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ADVANCED TESTING METHODS FOR PROTECTIVE RELAYS USING NEW DIGITAL SIMULATOR DESIGNS

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SUMMARY

This paper discusses new testing methods as means of improving the performance of the protection system. Present test practices and existing limitations of the standard test equipment are outlined. New developments of digital simulators are mentioned to indicate their enhanced capability when compared to the standard test equipment. As a result of the simulator availability, new methodology for relay testing is introduced. Several examples of the use of new test methodology, utilizing digital simulators, are presented as an illustration how the new methodology can contribute to the improvements in the protection system performance. Future relay test requirements and practices are given at the end.

Keywords: Protective Relay–Testing–Digital Simulator–Modeling–EMTP

INTRODUCTION

The main focus of this paper is on new ways of improving the protection system performance. The issue of improved performance can be discussed as it relates to design and manufacturing practices, installation procedures, maintenance, diagnostic techniques and testing methods. The emphasis in this paper is placed on new testing methods. The new testing methods are viewed as means of improving the performance of the protection system. The discussion includes the use of testing methods in evaluating both new relay designs and the ones that are already in service.

One of the driving forces in the considerations of the new testing methods by the utilities is development of new digital simulator designs that provide enhanced performance characteristics at an affordable cost [1]. The new digital simulator designs are providing quite powerful simulation, testing and evaluation tools that allow the utilities to make an extensive assessment of relay designs [2–6]. The assessment can be completed in a relatively short time. The final outcome is the selection of an appropriate relay design for future uses or explanation of an undesirable operation of an existing one.

The discussion given in the paper is based on the fundamental premise that correct relay design and operation need to be first defined and verified. Once a clear performance reference is established, any further assessment of the protection system reliability can be pursued.

In the light of such a premise, the paper provides an overview of the present practice regarding the test methods [7]. It emphasizes the existing limitations in the ability to establish a full qualification of the performance of a protection system using the standard test equipment and methodology. The next topic is discussion of the new test equipment and methodologies made available with the new digital simulator developments. Several examples of the use of new testing methods and simulation tools in evaluating the performance of the new and existing protection systems are provided. Examples based on recent practices undertaken by four different utilities in the U.S.A. are presented [8–12]. The paper closes with a discussion of the impact of new practices. The related requirements and consequences that may have to be considered if the proposed methods and tools are to be widely used in the future are outlined.

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PRESENT PRACTICES AND EXISTING LIMITATIONS

A common practice today is for utilities to use standard portable test sets to evaluate new relay designs or to verify operation of the existing ones. In addition, it is quite common for relay vendors to perform extensive design tests for a new relay product at the development stage. This results in a recommended practice of performing only the type tests in any future evaluations of this relay either at the production stage or for the application in the field. The portable test sets are well designed to support the test procedures recommended by the vendors and the utilities have well trained personnel to carry out such tests. This practice worked rather well in the past for most of the relays and applications. In particular, if the overall performance of the protection system was satisfactory over a long period of time, the utilities did not have any particular reason to explore new ways for the testing improvements.

A necessity to reexamine the existing relay test practices surfaces in the following cases:

- an unexpected relay operation is encountered in the existing protective system
- an existing protection system needs to be replaced with a new design implementing new technology
- a new relaying application needs to be considered due to an expansion of the power system
- a precise characterization of the relay performance needs to be established as a reference for new reliability monitoring and evaluation practices for a protection system

Several examples of the above mentioned cases are discssed later on in this paper. A summary of the examples is given in Table I.

