Dynamic Relay Testing

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Introduction

The traditional method of testing individual relay functions using steady-state calibrations is no longer a viable test method for testing modern multifunction relays. Today, relay designs include innovative numerical techniques that enhance relay performance by combining a number of measuring criteria and by optimizing the relay's operation for power system conditions. If these relays are tested under the pseudo power system conditions created by steady-state testing, problems in testing and understanding the relay's operation can occur. In addition, the time for testing individual elements would be excessive because of the time required to reconfigure each individual element tested.

Relay Test Methods

A report from IEEE entitled *Relay Performance Testing* discusses the methods of steady-state, dynamic-state and transient testing of modern relays. A steady-state test is defined as applying phasors to determine relay settings by slowly varying relay input. Obviously, this test method does not represent power system faults. Dynamic-state test is defined as simultaneously applying fundamental frequency components of voltage & current that represent power system states of pre-fault, fault and post fault. Utilizing this technique results in faster relay testing because, in most cases, relay elements do not need to be disabled in order to test a relay function. Transient testing is defined as simultaneously applying fundamental and non-fundamental frequency components of voltage & current that represent power system conditions obtained from digital fault recorders (DFR) or electromagnetic transient programs (EMTP).

Dynamic Relay Testing

Dynamic relay testing means testing under true simulated power system conditions. Depending on the level of testing required, test values can be easily calculated with PC-based short circuit or EMTP programs. For dynamic-state testing, a short circuit program would be used to calculate the fundamental component of voltage and current values for pre-fault and fault conditions. For transient simulations, an EMTP program would be used to create waveforms that represent the fault condition. Dynamic-state testing and transient simulations provide a faster and more meaningful way to test relays and relay systems. These techniques provide the user with a far better understanding of how the relay system performs and can aid both relay application and test engineers in evaluating relay operations.

Dynamic-state testing is based on a power system model that is used to simulate different events selected according to the application. Events are played back through power system simulators that also monitor scheme performance. Each event is modeled to simulate conditions for the tested relay circuit but only for the time period needed to test.

Why Use Dynamic Relay Testing?

Modern relay systems are multi-function digital devices that are designed to provide complete protection for a power system component. Some of the newer designs have over 2,000 setting possibilities and require extensive configuration and setting procedures. The traditional method of testing individual steady-state calibrations, one at a time, is no longer a viable method because of the excessive time it would require to reconfigure for each individual element tested. In addition, traditional test methods were designed on the assumption that users did not have test equipment for testing relays under power system conditions. So, traditional test procedures were developed using basic test equipment components such as variacs, phase shifters, and load boxes. With today's modern test equipment, power system conditions can easily be simulated. By making a profile of the operation of the scheme, malfunctions can be found faster because it is easier to identify the changes in areas that don't operate the way they are expected.

Advantages of Dynamic Relay Testing

Some of the advantages offered with dynamic-state testing as compared to traditional test methods are:

1. Complete relay scheme tests.

   For each simulated power system event, the performance of the complete relay scheme is tested. The high power capability of power system simulators allows the user to test the complete relay scheme. This provides a faster way to test relays since relay settings or configuration need not be changed as they would if individual circuits were tested one at a time. The performance of all scheme responses, including unfaulted phase units, can be evaluated since the model and simulators generate three-phase wye voltages and currents. This allows the accurate modeling of power system events. In addition, if the relay scheme includes programmable logic, simulated events, which test how the complete system logic operates, must be used to assure the relay logic is performing as intended. Contact races and operating and resetting of measuring units may be common problems. Therefore, the complete relay scheme needs to be tested as a whole, to insure proper operation and proper non-operation under simulated power system conditions.

2. Realistic relay operating time tests.

   The operating time of many line relay systems depends upon the system impedance ratio (SIR). With dynamic-state testing, different SIRs can be modeled to determine the range of relay operating times. The traditional test method never considers the affect of SIR on relay performance.

3. Evaluation of future relay operations.

   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 becomes a useful relay performance database. When the relay system is in service and operates for a power system event, its performance can be compared to the relay performance database to determine if the relay scheme has operated correctly. Many companies have experienced that, after a questionable operation has occurred and a request for investigation was made, no findings could be gained from the steady-state test method in most cases, since only the set points of individual components were checked. To meaningfully investigate a questionable operation, the actual power system conditions at the time of the incident need to be simulated to be able to observe the reaction of the system as a whole.

