ARENE : A NEW SIMULATOR REDUCES THE COST OF EQUIPMENT TESTS

Olivier DEVAUX, Pierre LEMERLE, Olivier DELSOL, Sylvain MARTINO
Electricité de France - Direction des Etudes et Recherches
1, Avenue du Général de Gaulle – 92141 CLAMART

INTRODUCTION

ARENE is a real-time Digital Transient Network Analyser which performs real-time tests using a standard parallel computer. It is designed to facilitate the operator in its tests, and reduce the cost of testing campaigns.

It simulates high frequency phenomena (Electromagnetic transients) and allows the test of the interactions between real equipment and the power system. To study several protective relays in the same distributive power system (for example cable differential protective relays), it is important to enable these interactions. Classical simulators work in ***open loop****: the signals are sent to the equipment but there is no interaction with the simulated network. If several relays are studied at the same time, a stochastic approach is usually used, which leads to a huge number of combinations, and long and costly series of tests*

This can be achieved in a much more convenient and painless way using ARENE which works in ***close loop****. To illustrate this point, we present the study of a connection of two line differential protective relays (study done by the R&D Division of EDF for the centre of the Distributive Division of EDF in Essonne). Before the connection on the field, the relays have been tested under real conditions with ARENE, in order to verify that their behaviour is correct with several kinds of faults.*

A NEW TYPE OF SIMULATORS

The need: shortening relay tests

The diversity of the equipment that protect the power grid is always increasing, along with their complexity. In order to verify that the behaviour of these equipment is correct, long and costly testing sessions are needed. These tests can be made at different steps of the equipment's life : during the design phase by the manufacturer, during qualification, or after a malfunction.

To probe its full operating range, the equipment is usually connected to a simulator that will run hundreds of tests, with different parameters each time : e.g. distance of the fault, fault impedance, line impedance, phase to ground or phase to phase, …

Such a large quantity of tests drives the need of an automatic and user-friendly facility that takes care of all the tedious and repetitive tasks, and shortens the testing campains, thus reducing their cost.

Standardisation along with versatility

To perform these tests, two main types of simulators have been designed over the years :

- **analog simulators**, where grid components are represented by analog downscale models. These simulators run in close loop but the simulated phenomena are limited by a narrow frequency bandwidth. Moreover, the poor flexibility and the maintenance costs of these simulators opened up the way for the next family of simulators:
- **digital real-time simulators** able to simulate high frequency phenomena: the real-time Digital Transient Network Analysers (DTNA). Due to the insufficient computing power of standard computers, hybrid or DSP (Digital Signal Processors) based technologies were usually used in order to run in close loop.

However, until 1996, no fully digital simulator was able to use any standard computer, even those used in high performance computing. Today, the calculation power has reached a level that allows real-time simulations of fast phenomena to be run in close loop.
EDF has developed a new fully digital simulator, called ARENE, that is able to run on a standard multipurpose parallel computer, in close loop: the interaction between the real equipment under test and the simulated system is taken into account at each time step. This allows the study of several equipment operating on the same network simultaneously. In order to shorten the time step to the minimum, ARENE, is able to split the power grid simulation on different processors, taking advantage of the full power of a parallel computer.

This DTNA is a multi-purpose and versatile simulator, and is designed to test a wide range of equipment:

- Grid relays (Protective relays, Busbar relays, Transformer relays, MV power system fault detector)
- Grid control systems (Station automatic control systems, MV and HV capacitors command)
- Generator relays and controls
- Power system control equipment (Emergency control system, Automatic Gain control equipment, FACTS and DC link controls
- Equipment prototypes (FACTS and DC link prototypes)

The general architecture of the DTNA is shown in Figure 1.

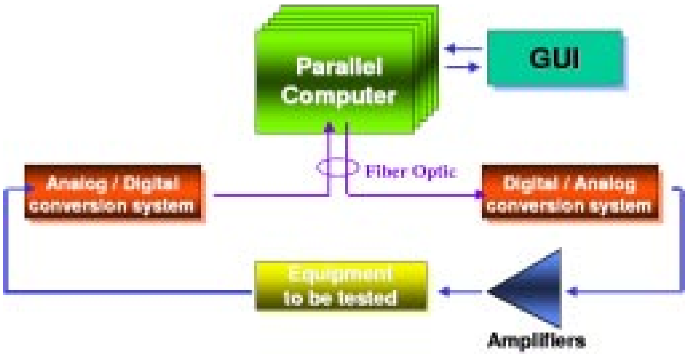

Figure 1.ARENE architecture

PRESENTATION OF A PRACTICAL STUDY

In order to show the main advantages of this new loopback TNA, the next paragraphs will show a typical simulation session, based on a real study made on the EDF distribution network. We will go through all the different steps, beginning with the network input and initialisation, some off real-time simulations, and the real-time tests of the equipment that will be installed on this network.

This study was started after an incineration factory decided to become an independent producer and revert the generated energy through the existing 20 kV network it was connected to. Once the interconnection feasibility studies were made, it was necessary to design the protection scheme.