The test methods and equipment presently used may have limitations when utilized in dealing with the specific situations described in Table I. The following is a list of examples of the requirements for test procedures and equipment that may have to be considered in order to deal with the mentioned cases, and yet may not be a part of the everyday practice:

- Extensive power system modeling and simulation capabilities, including improved models for nonlinear elements and instrument transformers
- Automated procedures for generating a large number of fault cases and test runs
- Capability to perform simultaneous testing of multi-terminal relaying system
- Ability to test real-time interactions between the relay and the power system

Table I. Cases Requireing Application of New Test Methods

Situation	Examples
Unexpected Relay Operation (References [10], [11] and [12])	• Nuisance tripping of ungrounded capacitor banks • Saturation of auxiliary current transformers • Tripping of a generator unit due to an inrush of a nearby power transformer
Evaluation of New Relay Designs (References [8], [9])	• Comparative testing of five different distance relays which utilize various technologies
New Relaying Applications	• Selection of a relaying system for newly erected transmission line with series compensation
Characterization of Performance of a Relaying System	• Evaluation of relaying panels using high power test signals with simultaneous testing of several relays

- High power capacity to inject current and voltage signals into excessive relay burdens
- User-friendly graphical interfaces to support creation of power system models, selection and specification of tests, automated execution of tests, and automated analysis of test results
- Improved performance and flexibility allowing automated testing using very accurate phasor and transient test waveforms

The portable test sets are not designed to handle such an elaborate set of requirements. Even though the latest improvements in the portable test sets may meet some of the mentioned requirements, there is no test set that can meet all the requirements. On the other hand, the new designs of the digital simulators are implemented with the main goal of meeting exactly the mentioned requirements.

NEW DEVELOPMENTS OF DIGITAL SIMULATORS

This section gives a brief overview of a new simulator design recently developed by Texas A&M University. This discussion is only used to illustrate the capability that the new designs offer. The new capability is a necessary condition for defining, and promoting, the new methods for relay testing since the existing portable test sets can not be used to implement the new methods.

The mentioned simulator developments were commissioned by the Electric Power Research Institute (EPRI) and several other utilities through a variety of different contracts. However, a common set of development requirements and goals can be summarized as follows:

- The simulator designs need to be implemented using commercial computers and interfaces as much as possible to assure future upgradeability and portability
- The implementation needs to be modular to allow full flexibility in configuring a wide range of designs from a low, to medium, to high cost providing different performance capabilities
- The simulators need to have extensive hardware/software capabilities for power system modeling, automated testing and automated test result analysis
- The user interfaces need to be friendly and simple to use

As a result of these projects, a modular digital simulator design was developed [2]. It enabled implementation of a variety of digital simulator configurations, as summarized in Table II.

NEW METHODOLOGY FOR RELAY TESTING

The new methodology includes two steps:

- Power System Modeling
- Relay Testing Approaches

Each of the steps are discussed separately.

Power System Modeling

The initial part of any simulator study is the development of a theoretical model of the portion of the power system being studied. This model, while based upon individual element models, almost certainly depends upon a number of variables that are poorly determined, or based upon an individual modeler's resources. Thus, the initial model should be considered to be a first approximation of the true system. This model is adequate for the testing of equipment to determine the suitability of a particular equipment design for the particular application, or for the investigation of a design's response to the coarser aspects of the application. It is usually not adequate for investigating subtler equipment misoperations, optimizing equipment settings, evaluating new relay designs, or for characterizing a relaying system.

Once an initial model has been developed, it is imperative that the model is compared against actual field data taken from the actual system being modeled. This data may be derived from existing fault recorder traces of extremes of operation, or from field tests performed specifically to provide

Table II. Digital Simulator Configurations

Configuration Type	Performance Characteristics
PC-Based Digital Simulator (Reference [2])	• Automated phasor testing • Generation of fault transients using EMTP • Replaying of fault transients recorded by digital fault recorders (DFRs) • Signal processing software for test waveform analysis • Open-loop testing
RISC-Based Open-Loop Digital Simulator (References [5], [6])	• Two-terminal back-to-back testing of a relaying system • Graphical user interface for EMTP • Automated generation of fault waveforms and batch processing of test cases • Automated analysis of test results • Data base capability for storing test results and cases
RISC-Based Real-Time Digital Simulator (References [3], [4])	• Multi-terminal configuration for simultaneous testing of up to three relay terminals • New electromagnetic transient program for real-time simulations • Both open-loop and real-time test modes • Graphical user interface for automated fault generation and testing

the data. For whatever reason, there is almost always some difference between measured waveforms and those produced by the model, regardless of the skill and care taken in developing the initial model. In studies where the equipment under test is likely to respond to these differences, the initial model must be modified to produce, as closely as practical, waveforms identical to those recorded. Experience has shown that these modifications are usually not difficult, and can lead to waveform matches that are almost perfect.

