Protective relay testing using a modern digital real time simulator

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Abstract: Real-time power system simulator testing provides an invaluable means to evaluate relay performance under realistic conditions. Simulator testing has been and will continue to be essential for achieving reliable transmission line relaying and it is expected to contribute to improved designs in other areas of protection, as for example in transformer protection relaying. Examples of testing of line protection and transformer protection are described.

Key words: digital simulator, relay testing, protective system verification, protection application, transformer protection, distance protection.

I. INTRODUCTION

A power system simulator for relay testing should be flexible in configuration and parameter adjustment and it should provide for a rapid execution of test cases. It must not only function in real time, but in a closed-loop mode with relays tripping and re-closing circuit breakers within the simulator. The authors' company has developed earlier a digital, computer-controlled, electronic, analog power-system simulator [1,2]. This simulator was used to evaluate new protection concepts in connection with product development work by its efficient real time simulation capability, which enables parametric testing. Moreover, it was also utilized for the type testing of prototype equipment and verification for various customer applications.

Power system simulations for relay testing can be motivated because of the development of the power systems and the development of the protection techniques, for example:

- network topology such as multi-circuit lines and multi-terminal lines
- components in the networks such as series capacitors, MOV's, FACTS, static VAR compensators and HVDC
- fast operating protections
- protection systems as multi-terminal relays
- numerical techniques used in the protections, for example, adaptive algorithms and fuzzy logic

The utilities want to verify the protection in special applications and the manufactures use simulators to verify their design. During a recent development of a new reliable distance protection, the performance was verified in around 100 000 fault-cases. The use of calculation programs, such as EMTP [3], EMTDC, etc., for off-line testing will then be a limited approach.

The manufactures also have to meet the demands of simulations and verifications from their customers. Both utilities and manufactures of relay protection are then facing the need of simulations and are obviously prepared to invest in advanced simulators.

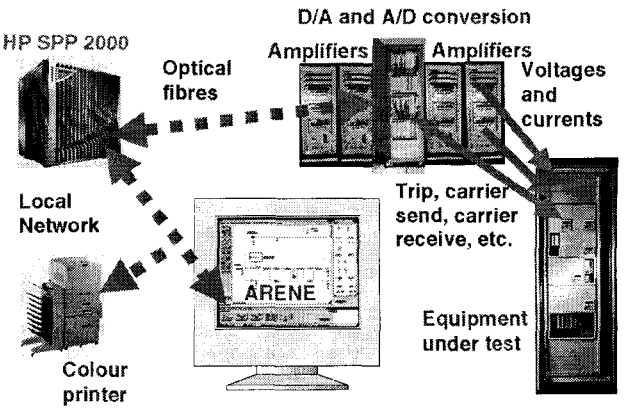

Fig. 1. Configuration of the new digital real time simulator, ARENE™, at ABB Automation Products AB.

II. SIMULATOR

The presented protection testing has been performed at ABB Automation Products AB in Västerås, using a new simulator under trade name ARENE™ [4,5]. It is developed by the French utility Electricité de France (EDF). The new simulator has replaced the computer controlled analogue simulator used by ABB since 1985 [1, 2].

The basic specifications of the simulator are:

1. ARENE™ software, developed by EDF, is implemented in a HP SPP 2000/S-16 computer with 16 parallel processors and 1024 MB memory.
2. The computer is connected via a low latency communication system using optical fibers to an I/O-equipment for D/A and A/D conversion, all delivered by EDF.
3. The I/O equipment is connected to amplifiers giving current and voltage signals to the tested equipment. The English Company Analogue Associates has delivered the amplifiers.
4. The connections of logical signal to and from the tested equipment are made directly to the simulator I/O equipment.
5. Possible number of input signals to the tested protection in the ABB installation are:

    - 12 currents from power amplifiers for current (Techron 7790 RLY)
    - 12 voltages from power amplifiers for voltage (Crown 3622)
    - 48 logical signals indicating breaker position, blocking or permissive signals from remote end, etc.

6. Possible feed back from the tested equipment:

    - 80 logical signals: trip signals, signals to remote end, etc.
    - 20 analogue signals from amplifiers or tested equipment

The amplifiers for current signals are designed to give a peak current of 160 A at a voltage of 100 V.

