New Approach to Simulation Based Type Testing of Protection Relays

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Abstract

The paper presents an overview of the advantages of using transient simulation for assessing protective relays. It shows that even upcoming standards for type testing are relying on these methods. The importance of the use of statistical methods to investigate the behavior of algorithms is discussed. Finally a new product for performing these kinds of tests is introduced.

Keywords

digital simulators, application testing, protective relays, electromagnetic transients

Introduction

Testing relays and showing that they operate according to the specifications is a very important task to ensure the security and reliability of power systems.

Or like the 2008 report from the PSerc (Power Systems Engineering Research Center) says “appropriate relay testing should help validate the design of the relay logic, compare the performance of different relays, verify selection of relay settings, identify vulnerable conditions apt to causing unintended operations, and carry out post-event analysis for the understanding of unintended or incorrect relay behavior.”

The testing tasks during the development, the commissioning and maintenance of relays or in the post-fault analysis are all covering different aspects. These include the quality of the algorithms, the correct calculation and setting of the relay's parameters and the aspects of the aging of the relay's components.

Today’s most common technique to perform all these tests is to use phasor-based tests. Sine signals are calculated based on phasors and are injected using a relay test set. By adjusting the amplitudes and phase angles of the phasors and observing the reactions of the relay, the relay's behavior is measured and compared with the specifications.

But this way of performing tests leaves out important aspects of the power networks and its components. The aspects, for example exponential transients, harmonics and non-linearities have a big influence on the algorithms that the relays use to analyze the currents and voltages from the network.

Models in Testing

To be able to test a device of any kind the tester has to have a definition of what the device should do.

Usually this is described in a product definition. The tester himself then has to find out how to test all aspects of the functionality of the device under test (DUT). A stimulus leads to a reaction of the DUT, the reaction is assessed.

Applying a correct stimulus is sometimes very difficult, as the tester has to simulate the relevant environment of the DUT. Some functions, like the overcurrent protection function might not need a complex simulation, but others like the out-of-step detection are more complex.

In any case the term "model" can be used to describe a means to calculate the correct stimulus for a specific test:

According to the definition a model is a representation containing the essential structure of some object or event in the real world. Models are always simplified representations of the reality [1].

For an overcurrent relay the model is very simple, a current source delivering a current, testing other functions is much more complex and need more complex models.

History of Relay Testing

The first relays were electro-mechanical relays. These devices were quite simple compared to today's relays and so were the test devices and the test methods. For testing overcurrent protection for example the model is also very simple and fully described with the time-overcurrent characteristics.

Traditional test methods were designed on the assumption that users did not have test equipment for testing relays under power system conditions. So, test procedures were developed using basic test equipment components such as variacs, phase shifters, and load boxes.[5]

Due to the fact that the relays become more and more complex with some devices having more than 2000 settings, traditional test methods are no longer appropriate. The relay functions are very advanced and also use complex models of the network for calculating.

The testing side has to adapt its methods to be able to assess the relays functionality.

Steady-State and Sequence of Steady-States

When thinking about models of electric network faults the simplest model is to describe components like sources, lines and loads using a static model with fixed voltages and impedances. The representation of voltages and currents in a static network model are steady-state phasors. For each state of the network a set of current and voltage phasors can be calculated: pre-fault state, fault state, post-fault state.

Using such a steady model, the test signals injected using a test set are pure sine waves. Usually a test case consists of a sequence of several steady states, according to the states of the network.

Most often just a pre-fault and a fault state are used. QuickCMC is able to generate the signals for this way of testing, but also many other test modules from the Test Universe use this way of testing to test several protection functions.

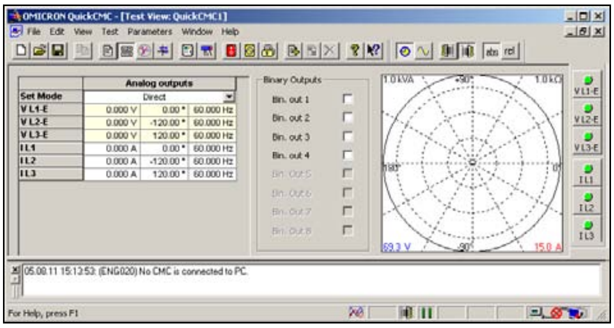

Fig. 1 QuickCMC for steady-state testing

Modern digital relays are usually well prepared for working with these kinds of signals. The signals itself are quite simple, as they are stable and sinusoidal. Relays using some kind of Fourier-transformation algorithm for converting sinusoidal signals back into phasors should achieve very good results when testing with this approach.