The existence of a verified model allows the user to investigate the effects of future changes in the system, or to confidently investigate misoperations due to unforeseen circumstances. Additionally, the verified model can be used to provide waveforms for routine maintenance testing where the portable test equipment cannot produce the appropriate stimulus.

Relay Testing Approaches

The relay testing approaches can be classified in two broad categories, namely design and application. The design testing is aimed at verifying relay performance characteristics as specified by the vendors. The application testing is aimed at confirming that a given relay can adequately perform in a given application.

A variety of options in using test waveforms and applying the mentioned tests are illustrated in Figure 1. It should be noted that this figure gives only some typical examples while many other test approaches can also be defined.

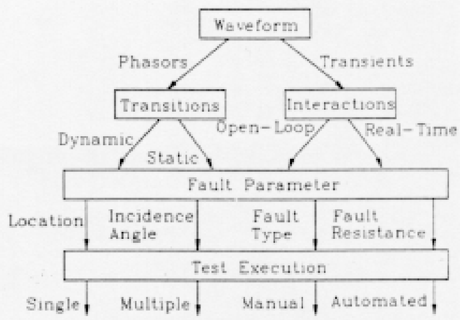


Fig. 1. Typical Relay Test Approaches

EXAMPLES OF THE NEW IMPROVEMENT METHODS

Case I: Selection of Relays for Series Compensated Lines

In the Western US, most series compensated lines are considered critical for system operations. Outages, particularly outages due to incorrect relay operation, can have a severe economic impact and may degrade system stability. This has led to the use of digital simulators to qualify, test, and optimize the relays installed on such lines. Two of the US utilities which employ digital simulators regularly (BPA and WAPA) have developed an extensive testing procedure especially for series compensated lines.

The response of protective relays on series compensated transmission lines is one of the more critical uses for a digital simulator. The demand for new test equipment arose because standard test equipment, available from a number of vendors, is physically incapable of producing the transient waveforms typical of a series compensated line.

The use of the digital simulator has introduced a new relay testing and evaluation procedure as summarized in Table III.

Table III. New Relay Performance Improvement Test Method for Compensated Lines

Methodology Step	Description
EMTP Model developed for the new line	Model is developed based upon design data available for the new transmission line
Relay Testing Using EMTP-generated waveform	Settings are defined and relays are tested A ranking of potential relay candidates is performed
EMTP Model tuning based on stage fault tests and related simulations	This is performed at commissioning of the line. Comparison of simulated and recorded waveforms is performed and appropriate model adjustments are made.
Additional relay testing to tune relay settings	The installed relays are tested again to optimize their settings.

Experience reported by many utilities and vendors, shows that understanding the response of a relay to transients may be critical in properly applying the equipment. In fact, some relay designs make use of various types of filters that allow the relay to respond correctly only to realistic waveforms. These transients can be classified in a number of ways, but for our purposes, we may consider them to be:

- High Frequency Transients – Caused by the series capacitor interaction with the inductive line component, the typical light dampening of EHV lines, high frequency ringing in the CVT's, high frequency components caused by either the fault arc or a gap flashing.
- Low Frequency Components – Sub-synchronous oscillations, local mode oscillations, etc. that are typical of systems which have a need for a series compensated line.
- Nonlinear Effects – These may be caused by a number of elements in the power system, but are typically due to conduction of the Metal Oxide Varistors (MOV) used to protect the series capacitors, protective gap firing (either triggered or voltage level induced), saturation of power reactors or power transformers, or instrument transformer saturation.

