

# **End-to-End Testing for Routine Maintenance**

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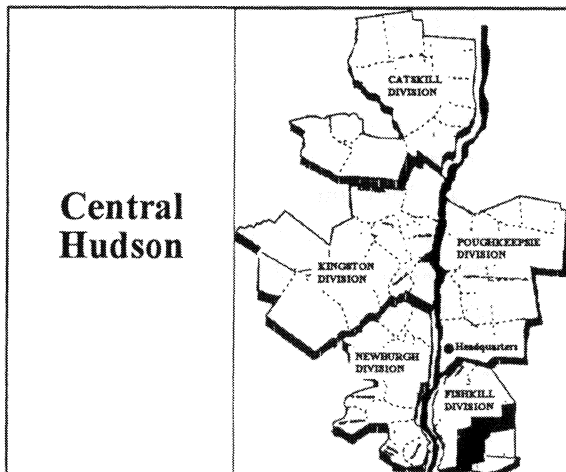
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## Abstract

The economic justification, procedure and experience for routine maintenance using dynamic-state scheme testing and end-to-end satellite testing is discussed. The testing provides significant advantages of obtaining more reliable test results which confirm the configuration, settings and correct operation of the protection scheme while significantly reducing test time. Since the test results describe how the relay scheme operates under power system conditions, the test data can be used to help evaluate future relay operations.

## Introduction

Central Hudson Gas & Electric Corp is an investor-owned utility with offices located in Poughkeepsie, New York. With approximately 100 substations, transmission voltages range from 35kV to 345kV that are transmitted through a total of 608 miles of overhead lines. Distribution voltages range from 5kV to 35kV with 3,150 miles of overhead distribution plus an additional 516 miles of distribution in underground cable. A total of 80,982 distribution line transformers provide a total capacity of 2,225 MVA. Major interconnections include Niagara Mohawk, Consolidated Edison, Jersey Central Power & Light, Orange & Rockland Utilities, New York State Gas & Electric, Northeast Utilities and New York Power Authority.



The Relay Protection Group, part of the Operation Services Division, is now taking advantage of new satellite-based technology to successfully improve the productivity of testing substation protective devices. The Relay Protection Group consists of eight employees who are responsible for installing, maintaining and testing all protective devices in the utility's substations and power plants throughout the company's transmission and distribution system.

Central Hudson moved from manual testing to automated testing approximately two years ago. The company has employed steady-state testing, i.e. testing individual set points of individual relays to prove correctness of operation. The inadequacy of steady-state testing is that, while it tests the components of the system, the protective relaying system is never tested as a whole. Therefore, it is not possible to predict with confidence how the entire system will perform under power system conditions.

Advancing to dynamic-state scheme testing, the company was able to more accurately simulate fault conditions, at the same time, reduce testing time. This test method enhanced the quality of the test by allowing personnel to draw conclusions from the simulated tests to better determine the protection's operation under power system conditions. Using satellite-based technology in testing allows end-to-end coordination of dynamic testing to further improve the quality of the test.