III. ISOCHRONES - EXAMPLE OF BATCH TESTING

A study of isochrones is a typical simulation task of a Digital Transient Simulator. The flexibility to change the power system network connected to the protective relay(s) to be tested is important. Using a batch-testing feature, it is possible to automatically test the relay in many network configurations and with different kinds of faults. The batch-testing mode in ARENE™ meets the need to have many simulation results with variation of parameters, for example:

- length of a line
- source impedance
- location of a fault
- fault type
- fault resistance

In such a test a simple network is normally used, but a large number of fault cases, has to be registered (Fig. 2). The network is a single circuit line connected to a voltage source with variable source impedance. The goal was to evaluate the tripping time and transient overreach of the distance protection and its dependence of SIR (Source to line Impedance Ratio) and the distance to the fault. In the example maximum and minimum of the operating time has been measured during the variation of the fault inception angle. This has to be done for different fault types.

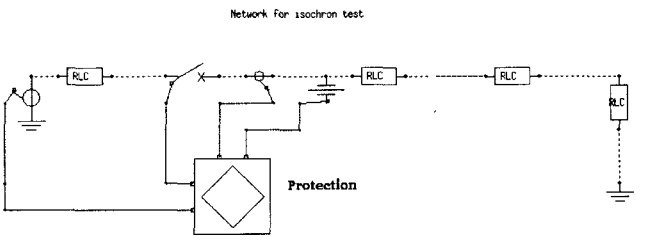

Fig. 2. Network used in, ARENE™, during isochron test of a distance protection.

After the batch session a summary report shows the maximum and minimum tripping time, one table for each fault type. Such tables are used to design the isochrones normally used in protection documentation. As an example, the results of a phase to phase fault are shown in the table 1 below.

```
-----------------------
Case Name : "Isochron test"
-----------------------
"L1L2" fault - 30.00 deg. Steps
XM(sec)  = "10 ohm"
XM(prim) = "36.4 ohm"
I(prim)    = "1000 A"
I(sec)     = "1 A"
U(prim)   = "400 kV"
U(sec)    = "110 V"

General trip
--------------
Minimum tripping time :
Fault pos. (%)
   100.00    24.22     31.85     25.06
    80.00    16.17     17.71     26.39
    60.00    15.40     18.27     29.89
    40.00    14.35     15.40     24.78
    20.00    13.30     15.12     19.18
     0.00    12.25     13.58     18.34
              0.20      1.00      5.00   SIR

Maximum tripping time :
Fault pos. (%)
   100.00    53.97    999.00     66.36
    80.00    25.06     30.24     33.44
    60.00    27.79     28.23     33.86
    40.00    22.96     25.55     33.81
    20.00    15.96     17.15     32.62
     0.00    14.35     16.31     27.44
              0.20      1.00      5.00   SIR
```

Table 1. Presentation of results from a simplified batch-test for phase to phase fault (999= no operation).

Normally smaller steps of SIR and fault distance are programmed. The table can be used to examine where the operating time is between 12 and 30 ms.. This is shown in the table 1. The procedure is programmed for single phase to ground faults, two phase to ground faults, phase to phase faults and for three phase faults.

IV. SERIES COMPENSATED NETWORK

The second typical use of a real time simulator is the testing to evaluate and analyze the protection system in special applications.

Simualtion

The simulated network in the example is presented in the way it is built in the graphical interface of the digital simulator (Fig. 3). It is composed of three voltage sources (G1, G2 and G3) with infinite busses behind internal source impedance's, two transformers (T1 and T2), 500 kV to 130 kV, a series-compensated double-circuit 500 kV transmission line (L1.1=105 km, L1.2=86 km, L1.3=97 km) with shunt reactors in its terminals and two single circuit 130 kV lines (L3=250 km, L3=125 km). The series capacitor banks with MOV-protections are modeled at C1 and C2. The compensation was 59 %. The characteristic of the MOV is defined by 7 values of voltage and current.

Eight breakers were simulated. The internal trip delay of the breakers was set to 20 ms. Faults could be inserted in different places (F4, F6 and F9). Changing the value of fault position parameters sets different locations of the faults F1 and F9. The position of F6 is fixed.

One of the parallel lines was protected by distance protection type REL531 [7] (Protection 1 and 2 in fig. 3.) Line currents and phase to ground voltages from simulated CT and CVT was connected via the simulator output equipment to the tested relay in each end of the protected power transmission line.

The relays are connected for single pole tripping and to send and receive phase-segregated carrier signals plus ground fault detection signals. The block "Carrier" in fig. 3 simulates the transmission delay of carrier signals. The block is receiving signals from and sending signals to the tested equipment. The total amount of used I/O is 12 analog outputs, 14 logical inputs and 8 logical outputs.