Furthermore, contingencies and operating methods tend to produce fault scenarios that are very difficult to test by using standard equipment. The more obvious contingencies that need to be explored include: platform faults, MOV failures, incorrect gap flashing (which, for gaps that are not command triggered, would include uneven or failed conduction), line-side reactor failures, and, where applicable, parallel line faults. The operating methods which will have an impact on the relay response include: the protection scheme, single-pole or three-pole operation, and the type of reclosing implemented. Other areas of investigation may be that of the arc extinction reactors when operating in a single-pole reclosing mode, and required operating speed.

No discussion of the difficulties of protecting series compensated lines would be complete without noting that, depending upon the system configuration around the compensated line, the relays protecting adjacent lines must be tested to ensure that they do not trip for faults on the compensated line. Older distance protection schemes are particularly prone to misoperations due to capacitive faults in their reverse zone.

Table IV. New Relay Performance Improvement Test Method for Distance Relays

Methodology Step	Description
EMTP Modeling	• Model development using design and field data • Detailed modeling of instrument transformer • Model "calibration" using waveforms from a "known" fault case
Design Testing using one-terminal digital simulator (Reference [9])	• Measurement of the static relay operating characteristic • Measurement of the dynamic relay operating characteristic
Design Testing using two-terminal digital simulator (Reference [10])	• Evaluation of the relay operating characteristic under "in-feed" conditions • Evaluation of the operating times of the relaying scheme including the communications
Application Testing using single-terminal and two-terminal digital simulator	• Testing of selectivity and trip times for faults on short lines with mutual coupling • Testing of selectivity and trip times for faults on long parallel lines with weak infeed

Case II: Distance Relay Selection

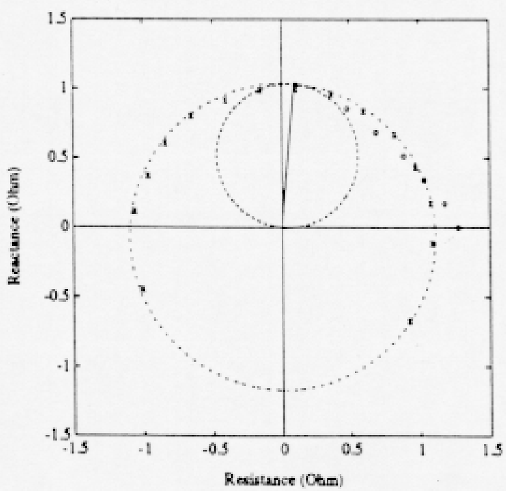
A typical situation in some of the utilities in the USA is that most of the protection relays in service are electromechanical. A goal is to evaluate relay designs. This process may be quite involved and may include the following two steps:

- Design testing
- Application testing

In recent evaluation studies, Houston Lighting & Power Company has pursued evaluation of 5 different designs of distance relays. One of these relays was an electromechanical design that is presently used to protect HL&P's 345kV lines. One of the designs was a solid state one, and the remaining three were microprocessor-based designs.

A summary of the tests performed is given in Table IV.

The tests were performed using an advanced, two-terminal, open-loop digital simulator. Some typical comparative test results are shown in Figures 2 and Table V. It can be seen that the study has indicated that not all of the designs have the same performance for specific test cases and situations. Furthermore, some of the designs have unacceptable, or random, behavior for particular applications, and therefore, may not be suitable for future use in the HL&P system.