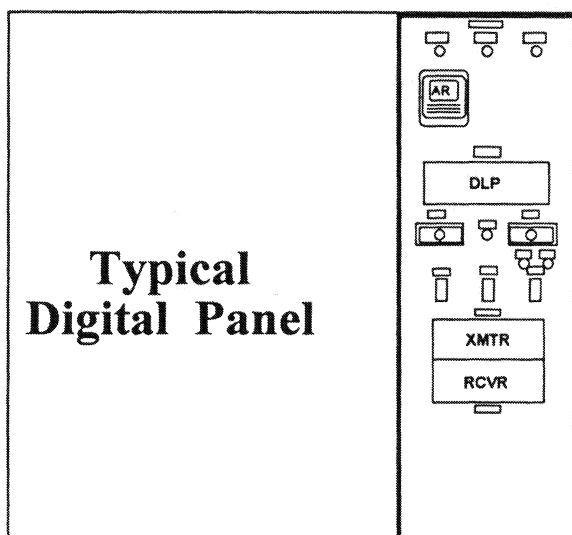
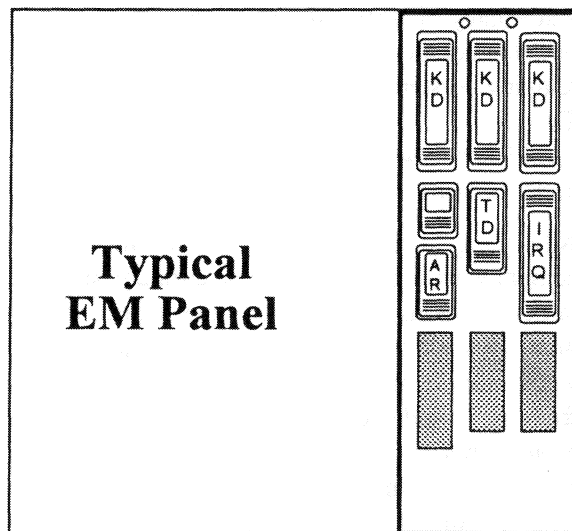
## **Evolution of Testing**

- > **Manual Testing**
- > **Automated Steady State Calibration**
- > **Model-based Scheme Testing**
- > **End-to-End Scheme Testing**

## Evolution of Testing

### *Manual Testing*

Prior to the advent of automated testing, the protection system was never tested as a whole, so no conclusions could be drawn as to how the system would actually operate under system conditions. The time-intensive manual testing consisted of testing individual components of a relay scheme one component or function at a time. Reviewing the test results could only lead to an assumption that, if all the parts tested correctly, the system would operate properly as a whole. Typical layouts for electromechanical and digital transmission line protective relay panels are shown.



### *Automated Testing of Steady-state Calibration*

The test automation program has been in place for two years. Central Hudson personnel meet each month to review test plans in place and to define test plans for additional automated testing. Training and input involves all personnel with the goal of all test routines being automated. This has allowed the size of the team to remain the same while productivity, accuracy and quality of protection testing has increased.

While the introduction of this technology allowed a reduction in the time needed to perform a complete set of tests, this level of automated testing still did not allow the check of the system under true operating conditions. Only set points were checked: the actual power system conditions were not simulated. Although an improvement on manual testing, automated testing was still time consuming because it required the check of each set point one component or function at a time.

The introduction of the new digital, multi-function relays presents a major problem to this test method. Their flexibility allows them to be configured in an almost infinite number of combinations. For the more sophisticated digital relays, there can be more than 2,000 setting possibilities. This makes steady-state testing a technician's nightmare. And, it remains a test where no real conclusion can be drawn on the performance of the protective system under power system conditions.

### **Modern Digital Line Relays**

- > 6 Zones Phase & Ground Distance
- > Choice of Characteristics Mho/Quad
- > Timers for Overreaching Zones
- > Choice of Pilot Schemes & Timers
- > Directional Ground Overcurrent
- > Instantaneous Overcurrent

## Modern Digital Line Relays

Continued

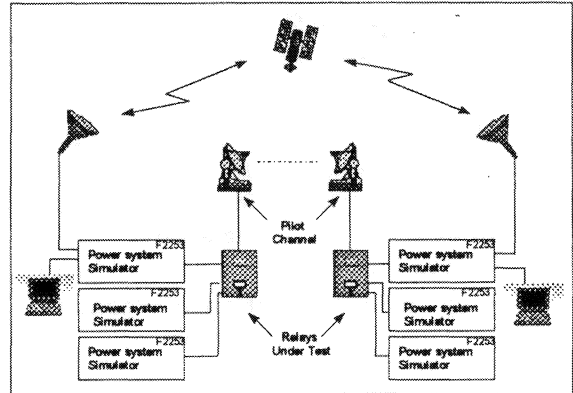
- > Switch onto Fault Detection
- > Blown Fuse Detection
- > Loss of Load Tripping
- > Breaker Failure
- > Reclosing & Sync Check
- > Fault Location & Records