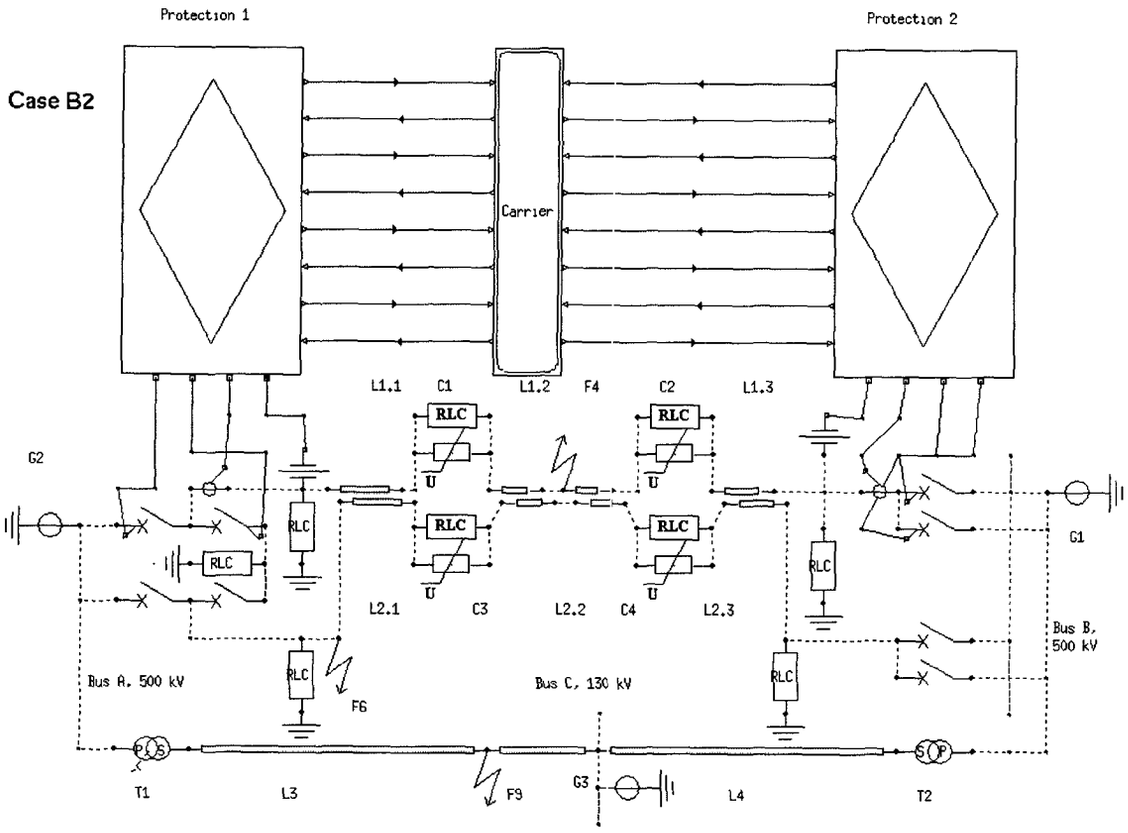

Fig. 3. The network built in ARENE™ for testing REL 531 distance protection in a series compensated network.

The presented cases verify the protection in case of faults on the protected line between the two series capacitor banks. A corresponding batch testing session is programmed to make a variation of fault type, fault position, fault inception time (angle) and load flow.

Presentation of results

The currents and voltages in both ends are registered in graphs showing the results. As examples of presentations using the postprocessor facility in the simulator the simulations of single-phase to ground and a three-phase to ground fault was presented (Fig. 3.). By setting the fault inception time as a reference the operating time of the tested relay is measured in the diagrams. (In batch mode the script provide same type of measurements.)