. . . . -: Theoretical steady-state characteristic
-.-.-.-: Theoretical Dynamic characteristic
x: Test results using one-terminal model
o: Test results using two-terminal model

Fig. 2. Typical Operating Characteristic Test Results for One- and Two-Terminal

Table V. Number of Relay Operations for 30 Tests Applied (Relays set at 85%)

Fault Type Locations	Rly A	Rly B	Rly C	Rly D*	Rly E*
A–G 50%	30	30	30	0	0
A–G 75%	30	30	30	0	0
A–G 80%	30	30	30	0	0
A–G 90%	0	20	0	0	0
A–G 95%	0	19	0	0	0
BC 50%	30	30	30	30	30
BC 75%	30	30	30	30	30
BC 80%	30	30	30	30	30
BC 90%	0	12	0	0	0
BC 95%	0	0	0	0	0
ABC 50%	30	30	30	30	30
ABC 75%	30	30	30	30	30
ABC 80%	30	30	30	30	30
ABC 90%	0	30	0	0	0
ABC 95%	0	0	0	0	0
BC–G 50%	30	30	30	30	30
BC–G 75%	30	30	30	30	30
BC–G 80%	30	30	30	30	30
BC–G 90%	0	14	0	0	0
BC-G 95%	0	0	0	0	0

* Relay D and Relay E do not have a ground distance element.

Case III. Analysis of a Transient Behavior of CT and Auxiliary CT Connections

A common situation in protective relaying is to have CTs with different ratios in the same substation. When these CTs need to be connected to the same protective equipment, auxiliary current transformers (Aux CTs) are widely used to match the ratios. If the V–I characteristic of the Aux CT is different than the V–I characteristic of the main CT, then the Aux CT can cause relay misoperations during system faults.

In a recent study, Commonwealth Edison Company has studied Aux CT transient behavior using EMTP simulations. The steps used in this study are described in Table VI.

The power system section studied is given in Figure 3. In this case, the fault occurred at location "F", first between phase C to ground, and then after 20 ms, phase B flashed to ground. CTs at circuit breaker CB1 are of 2000/5 A ratio. CTs at circuit breaker CB2 are of 1200/5 A ratio. To achieve a full ratio of 2000/5 A, Aux CTs of 1.67/1 ratio were added. Circuit breaker CB2 is normally open, but Aux CT secondaries were permanently connected in parallel to the CT 2000/5 A, as shown in Figure 3.

Table VI. EMPT Study Steps for CT Evaluation

Methodology Step	Description
CT Model Development	• EMTP Modeling using V–I curve and type 96 nonlinear element
V–I Curve Measurement	• Curve measurement • Comparison between measured and vendor curves supplied
Validation of CT Models	• Comparison between simulated and actual CT responses
Development of the Power System Model	• EMTP modeling of the power system section given in Figure 7
Fault Simulations	• Generation of CT secondary waveforms for faults of interest

To evaluate Aux CT behavior during the fault, first simulation included only phase C to ground fault. Figure 4 shows Aux CT and 2000/5 A CT secondary currents. It is evident that the Aux CT secondary current is distorted while the 2000/5 A CT's is not. The sum of these two currents through the DFR is also distorted as shown in Figure 5.

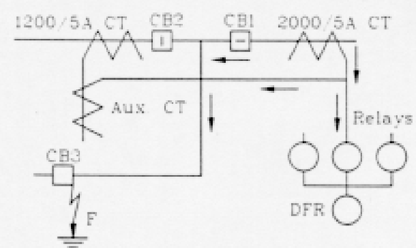


Fig. 3. System One–Line Representation

Phase B was also involved in the fault after 20 ms. Therefore, the next simulations included a phase C to ground fault followed by a phase B to ground fault. Since the recorder was monitoring the neutral, it could see the sum of phase C and phase B currents as presented in Figure 6. The recorded current is shown in Figure 7. Figures 6 and 7 show that simulated current waveforms are very close to those recorded by the DFR. The cause of the current distortion is the Aux CTs. First, because they were permanently connected to the 2000/5 A CT secondaries, while the main 1200/5 A CTs did not have fault current flowing through them. Second, voltage knee points of these Aux CTs were at 100 V, and whenever voltage at the secondary terminals exceeded this value, they saturated causing CT secondary current distortion.