The company also found that, when a questionable operation occurred and a request for investigation was made, no findings could be gained from the steady-state test method in many cases, since only the set points of individual components were checked. To meaningfully investigate an actual operation, a method to simulate the actual power system conditions at the time of the incident was needed to be able to observe the reaction of the system as a whole. At this time, relay technicians would try to coordinate the timing of the input of the fault data in each substation via telephone and verbal countdown. Obviously, this method lacks the coordination needed to accurately test relay schemes.

Therefore, a faster, more realistic and meaningful method of testing was needed to prove the correct operation of the system under power system conditions. This is especially true at a time when the availability of manpower and time is decreasing.

### *Dynamic-State Scheme Testing and End-to-End Satellite Testing*

With a modest additional investment (less than 10%) in November 1995, the company upgraded its DOBLE relay testing equipment to add a satellite receiver system that coordinates with military and industrial satellites that orbit the earth. The ability to use these satellites in relay testing allows the technician at each substation to synchronize the timing of the start of each fault simulation down to a millisecond.



This method also provides the great advantage of testing the system under true conditions since both ends can be tested at the same time. This is especially important in pilot schemes where permissive or blocking commands are transmitted to the opposite line end. This not only improved the testing accuracy, but significantly reduced testing time. Steady-state testing required two to three days to test one panel. With dynamic-state end-to-end testing, an entire line panel is tested in less than one day at both ends.

### Procedure

The automated testing program simulates a fault on a line and determines the accuracy of the protective relaying system response to the fault input. The fault data is calculated by the protection engineering section using Aspen One-Liner and is input to the test equipment at substations at each line end where the simulated fault occurred. This insures that only the proper relays trip and allows a test of the entire protective scheme at the same time with pinpoint accuracy.

<b>Test Plan for Scheme Testing Characterize Scheme Operation</b>	
<b><i>Simulations</i></b>	<b><i>Response &amp; Time</i></b>
<ul style="list-style-type: none"> <li>&gt; <b>Faulted Phases</b> (A, B, C, AB, BC, CA)</li> <li>&gt; <b>Unfaulted Phases</b></li> <li>&gt; <b>Reverse Fault</b></li> </ul>	<ul style="list-style-type: none"> <li>&gt; <b>All Zones - Instantaneous &amp; Delayed</b></li> <li>&gt; <b>Communication Signals</b></li> </ul>

- Simulating mis-operations due to relay overreach.

<b>Problems Found</b>
<ul style="list-style-type: none"> <li>&gt; <b>Intermittent Carrier Cutoff Switch</b></li> <li>&gt; <b>Relay Overreach Misoperations</b></li> </ul>

This is accomplished with personnel at each end of the circuit who lock on to five different satellites to provide highly accurate timing data. Based on the satellite time, computers are set to simulate identical fault data at precisely the same moment. This guarantees that the relationship between the communications of the relays is synchronized, not only within its own substation, but also at the other end of the circuit.

**Advantages Gained**

Satellite-based, dynamic-state testing provides a more uniform, complete scheme test in less time and increases the quality of test results because it simulates power system conditions. Relay packages that are tested at installation and in-service thereafter, require synchronized tests to be performed at the substations at each circuit end. In addition, the communication between the protective relaying systems can be evaluated. This improves the reliability of the test data and insures the proper scheme operation as a whole.

The satellite synchronized end-to-end testing program provides great advantage by allowing the ability to more closely simulate a fault condition than was previously possible. The company has used its dynamic state testing to find problems that were not able to be explained with its previous test methods. Some examples are:

- Finding of an intermittently bad carrier cutoff switch on a blocking scheme of a 345 kV circuit.

