Network Simulation on the PC - New Options for Protection Testing

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Introduction

Latest developments in computer technology have opened a lot of choices that we experience every day. With a modern Laptop computer in his hands, every test technician carries as much computing power in his with him as a high tech laboratory had available a dozen of years ago. This also had tremendous impact on the testing of protective relays, and the trend will go on.

The current highlight in this development is NetSim, a PC based network simulation program for the relay test technician. Many tests which were only possible in especially equipped laboratories in the past are now even possible out in the field.

NetSim's non-scientific approach makes it extremely easy to use. Restricting the functionality to certain test cases releases the user from editing network configurations etc. It is really a "click-and-run" solution. This program brings network simulation into the reach of the test technician and makes applications accessible which were hard to imagine until now.

Despite its simplicity, NetSim is very powerful. It performs an offline (open loop) simulation, which means all calculations are performed based on settings that are predefined at the start of the simulation. Opposed to this is the closed loop simulation, which requires full blown real-time simulation system. Looking at the cases which can be sufficiently covered by an offline simulation, there is only a part remaining where closed loop simulation is an absolute necessity. Many tasks which were performed in laboratories with expensive real time simulators can now be done with NetSim, so relay developers can benefit from it as well.

Approximating the Reality

The generation of realistic test quantities has been always a main aspect in the development of testing software. The injection of pure static fault quantities was in many cases superseded by the introduction of fault models in the testing software. How the test quantities will differ depending on the tool chosen for generating them is shown in the figures below.

The voltages and currents in a State Sequencer change immediately from prefault to the static fault quantities. Especially remarkable is the discontinuity of the current at the fault inception and the fault end, which is contrary to the physics.

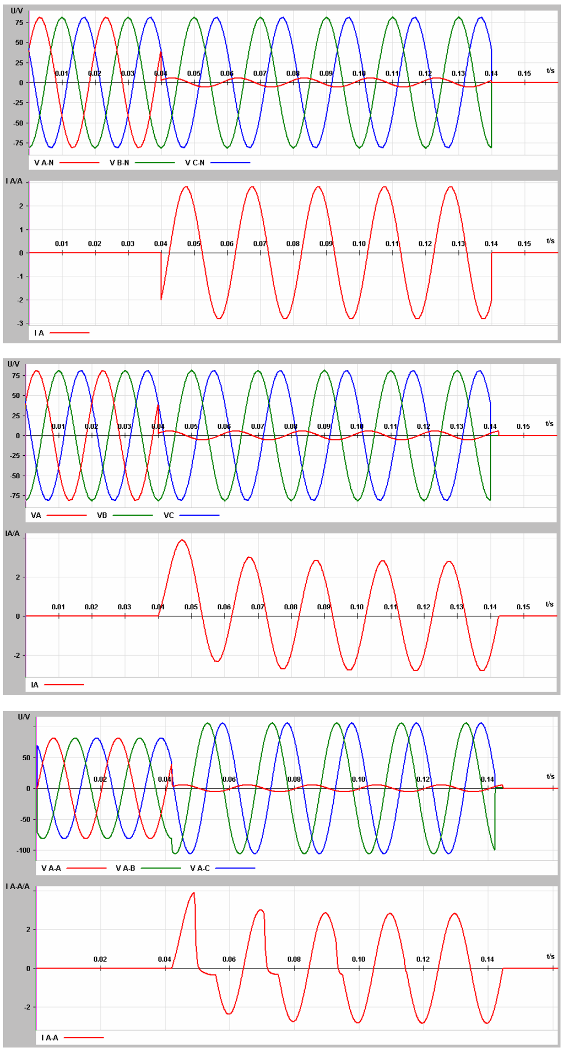

Figure 1: Test quantities for the same fault specification (fault type = A-N, fault inception angle = 30°, $Z = 1\Omega$, $\varphi = 75°$, $k = 1$; static fault current = 2A) from the State Sequencer (top), Advanced Distance (middle), and NetSim (bottom).

The fault model of the Advanced Distance testing software already goes one step further. The continuity of the current and the decaying DC offset that occurs in practice is correctly calculated by the fault model. A model like this is called "second order correct". The cancellation of the current flow at the zero crossing is properly regarded as well. To be complete it should be mentioned that Advanced Distance can achieve a closer approximation of the reality by using a "constant source impedance" model, as for example taking into account the voltage increase in the sane phases.

The network simulation delivers even more. Beside the displacement of the voltages due to the finite ground impedance toward the source feeding the fault, also the shape of the current waveform in the following figure is remarkable. This has been obtained by using a CT model for the simulation of possible saturation phenomena.