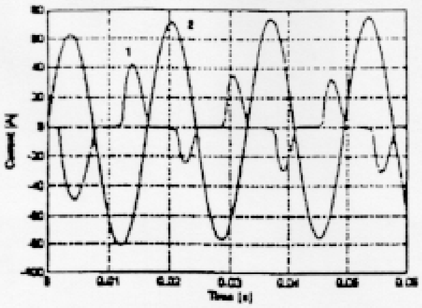


Fig. 4. EMTP Simulation of the Aux CT (1) and 2000/5 A CT (2) Secondary Currents for Phase C to Ground Fault

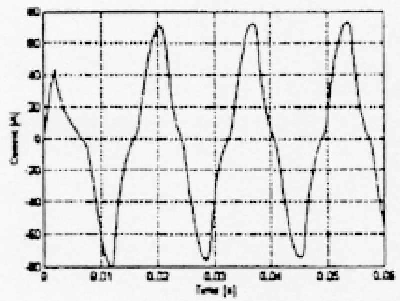


Fig. 5. Sum of the Aux CT and 2000/5 A CT Secondary Currents for the Phase C to Ground Fault

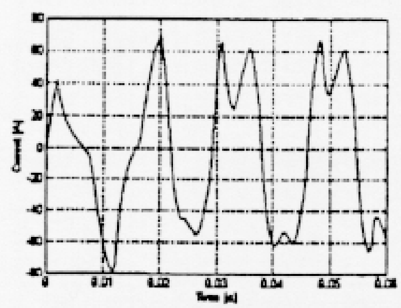


Fig. 6. Simulated Current Waveform seen by DFR for the Phase C to Ground Fault followed by Phase B to Ground Fault

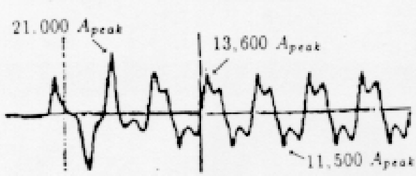


Fig. 7. Recorded Current for the Case Shown in Fig. 4

Case IV: Trouble Shooting of Generator Differential Relay Operation

A situation where CTs of different design are used in a generator differential protection scheme is studied in this case. A one-terminal digital simulator is used to recreate the fault waveforms. Three different relay designs are evaluated using the waveforms, including the relay design that has experienced a misoperations. The final outcome of the study is selection of a relay design that did not have misoperations under a number of different simulated operations in the power system.

This situation was studied by Houston Lighting & Power Company. A simplified one line diagram of the power system section of concern is given in Figure 8. The differential generator protection had a false operation under no-fault conditions, as described below.

The test methodology is descirbed in Table VII.

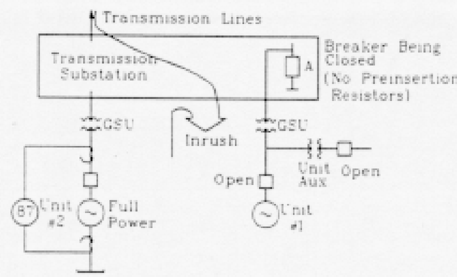


Fig. 8. Power System Configuration

Table VII. Test Methodology for Generator Differential Protection Study

Methodology Step	Description
CT Modeling	• V–I Characteristic Measurements • EMTP Modeling of the CTs
Power Sysem Modeling	• EMTP Modeling of the power system section of interest
Model Evaluation	• Recording of the inrush waveforms • Simulation of the same event • Comparison of recorded and simulated waveforms
Relay Selection	• Evaluation of three different relays using various simulations • Selection of the optimal relay design

While unit #2 was at full power, breaker "A" (which is not equipped with pre-insertion resistors) was closed, energizing unit #1 generator step-up and unit auxiliary transformers. The unit #2 generator differential relay (87) operated two seconds after breaker "A" was closed. Subsequent investigation found that the inrush current to the transformers contained a DC component which had a long time constant. In addition, it was found that the current transformers connected to the unit #2 generator differential relay had different transient response characteristics. With the Digital Fault Recorder (DFR) installed, primary inrush current, secondary currents at both ends, and current through the differential branch of the relay were recorded.