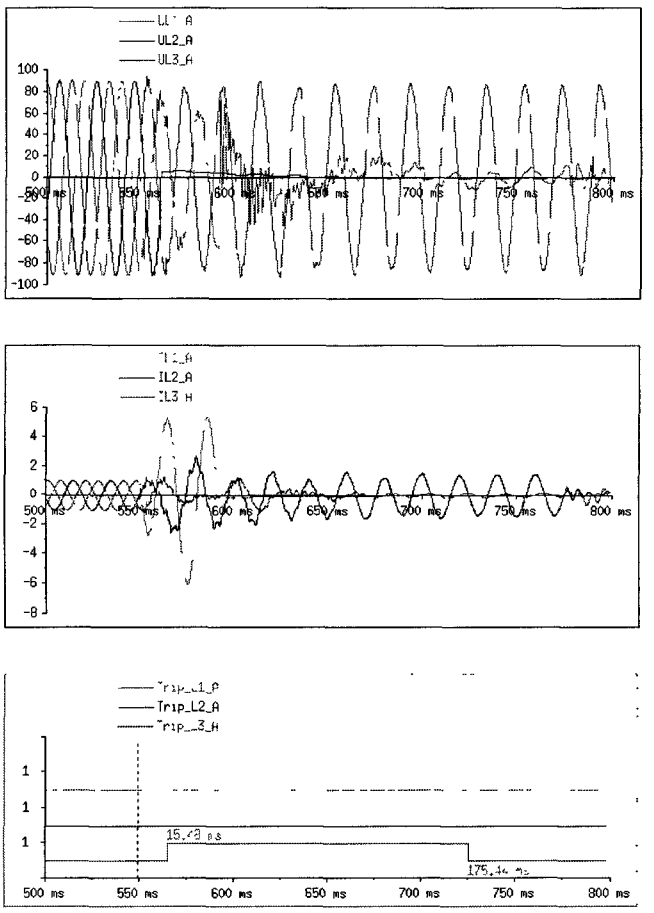

Fig. 4. Simulated currents and voltages in one end of the 500 kV line at a single phase to ground fault in phase L1 on protected line followed by a single phase bus fault at the beginning of the parallel line (Fig. 3).

In the first case (Fig. 4.), with two simultaneous faults, a phase *a* to ground at 40 % of the distance between C1 and C2 and a second phase *b* to ground fault 10 ms later on the bus A, 77 km from the series capacitor C1. This means a distance of 182 km from the protection 1 and 106 km from the protection 2.

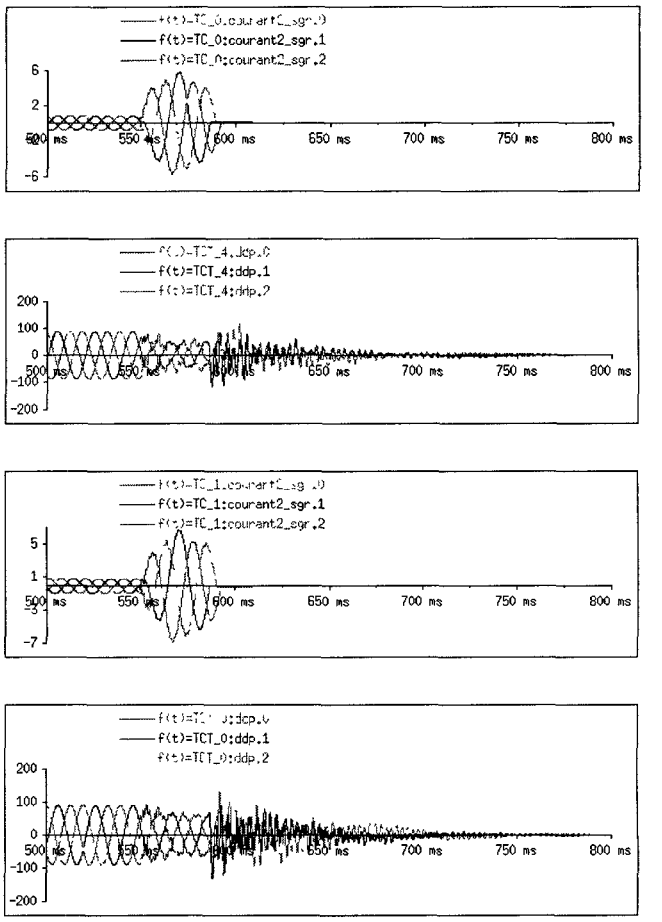

Fig. 5 a. Simulation results in the two ends of the 500 kV line at a three-phase to ground fault between the series capasitors

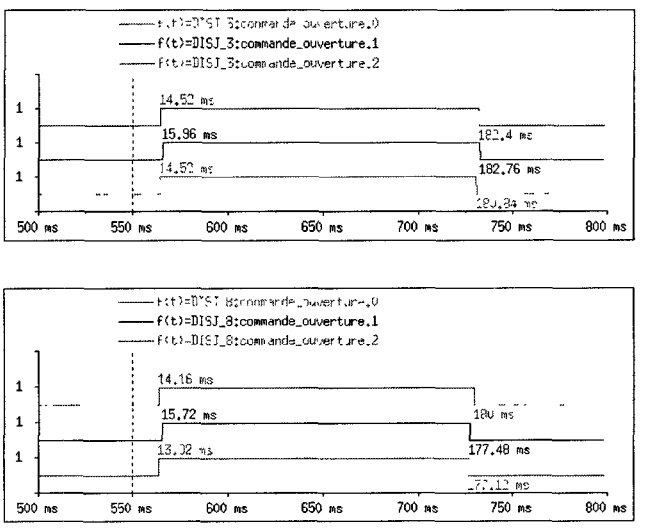

Fig. 5 b. The test result showing REL 531 tripping in the two ends of the 500 kV line at a three-phase to ground fault between the series capacitors.