Advanced Protection Algorithms

Recently, more and more relays are appearing in the market that present a new kind of testing problem for the tester. The availability of more and more processing capacity in the relays encourages the developers to implement always more complex algorithms. The exact prediction of the behavior of those algorithms in detail may become extremely difficult or maybe even impossible. To mention are for example distance relays with different k-factors for different sections of the line or differential relays with bias formulas that are immediately adapted to the operating conditions of the network. In these cases it must be stated that a classical, invariant characteristic that is the reference for a test and an assessment does not exist any more. Mathematically speaking this means that the protection algorithm is no longer unequivocal invertible or not invertible at all. But exactly this inversion of the protection algorithm is used in the classical calculation of test quantities.

What has always to be true independent from the applied functional principle is the correct detection and tripping at faults inside the sphere of responsibility of a protective relay. This can be easily verified with a network model and an appropriate fault simulation.

Generic Test Specifications

Looking at the very generic specifications for reach settings of a distance relay, they are actually made in terms of distances, even if in normalized form, expressed as percentage of the line length.

The fact that testers have to deal with impedances is because most testing tools (and also most relays) have no means to work with the generic terms, so that all specifications have to be transformed into the impedance domain.

Having entered the line data, NetSim allows the specification of the fault location, so the generic requirement on the protection function can be directly used for testing.

The figures below show two reach tests on a distance relay that should have a zone 1 reach of 80% of the line length. To verify this, faults at 70% and 90% of the line length are simulated.

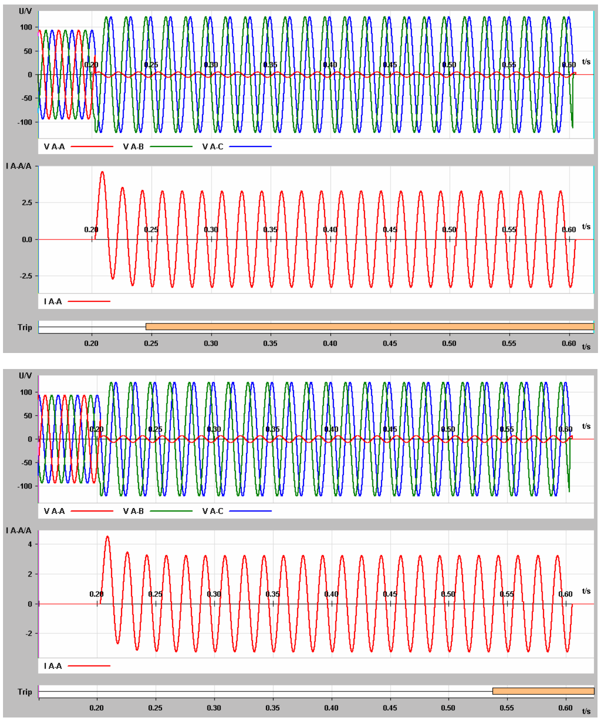

Figure 2: *Faults at 70% (top) and 90% (bottom) of the line length. The measured trip times verify the correct reach setting of zone 1.*

A fault at 70% of the line length must result in an instantaneous trip, while the fault at 90% of the line length must be detected to be in zone 2 and the trip has to be delayed by the zone 2 delay.

Both faults are correctly detected. The relatively slow trip time in zone 1 of about 43ms is due to the weak infeed (relatively high source impedance).

Automatic Sequences of Tests

For a more accurate determination of the reach and the dependency of the trip time from the fault location, multiple tests are necessary. This is easy to accomplish with a sequence function.

NetSim allows up to two parameters to be automatically varied during a sequence of tests. In this specific case, the fault location is this varied parameter.

The following figure shows the obtained relationship between trip time and the relative fault location.

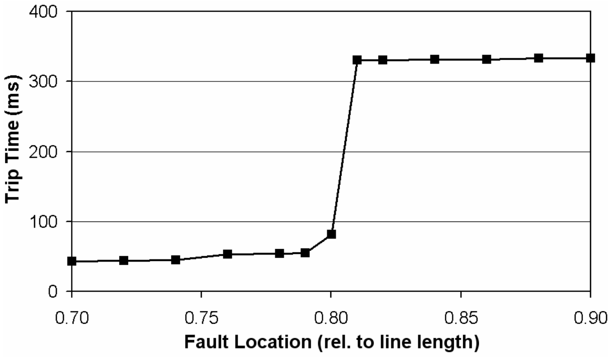

Figure 3: *Trip time over relative fault location.*

Another example for the effectiveness of the sequence function is the investigation how a relay's performance depends on the source impedance. In this case SIR is chosen as the varied parameter.