Problems found during type testing with the steady-state test method are mostly from a lack of accuracy in certain input ranges of the current and voltage inputs and some very basic calculation problems in the device firmware.

For field tests this method is a valid method for testing, if the goal of the tests is just to check that the relay uses the correct settings values for calculation.

Evolution of steady-state

A way of testing that is a bit more realistic is the usage of transient DC currents. As, due to inductors in the network, the rate of change of currents is limited, exponential currents appear when a sudden change of the network state happens - for example when a fault occurs. The calculation of the current is usually very easy, as it is just an exponential DC current with a certain time constant.

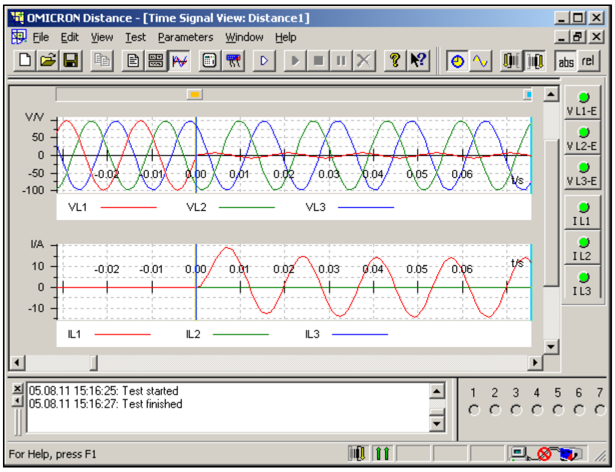

Fig. 2 Testing distance protection with DC-offset

For the relay's algorithm these kind of signals are a bit more challenging than pure sine signals, a very basic Fourier-Algorithm will produce some false results.

Again problems to be found during type testing in today's modern relays with their more complex algorithms are very basic problems in the calculations.

Transient simulation

Looking at the previous examples it is quite obvious that using pure sine waves for simulating network faults is a quite basic way of testing. The underlying model is always the same steady-state model, ignoring the dynamic behavior of all the electric components.

A digital relay internally works with very complex algorithms. These algorithms have to take certain deviations from the nominal state into account:

- Transient currents at fault inception
- Oscillations caused by capacities
- Current transformer saturation
- CVT behavior
- Evolving faults

When some or all of these aspects are simulated using a dynamic network model the test cases are a much tougher challenge for the protection algorithms than tests with simple sine waves.

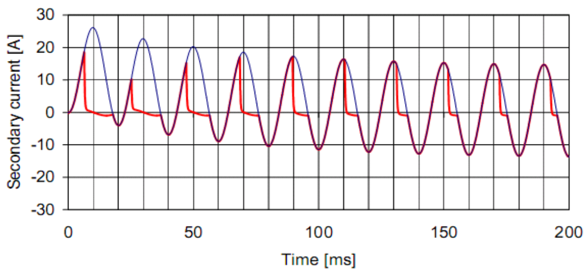

Fig. 3 Effect of CT saturation

In the past dynamic network models used to be very expensive and were difficult to handle, but at least since the late 90s “normal” desktop-PCs have enough calculating power to be able to simulate electric networks of sufficient size for type testing in a reasonable time. It is no longer necessary to buy expensive hardware that can only be operated by specialists. Nowadays the protection engineer himself can also use simulation methods to investigate relay behavior.

Advantages

As stated in [5] the purpose of transient-based test methods have the goal to assess the “overall relay performance under simulated ‘actual’ operating conditions.”

Testing during the development of a relay will in any case include phasor-based testing to be able to test individual aspects of the algorithms. But this is not sufficient. Algorithms are very complex, various digital filter sets are used and several functions “overlap” and interact with each other. Application tests are an essential step before a relay can be released.

Applications testing using network models for testing the relays in a simulated environment changes how the relay is tested:

When a tester uses the steady-state method he has to know a lot about what is going on inside the relay. This is called “white-box testing”.

Using network simulation testing becomes testing a “black-box”. It is no longer necessary to look into the internals of the algorithms, what is really important that the relay behaves correctly in all kind of realistic fault situations.

The study performed by PSerc [4] showed that “Test results provided information that was not documented in the relay manuals, and that definitely could affect proper coordination and performance of the relaying schemes.”

Transient Testing and Standards

The advantages of using transient simulation for testing relays are also seen by standardization committees. The TC95 MT4 is working on updating the standards for the IEC60255.

