumentation channel is input to the relay object (or DLL). Note that the relay object is the manufacturer’s software and therefore the response of this relay will be identical with the actual relay in the field. The paper proposes a specific standard for this interfacing. Assuming acceptance of this standard by the relay manufacturers, the virtual test bed could be used to evaluate any commercially available relay that meets this standard. This process protects the manufacturer’s software since the virtual environment interfaces directly with the DLLs and therefore the user of the Virtual Environment does not have access to the source code of the manufacturer’s software. This tool will be invaluable in two respects: (a) to test commercial relays within the virtual laboratory, an
inexpensive testing procedure, and (b) to train students and young engineers in the art of protective relaying.

Conclusions

This paper has discussed and presented protective relaying visualization objects implemented as tools of a general virtual environment software. We have discussed our recent work towards the development of visualization objects of various protective relays. Two examples of protective relay visualization objects have been presented: (a) a distance relay and (b) a transformer differential relay. From these examples, it is clear that this approach can be quite beneficial from the educational point of view as they can provide insight of the system under study that are impossible in a physical laboratory. In addition, the relay visualization objects are valuable for testing commercially available digital relays assuming that they can be encapsulated within a standard MS-Windows-DLL. The presentation of the paper includes a live demonstration of these examples. It is important to note that much more work remains to develop a comprehensive library of relay visualization objects for the plethora of existing power system relaying devices.

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References


Biographies

A. P. Sakis Meliopoulos (M ’76, SM ’83, F ’93) was born in Katerini, Greece, in 1949. He received the M.E. and E.E. diploma from the National Technical University of Athens, Greece, in 1972; the M.S.E.E. and Ph.D. degrees from the Georgia Institute of Technology in 1974 and 1976, respectively. In 1971, he worked for Western Electric in Atlanta, Georgia. In 1976, he joined the Faculty of Electrical Engineering, Georgia Institute of Technology, where he is presently a professor. He is active in teaching and research in the general areas of modeling, analysis, and control of power systems. He has made significant contributions to power system grounding, harmonics, and reliability assessment of power systems. He is the author of the books, Power Systems Grounding and Transients, Marcel Dekker, June 1988, Lightning and Overvoltage Protection, Section 27, Standard Handbook for Electrical Engineers, McGraw Hill, 1993, and the monograph, Numerical Solution Methods of Algebraic Equations, EPRI monograph series. Dr. Meliopoulos is a member of the Hellenic Society of Professional Engineering and the Sigma Xi.

George Cokkinides (M ’85) was born in Athens, Greece, in 1955. He obtained the B.S., M.S., and Ph.D. degrees at the Georgia Institute of Technology in 1978, 1980, and 1985, respectively. From 1983 to 1985, he was a research engineer at the Georgia Tech Research Institute. Since 1985, he has been with the University of South Carolina where he is presently an Associate Professor of Electrical Engineering. His research interests include power system modeling and simulation, power electronics applications, power system harmonics, and measurement instrumentation. Dr. Cokkinides is a member of the IEEE/PES.