With the same relay as in the former example, the fault location was set close to the reach of zone 1 (75%). The tests were performed for line-to-ground and line-to-line faults. This can also be carried out by the sequence function when the fault type is selected as the second varied parameter.

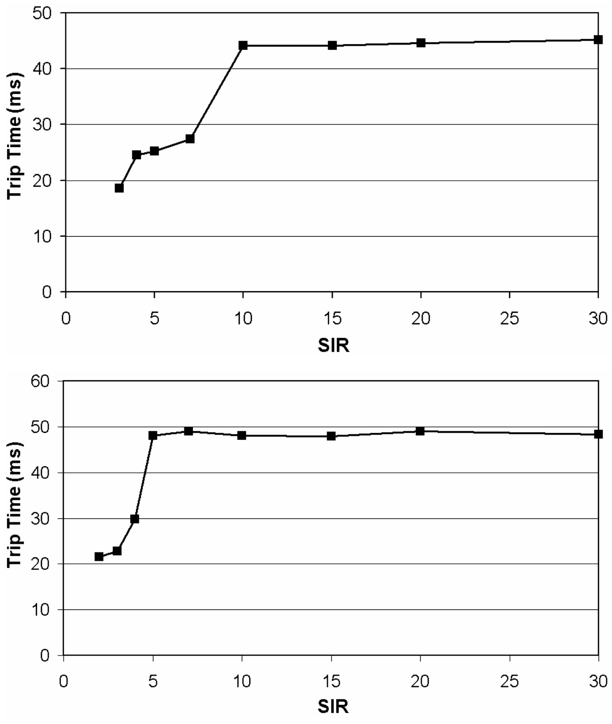

Figure 4: *Trip time over SIR for L-N (top) and L-L faults (bottom) for faults close to (but inside) the reach of zone 1.*

At small values of SIR, meaning strong infeed with high fault currents, the fault detection is performed faster. But also at large values of SIR the zone 1 fault is always properly detected.

Power Swing Blocking

Simulating power swings has always been a domain of network simulation. This is because of the nature of these events with relatively slow, continuous variations of all quantities involved that are impossible to specify by the static parameters magnitude, frequency and phase. Therefore, power swings are hard to reassemble with a reasonable number of states. Stepping through the impedance plane and hitting distinct power swing zones by purpose is only applicable for a limited class of relays. Even if the variation was done automatically, the course of an impedance e.g. along a straight line with constant rate of change is not close to what happens in reality. Some effort was undertaken to get to usable solutions without network simulation, but only with limited success.

With a dedicated test case in NetSim, the test specification is reduced to just the slip frequency between two sources feeding a line.

The figures below show the same power swing in different domains. The instantaneous voltages and currents show the typical "beat shape".

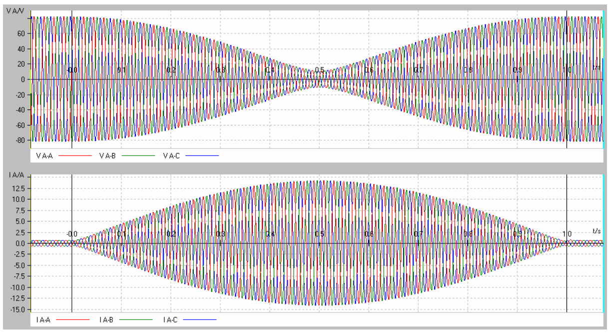

Figure 5: *Voltages and currents during a simulated power swing.*

The figure below shows how the impedance locus passes through the tripping zones.

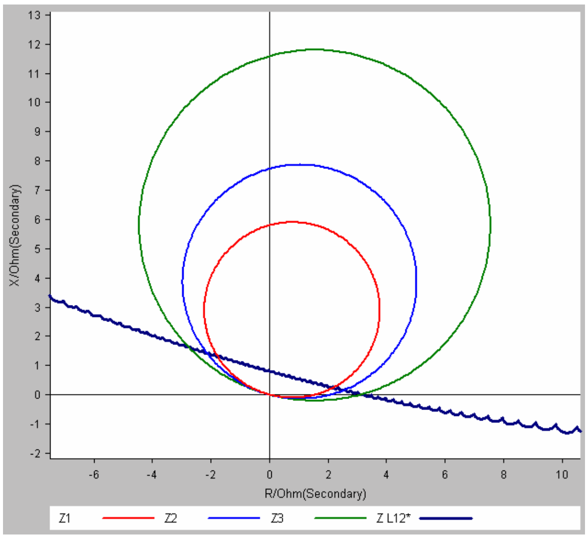

Figure 6: *The impedance locus passing through the zones of a distance relay during a power swing.*

For the cases where the slipping generator returns to a stable state after a transient excursion, tests can be as easily performed using test case "Synchronous Power Swing"

Out of Step Protection

Contrary to the blocking of the line protection function when a power swing phenomenon is detected, there are functions which have to take action just in this case. This may be in generator protection that has to selectively disconnect a slipping generator from the network. In the transmission networks, there are predefined separation points which have to be opened if severe instabilities are detected, to restrict the consequences on the smallest possible area. The famous blackouts of the year 2003 have shown how important the proper operation of such functions can be.