Other advantages of end-to-end dynamic-state scheme testing include:

- Insuring proper coordination on lines where electro-mechanical relays are located at one line end with digital relays located at the other line end as well as testing the coordination of time overcurrent relays for trip outputs and multiple reclose operations.
- Simulating power line carrier relaying problems.
- Confirming the wiring from the entry to the control house to the protective relaying panel by injecting test currents at the control house entry. In this way, if a problem exists that was not found in testing, the problem is known to be external to the control house and external cable connections, including polarity of CT connections are suspect. This procedure saves time when commissioning a new substation. Most of the work can be performed before energizing the substation.

- Confirming the accuracy of digital relaying remote metering measurements.
- Dramatically reducing test time. Where steady-state testing required two to three days to test one protective relaying panel, dynamic-state testing can complete testing of an entire transmission line protective panel in less than one day.

### **Economic Justification Line Relaying Panels**

- |  |                      |
|--|----------------------|
| > Manual Testing                         | > 3 Days per Panel   |
| > Automated Testing                      | > 1-2 Days per panel |
| > Scheme Testing &<br>End-to-End Testing | > Less than half day |

### **Looking to the Future**

The future of relay testing will allow reduced test time with increased reliability. The use of fault analysis programs, such as Aspen One-Liner, can be used to download relay setting information and power system parameters directly into ProTesT for Windows software. This eliminates errors and further reduces setup time.

With the present technology, transient tests can be performed easily and when needed. Relay performance can be observed for high frequency transients, CT saturation situations and other non-60 Hz phenomena. Using comtrade files, fault records can be downloaded from digital fault recorders into the test sets to play back any questionable operations.

### **Future**

- > Integrate Aspen One-Liner database with ProTest
- > On-site use of ProTest for Windows Power System Model
- > Playback of DFR Records using Trans2 and Comtrade
- > Transient Testing using EMTP and Trans2

### **Conclusion**

Satellite testing has allowed Central Hudson to decrease the amount of time needed for testing while significantly increasing the quality of the test and the documentation of results. Incident reports are now able to be meaningfully investigated and several problem areas have been identified that were not previously found with steady-state testing.

Whereas steady-state testing can only test each individual component of a system, the entire system cannot be tested as a whole to observe its behavior under true power system conditions. This inability to test the complete system leaves many gaps in the test procedure. Mis-operations when in service are generally due to the performance of the untested parts of the system. The use of satellite synchronized dynamic-state testing provides the closest simulation to true power conditions that is available with existing technology. This provides all the benefit of observing how the protection system operates and relates to all its components to dramatically increase confidence in the reliability and proper operation of the protection under actual operating conditions.

## Conclusions

- > **Reduced time needed to test relay panels**
- > **More meaningful test data**
- > **Faster diagnostics of questionable operations**

Satellite-based dynamic-state testing now makes routine end-to-end testing feasible and desirable. The quality of the test results, combined with the reduction in test time are major advantages. Once a company starts the process of end-to-end dynamic state scheme testing for routine maintenance and experiences the technical advantages and potential cost savings like Central Hudson has experienced, there would be no returning to the "traditional" time consuming test methods.

## References

1. IEEE Special Publication # 96TP115-0 Relay Performance Testing Power System Relaying Committee, *Report of Working Group I 13*.
2. *Distance Relaying and Dynamic Relay Testing Seminars*, A.T. Giuliani
3. *Dynamic Relay Testing*, A.T. Giuliani, Pennsylvania Electric Association Relay Committee, February 2, 1990
4. *Protection Scheme Testing Using a Power System Model*, J.A. Jodice, Doble Engineering Company and A.T. Giuliani, ATG Exodus, International Conference of Doble Clients March 25-29, 1996.

5. *Re-engineering Relay Engineering*, A.T. Giuliani, Pennsylvania Electric Association Relay Committee, May 16, 1996

6. *A New Philosophy for Protection Diagnostics*, J.A. Jodice, Doble Engineering Company and A.T. Giuliani, ATG Exodus, Pennsylvania Electric Association Relay Committee, September 18, 1996