They have found a very interesting approach for the IEC 60255-121, the standard describing the “functional requirements for distance protection”.

As the implementation of distance relays is different for all the manufacturers, the committee had to find a way to make the relays comparable without preferring a specific implementation of the relays distance characteristics.

The solution is to use transient network simulation to test various aspects, including the behavior regarding different SIR factors (source impedance ratio), fault types and inception angles and load conditions.

Requirements for test systems

The upcoming standard IEC60255-121 defines several different tests for qualifying a distance relay that can be used to define requirements for network simulators used for relay testing. A test system shall be able to perform:

- Static accuracy tests (steady state)
- Dynamic performance tests (transient)
- Harmonics tests (both)
- Off-frequency tests (both)
- Double-infeed tests (transient)

The most important of these tests are the dynamic performance tests. In the IEC standard they are performed using a very simple network

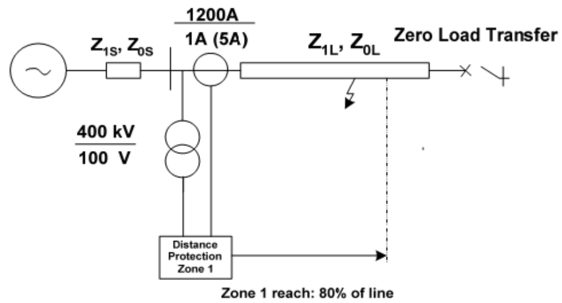

Fig. 4 Simple network for dynamic tests according to IEC60255-121

Requirement concerning the simulation model include a capacitive line model and CVTs. To be able to test according to standard the simulation of CT saturation is also necessary.

Existing approaches to simulation based testing

Several approaches to use network simulation for relay testing exist. They are mostly used during the development, for acceptance testing or for supporting the design of a protection system. All the existing approaches are either based on offline simulation and injection of these pre-calculated fault records or use closed loop simulation.

Offline simulation

For this approach the network is modeled in a tool like ATPDesigner. Test cases are defined and for each test case the transient signals are calculated and stored as a file most likely a Comtrade file.

Several tests are stored for example in a database or in a common directory.

For testing the pre-calculated transients are injected using a test set. The injection is either done using one of the test set's test programs or using self-implemented software using a programming interface of the test set.

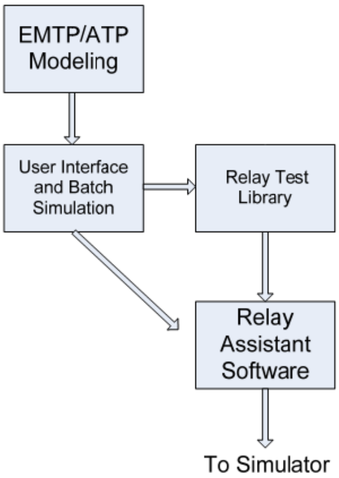

Fig. 5 Offline calculation for simulation tests [4]

The advantage is the fact that the simulation expert is able to use the simulation program that he is used to and that he knows well.

On the downside, the fact that this solution needs several tools from different vendors is a big disadvantage. There is a lot of export/import in the workflow a lot of data handling between the applications. The evaluation of the test results is also difficult, as the results have to be extracted from several test cases.

The test signals are not influenced by the relay's behavior. So the signals will not change when the relay trips a breaker. Therefore only the "trip" can be tested properly, but not the function of a reclosing function or more complex evolving fault scenarios.

Closed-loop simulation

To be able to let the relay change the condition of the simulated network there has to be some kind of feed-back loop from the relay to the simulator.

"Closed-loop simulation" is a term that describes how simulation is performed and how feedback from the device under test is fed back into the simulation system.

With closed-loop systems the feedback of the relay if fed directly back into the simulation, this way a circuit breaker can be operated as in "real life". The network calculation has to be performed in "real-time", so the signals are calculated during the injection.

When talking about closed-loop simulation systems for electrical networks the most common system to be used is an RTDS. It has the huge advantage of a dedicated hardware that is able to perform high-quality simulation in real-time.

As the RTDS is excellent for many simulation tasks like simulating cables and electronic controllers for easier tasks it might be too complex.

For performing test campaigns it is also possible to automate tests using a batch mode.

The disadvantages of the system are not to be found on the technical side. But for relay testing only it might be a bit too complex, as relay testing is only one of the things that it can be used to.