What Is Needed for Dynamic Relay Testing?

The test method involves testing the complete scheme with dynamic-state simulations that model the power system the relay scheme will protect. Computational programs such as One Bus, One Liner, CAPE and other mathematical calculation tools such as spreadsheets and Mathcad can be used to model the power system in order to derive the fault voltages and currents for the power system event.

Dynamic Relay Test Procedure

1. Create a dynamic-state test plan.

The test plan for dynamic-state testing depends on the type of protection to be tested and how it is configured. The intent of the test plan is to test the relay scheme's operation under simulated dynamic-state conditions. To generate a test plan for a line relay scheme, the following tests should be taken into consideration:

- Reach and Direction tests of all zones of protection.
- Operating time tests for different SIRs.

- Memory circuit tests.
- Pilot scheme performance tests for internal and external faults.
  Include the effects of load flow and fault resistance. Also include current reversals due to faults cleared on parallel lines, if applicable. Since this is a three-phase simulation, what is happening on the unfaulted phases should be taken into consideration as well as the operation of communication signals.
- Other simulations depend on how the relay is set and configured. Such tests could include testing for:
  breaker failure relaying
  reclosing
  restoration
  programmable logic
  switch-onto-fault
  power swing blocking and tripping
  blown fuse detection

Additional testing which may be considered and included in the test plan at the time of commissioning could be to:
verify DFR trigger settings
calibrate DFR measuring circuits
check and verify operation of events recorders
verify accuracy of metering

2. Calculate values for simulated fault conditions.

A power system model of a two-machine equivalent system can be used to aid in the calculation of voltage and current values for line relay testing. For the application to be tested, line and source values are entered. Faults are simulated on the model with varied fault locations, resistances and load flows according to the tests defined in the test plan. Each case is a test that will characterize the scheme operation for reach and direction (faults behind and in front) and for the various zones and combinations of zones. For reach tests, the fault locations are defined according to the accuracy of the unit being tested. For a zone 1 relay with ±5% accuracy, an operation test would be defined at 95% of setting (op case). A test for no operation would be defined at 106% of setting (non-op case). These two cases confirm the accuracy of the zone 1 relay. The reach tests are conducted for phase and ground distance relays. For phase distance tests, use a phase to phase fault type; for ground distance tests, use a phase to ground fault type.

3. Make dynamic-state test cases.

Each test case requires three-phase voltage and current values. For reach and direction tests for line relay schemes, three states are usually defined for each test case. The pre-fault state provides balanced three-phase voltages to the relay long enough to stabilize the relay before a fault is simulated. The pre-fault time assures that the relay will have the proper memory circuit response. The test time for the fault state must be long enough to operate the tested zone of protection, but short enough not to operate the next overreach zone of protection. In this way, the faulted zone can be tested without disabling the adjacent overreaching zones. The post fault time is required to re-apply restraint voltage after the test to prevent any spurious operations.

4. Playback with power system simulators

Depending on how many relay functions are configured, there may be a number of cases to run. However, it only takes seconds to run a dynamic-state test so that 150 tests will take approximately five minutes. To run a steady-state test with this amount of detail will take significantly longer because of all the communications that is required with the relay to reconfigure its settings. Also, dynamic-state testing gives true relay operating performance for each power system event tested.

Conclusion

Dynamic relay testing has allowed users to significantly decrease the amount of time needed for testing while increasing the quality of the test and the documentation of results. Dynamic relay testing has also provided the user with the capability of developing an understanding of the power system and the protection scheme's function within that power system. Utilities have used dynamic relay testing to find problems that were unexplained with previous test methods. Incident reports can now be meaningfully investigated.

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About The Author

A.T. Giuliante is president and founder of ATG Consulting (previously ATG Exodus). Prior to forming his company in 1995, Tony was Executive Vice President of GEC ALSTHOM T&D Inc. - Protection and Control Division, which he started in 1983. From 1967 to 1983, he was employed by General Electric and ASEA. In 1994, Tony was elected a Fellow of IEEE for "contributions to protective relaying education and their analysis in operational environments." He has authored over 50 technical papers and is a frequent lecturer on all aspects of protective relaying, including electromechanical, solid state and digital based equipment. Tony is a past Chairman of the IEEE Power System Relaying Committee 1993-1994, and past Chairman of the Relay Practices Subcommittee. He has degrees of BSEE and MSEE from Drexel University 1967 and 1969.