Typically, these functions need to see multiple "slips" before they issue a trip command.

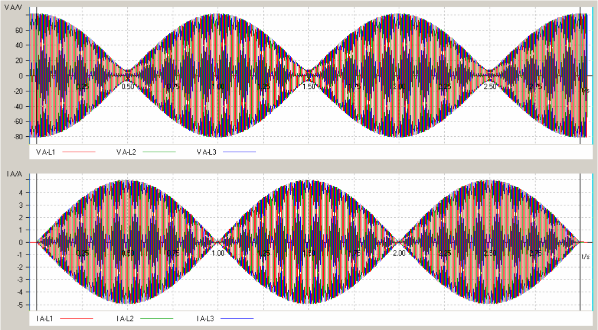

Figure 7: Multiple power swings for testing OST functions.

A realistic simulation of this is performed as easy as the "simple" power swing, just repeated the necessary number of times.

Three Terminal Lines

Due to various reasons, tapped lines become more and more frequently installed. Deregulation has opened the need for new connections to the existing networks, and putting a tap directly on an existing line is a very cost effective option.

This can have severe consequences on the impedance situation seen from the different ends. Reasons can be an unconventional mix of line types (e.g. a cable tap on an overhead line), or an "unbalanced" topology (e.g. a tap close to one end). For distance protection, this may result in very difficult reach settings, which most probably cannot be evaluated by paper and pencil alone. In such cases, a fast and simple simulation tool is especially required during the elaboration the relay settings.

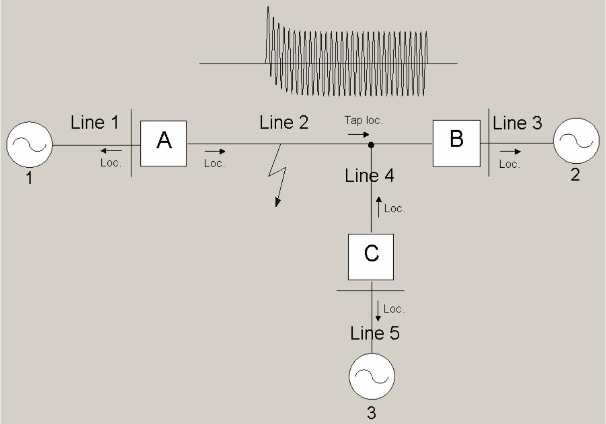

Figure 8: Test case for three terminal lines.

But even in cases which can be regarded as simple, the settings of the distance protection have to be re-evaluated, which is best verified by simulation.

End-to-End Tests the Easy Way

Despite conventional perception, network simulation can greatly facilitate End-to-End testing [2].

The essential advantages of using network simulation are the savings during the test preparation. Up to now, using sequences of states were one of the most common methods. Test documents with matching, "mirrored" pairs of test sequences had to be prepared. This required some effort and skills in the usage of the test software. Working with matching pairs of transient files required even more preparation efforts. When it comes to three terminal lines, "pairs" have to be replaced by "triples", making this an almost impractical task.

With NetSim, the effort is reduced to the configuration of the network parameters. The same configuration can be used at all ends of the line. In the worst case, that means differing CT or PT ratios, the impedances on one end have to be scaled by a constant factor. The fault parameters are set identically at all ends. Getting the test for other ends is more or less reduced to a copy and paste action.

The only essential difference in the test configurations at the different ends is the selection of the simulated quantities which are actually injected into the protective relays. Here simply the corresponding end of the line is selected; the network simulation program then delivers the appropriate fault quantities for the respective relay location.

Conclusion

Thanks to NetSim, network simulation is no longer an academic discipline. Testing with realistic quantities can now be performed with relatively simple means, opening many new applications for network simulation.

The "matching" problems are there. In many cases, only testing with a "real fault" can solve the problem or delivers the required quality in the results.

NetSim offers the user many useful options, for which he had to invest much time and money in the past.

References

[1] Fred Steinhauser, "Netzwerksimulation auf dem PC - neue Möglichkeiten für die Schutzprüfung", OMICRON User Conference, Lindau, Germany, 2002.

[2] Fred Steinhauser, "New Tools for Straightforward End-to-End Testing", OMICRON User Conference, Johannesburg, South Africa, 2003.