In the second case (Fig. 5), a three-phase fault, the position in the presented case was in the middle of the section L1.2. or 148 km from the protection 1.

V. TRANSFORMER PROTECTION TEST

A transformer protection was tested at internal and external faults. The network in fig. 6 shows an interconnecting 250 MVA autotransformer 500 kV/ 132 kV. The magnetizing properties can be introduced by using data from a transformer test report giving measured no load current and active power for different voltages.

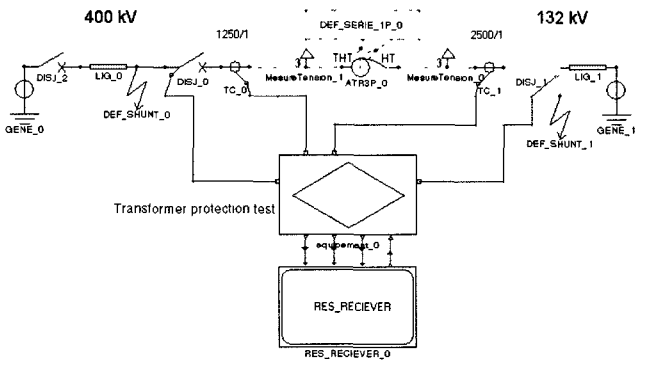

Fig 6. A network for testing Transformer Protection.

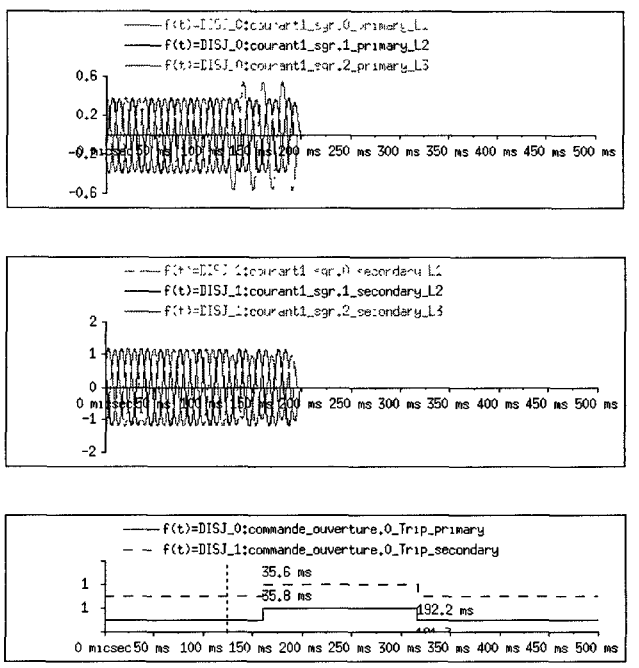

Fig. 7. Tripping of RET 521 at a fault between turns.

Internal faults, winding to ground, winding to winding and turn to turn faults were simulated as well as external faults. The result in fig. 7 is obtained during a turn to turn fault.

The fault is connected between a fault point at 5 % the ground to a point at 2 % in the winding in phase b. The resistance was 1 ohm. By the variation of parameters defining the fault-position and fault-resistance the sensitivity of the transformer protection can be examined in many cases. The tested relay was a RET 521 transformer protection [7].

VI. CONCLUSION

The introduction of a new digital real-time technique for power system simulations has given a digital transient analyzer, DTNA, well suited for protection system verification tests. It meets the demands of flexibility, illustrated by line protection testing and transformer protection testing.

By using the batch mode operation for automatic testing the simulator is very suitable for test sessions with a great number of fault cases which will verify the reliability of the protection.

VII. ACKNOWLEDGMENT

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IX. BIOGRAPHIS

Gunnar Nimmersjö was born in Sweden 1940. He received his M.Sc.E.E. at the Royal Institute of Technology in Stockholm, 1965, and is employed as project manager at ABB Automation Products, Substation Automation Division, Vàsterås Sweden. His special area is line protection development and especially development of wave detecting algorithms, including simulation equipment for testing. At present he is managing the Simulation Centre for product verification and the development of simulation facilities.

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