OMICRON's NetSim

For some years OMICRON provides NetSim as part of the TestUniverse. NetSim is able to simulate pre-defined network configurations and it can even automate tests. For example it is possible to easily define an automated test with a variation of the fault location.

But NetSim was never able to work with user-defined networks. It cannot simulate line capacities, nor capacitive voltage transformers.

NetSim is also only capable of offline simulation only.

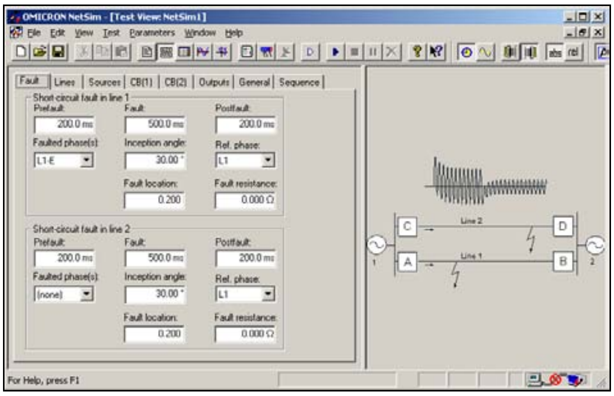

Fig. 6 OMICRON's NetSim

OMICRON's new solution

Especially for intensive testing during development and evaluation and to fulfill the requirements of tests according to IEC60255-121 OMICRON´s new product "RelayLabTest" will be available by the beginning of 2012. It provides many new features for simulation, testing and analysis of the test results.

A major advantage of RelayLabTest is the provision of unique test automation features for tests with a quite high number of test "shots". A test document may consist of several test cases and each test case allows the definition of up to 5000 shots. For each shot certain parameters of the grid or the fault might be varied easily.

Complex analysis round up the package allowing the creation of SIR diagrams, calculation of average trip times, etc.

To ensure the user-friendliness of RelayLabTest a great emphasis on usability was placed from the very beginning of its development. Quite early in the project typical use-cases were collected and they were also taken into account later during the design of the user interface.

The editor

The editor of RelayTestLab is based on tiles, just like a mosaic in a substation. The elements can be inserted using an in-place toolbox. The settings of the equipments can be edited in a settings toolbar to the left of the editor. The visual design and very carefully designed animation support the drawing of the grid.

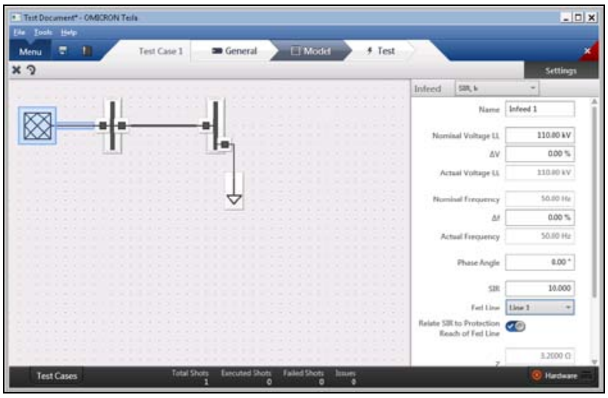

Fig. 7 Grid editor of RelayLabTest

Defining fault scenarios

After a grid is completely drawn the test mode can be activated. In this mode the grid will be protected from unintentional changes and new possibilities are offered. For example a line fault can be applied to the network.

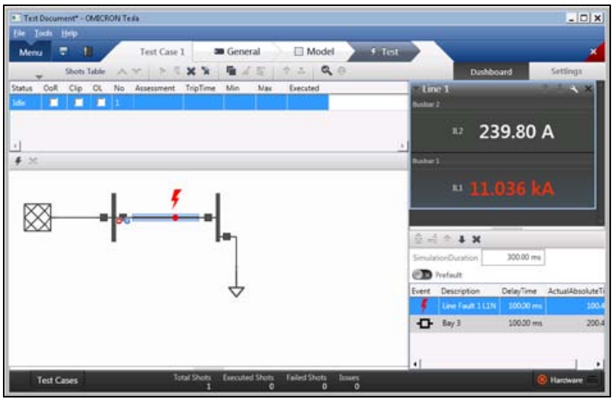

Fig. 8 Defining faults in RelayLabTest

Even more complex scenarios can be defined including the opening and closing of breakers and evolving faults.

Steady state calculations of the various states make it possible to easily control the voltages and currents.