The time domain waveform representing the current flowing through the differential branch of the protection relay is shown in Figure 9. Due to the needed length of the record (> 7 seconds), only the onset of the switching event is shown in Figure 9(a), and the distorted transient waveforms after 2 seconds is shown in Figure 9(b).

The frequency content of the waveform as a function of time is given in Figure 10. This simple assessment shows an excessive harmonic content and the second harmonic build up generated by DC offset which has very likely caused the relay undesired operation.

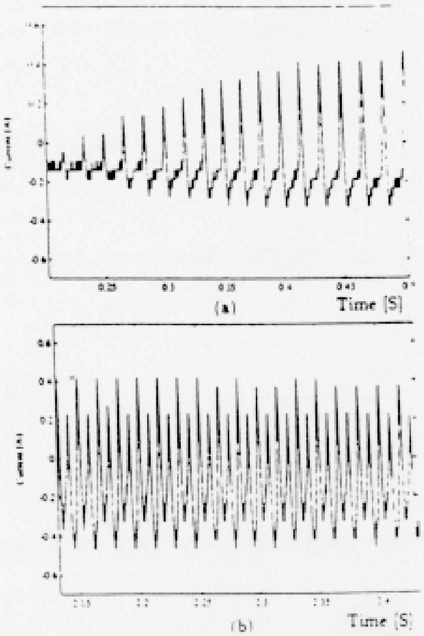


Fig. 9. Time Domain Signal Representation, (a) Initial Inrush Signal, (b) Inrush Signal after 2 Seconds

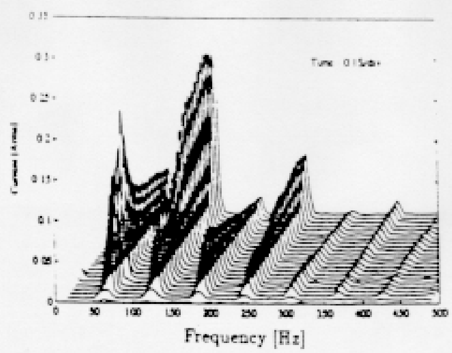


Fig. 10. Frequency Domain Signal Representation

Case V: Trouble Shooting of Nuisance Tripping of Ungrounded Capacitor Banks

The primary protection device used to detect failure of a shunt capacitor bank is the automatic control device type "UP". The UP device is capable of detecting the loss of individual capacitor units (cans) within a capacitor bank. The UP device operation is studied using various EMTP simulation. The simulations are confirmed with field measurements. Once the case that was causing the problems was discovered, the situation was recreated using a digital simulator.

Such a study was recently completed by Florida Power & Light. The methodology used in the study is summarized in Table VIII.

Table VIII. Study Steps for the Nuisance Tripping of Ungrounded Capacitor Banks

Methodology Step	Description
Field Recording	• Conducing of field experiments • Recording of corresponding waveforms
Event Simulations	• Creation of the EMTP model • Verification of the model using field data
Simulation of Most Interesting Cases	• Selection of most interesting cases using EMTP Simulation
Recreation of the Device Nuisance Tripping	• Use of MATLAB software to simulated cases of interest • Use of digital simulator to test UP devices utilizing the selected case
Correction of System Conditions	• Discovery of operation problems • Correction of the problems in the field

The protection system under study is shown in Figure 11. As it can be observed from Figure 11, in order for the UP device to determine if the voltage present is due to capacitor bank or system unbalance, compensation for system unbalance is provided. The circuit is essentially a voltage differential circuit. If the two voltages disagree in either phase angle or magnitude, an operate quantity is generated. It should be noted that for economic reasons, the capacitor bank is energized (switched in and out) with a circuit switcher (motor operated "F switch") rather than with a more expensive circuit breaker.