Testing

For type testing relays it is most interesting to have a variation of certain parameters, so that a large variety of different test cases can be applied to the relay. For supporting this up to 5 equipment or fault parameters can be selected. Using a permutation of possible settings (e.g. fault type L1-E, L1-L2, L1-L2-L3-E and fault inception angle 0°, 45°, 90°) a very big number of tests can be defined very easily.

Measurements can be defined just like in OMICRON's sequencer test module to be able to assess the relay's behavior. It is possible to measure the time from a specific incident to a relay trip or the time between two relay reactions, for example the time between pick-up and trip.

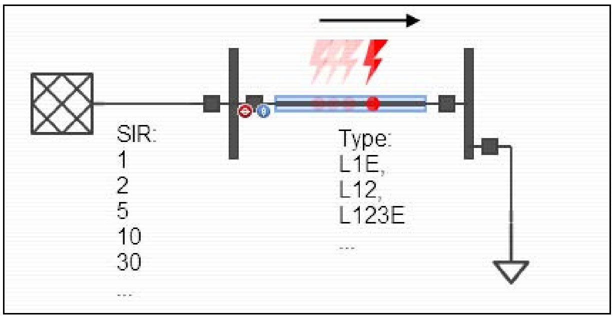

Fig. 9 Variation of parameters

Closed-loop testing

RelayLabTest supports incremental open-loop testing that brings the advantages of real-time closed-loop testing to the PC:

First the test signals are calculated and injected just like with offline simulation. The reactions of the relay are recorded and built into the simulation. Calculation and injection are repeated, now including the breaker operation.

This all is done as often as necessary and fully automatically and with no extra effort for the tester.

After the process is completed the final test results are almost identical to those achieved using a full closed-loop simulation.

Analysis of results

An important task especially when analyzing a huge number of tests as described in the IEC60255-121 standard is the analysis of the results.

As in Test Universe it is possible to define rules for each individual shot to be able to get a positive or negative assessment, so for example the trip time can be assessed very easily.

In addition statistical analyses allow illustrating the behavior of the relay and especially the dependencies of the relays algorithms regarding the variation of fault or network parameters.

A good example is the SIR diagram, showing the trip time for certain fault locations. Each curve is measured using a specific SIR ratio. By increasing the SIR the fault impedance is not changing, but the fault current and the measured voltage for the fault loop are decreased.

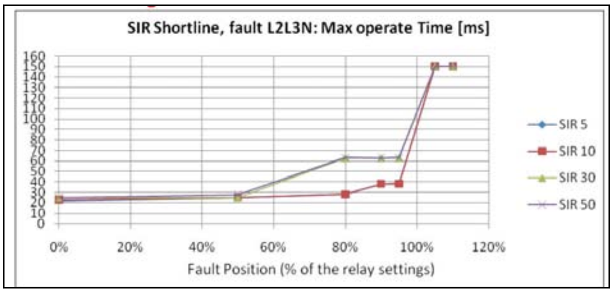

Fig. 10 SIR diagram

But this way of analyzing data is not limited to SIR diagrams. All kinds of dependencies can easily be visualized. It is even possible to compared different test cases to one another. For example: different CT models, behavior with and without line capacities, overhead line vs. cable, etc.

Summary

The advantages of using transient simulation for testing relays are numerous. The quality of today's complex relays can be assured only by using appropriate testing methods. This trend is also reflected in the most recent type testing standards.

At the beginning of 2012 OMICRON will release the new product RelayLabTest allowing all kinds of intensive simulation based tests.

A very easy-to-use user interface, unmatched possibilities for test automation and a large variety of methods for analyzing the results make this product a must-have for all who really care about the quality of protective relays, especially for all who perform type testing or who are responsible for acceptance tests.

In the future it also seems to be a good idea to widen the scope for simulation based test methods for additional tests during commissioning and maintenance.

Literature

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About the Author

Stefan Schwabe works as product manager for OMICRON's CMC line, specializing on simulation based tests, but also takes care of the CMControl.

Before joining OMICRON he worked as a technical consultant for fuel cell systems in the aircraft industry, also using simulation techniques to evaluate the performance of technical systems and validating requirements for specific components.

From 1996 until 2007 he worked at SIEMENS in the development of SIPROTEC relays, specializing in the area of test automation and simulation.

OMICRON is an international company serving the electrical power industry with innovative testing and diagnostic solutions. The application of OMICRON products allows users to assess the condition of the primary and secondary equipment on their systems with complete confidence. Services offered in the area of consulting, commissioning, testing, diagnosis, and training make the product range complete.

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