During the energization of a capacitor bank, transients are generated within the capacitor bank and the system when asynchronous charging of the capacitor bank occurs. Take the instance when one blade of the "F switch" closes much earlier than the other blades. The entire bank will tend to rise to that phase potential including the neutral of the bank. Very little current is required to charge the bank at this point. With the high impedance of the Resistive Potential Device–RPD($\sim 16M\Omega$), there is no path for current to flow. Therefore, the only charge on the bank is surface charge. When the second phase closes, load current flows in the two phases connected to the system with the surface charge on the other phase capacitor floating at the neural voltage. With the closure of the third phase, the capacitor bank currents should rapidly balance to their steady state condition.

However, this was not always the case. The unbalance meter, which shows the voltage unbalance on the neutral of the capacitor bank, would peg and then take several minutes to settle to near zero after the bank was energized. This apparent high transient voltage on the neutral of the capacitor would randomly result in a UP device trip. Since the surge arrester is clearly the only path through which current can flow, the surge arrester must have been operating or firing during the initial closure of the bank.

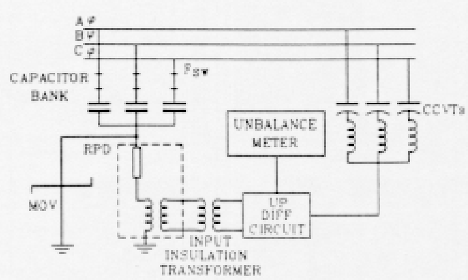


Fig. 11. UP Device Connection

The studies were performed using EMTP simulations. After it became clear what the properties of the waveforms were, relay testing was carried out using MATLAB waveform generation with simulator replaying [14]. The use of MATLAB enabled an easy way of changing parameters of the waveforms of interest.

The studies have shown that the first blade of the F–switch closing near the peak voltage would set up a high voltage and the surge arrestor would momentarily conduct, causing a DC voltage on the neutral bus with respect to ground, saturating the transformer in the RPD making it unable to pass its normal AC signal. The unbalance compensation circuit nulls this voltage against the CCVT inputs. Because this is a differential circuit, the loss of either voltage will cause a trip. The arrester was disconnected to prevent more misoperations. Field tests were conducted with the arrester removed, and no abnormalities were observed on the unbalance meter upon energization. There is arrester protection on the bus phases upstream of the capacitor bank.

It should be noted that this problem will only exhibit itself at locations where the unbalance is high enough to cause a trip, in conjunction with asynchronous closing of the source "F switch" contacts. System conditions vary, and under severe situations when the banks are needed the most, false trips may occur at just the wrong time.

FUTURE REQUIREMENTS AND PRACTICES

The performance improvement examples discussed in this paper indicate that, when required, relay testing methods should include the following:

- Extensive system modeling using EMTP
- Use of field recorded data for model evaluation and tuning
- Utilization of digital simulators to perform relay testing
- Automation of model creating and relay testing to allow generation of a large number of fault cases

An assessment of the new situation indicates that the user will be faced with the following:

- Additional training of personnel to conduct more complex studies
- Increased investment in test equipment to provide the required simulation environment and testing tools
- Prolonged time in relay evaluation to allow for more elaborate modeling and testing procedures

However, the improvement of the overall performance of the protective relay operation due to the use of the new test methods may justify the new investments in the simulator technology. In the examples discussed in this paper, the final result of improved operation of the protective system fully justified the use of digital simulators for such applications.

CONCLUSIONS

Based on the discussions in the paper, the following can be concluded:

- Improvements in the protective system performance can be achieved through improved test methods
- The improved test methods are made possible due to the latest developments in the digital simulators
- The use of digital simulators has been necessary for selection of new relays and trouble shooting of misoperation of the existing ones
- The new practice in the future may be to seek the relay operation improvements through implementation of the new test methods

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