The main part of the study consisted in the choice of adequate relays to protect the three 7 km long connection cables. French distribution systems are indeed radial and supplied by a single main source. Their protection plans are therefore based on the principle that the fault current always flows in the same direction. Part of the connection cables protection scheme was to be provided by sets of differential current relays which are supposed to ensure fast and selective clearance of faults occurring on a cable. Backup of the differential relays and co-ordination with other relays in the substation and in the producer plant is guaranteed by overcurrent directional relays.

This paper deals with the evaluation of the differential relays performances. The study is split in two parts. First, the network is simulated off-real-time, in order to analyse the different scenarii, with different positions and several types of faults. The goal is to see which scenario would be the most interesting, and select them for further analysis. The results of these scenarii are sent to a program written in Matlab, representing the algorithms implemented in the relays. Hence, this first part of the study serves as a reference, showing the theoretical behaviour of the relay.

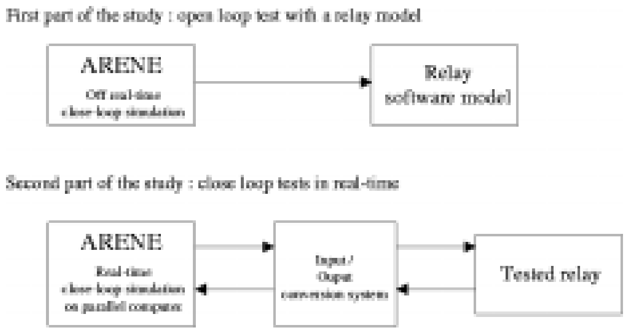

Figure 2.ARENE architecture

The second part of the study is made with the real differential relays. The simulations are run in real-time loop-back : the simulations selected during the theoritical study are run with a 60 µs time-step in real-time. At each time step, the currents are sent to D/A converters, and then to the relays after amplification. The orders coming from the relays are also sampled at the same rate, and sent back to the simulator which takes them into account for the simulation (e.g.: it will open the circuit-breaker in the simulation, if the relays tells him to do so). The relays will then receive the resulting transients and react exactly as if they are on the real network, with full feedback).

The ability of making real-time loop-back simulations is one of the big assets of this simulator, which allows to test the relays in real-life conditions.

The results of these simulations are then compared to the first part of the study. This comparison will immediately show if the relays can have a different behaviour from what was predicted, and also validate or invalidate the protection scheme that was defined.

SHORTENING THE NETWORK DESCRIPTION

An immediate productivity gain with a smart GUI

Each part of the simulator is controlled through the Graphical User Interface (GUI). A special attention was dedicated to this GUI, in order to facilitate the operator in its tests, and reduce to the minimum the time needed to enter a complete network.

The first task consists in designing the network, which is a matter of point-and-click with the mouse. In a few minutes, the network is drawn, and the user then starts feeding the electrotechnical data. This is as simple as double-clicking on each element of the network, and filling in the fields in the windows that appears. To save even more time, the user will use its own model database, with ready-to-use elements, containing all the parameters

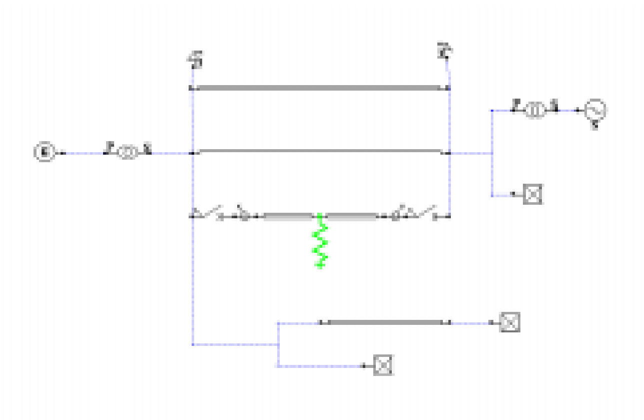

Figure 3. How the network appears in the Graphical User Interface

An important asset of this simulator is the ability to use variables instead of numerical values for any parameter of any model. For example, instead of writing «150» for the length of a line, it is much more interesting to write your own variable «MyLength». This variable is automatically added to a table in which the user can define sets of values. This way, a single generic network can be used to run hundreds of cases, without the need to reload a new network each time.

These facilities, along with many others, allow the user to enter the complete network in a very short time, and spend more time on what really matters : analysing the results of the simulations.

Initialising the network : benefits of a complete load-flow

Before starting any transient simulation, ARENE calculates the network loadflow. A simulated power system usually includes complex non-linear elements (rotating machines, transformers, ...), control-systems and interactions between them, making the load-flow calculation very difficult to solve manually.
The initialisation program includes 4 parts : a pre-processing code, a positive-sequence load-flow program based on Newton-Raphson algorithm, a global initialisation to compute on the frequency domain unbalanced solutions and finally the initialisation of the variables of the simulation code.
This is a great help for the end-user, and time saving, as most of the calculations are done automatically, and displayed on the screen for final verification

BATCH TESTING

In any relay test, there is a need to have many simulations with some parameter variation:

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

These variations can be simply notified in the GUI through a C-like script language, in order to handle automatically the launch of the simulation shots, without any user intervention. For each simulation shot, the results are saved for further investigation. During the batch-testing session, the user can see or print the results of the last shot to check some results. The display of the results is made trough a post-processor that allow to specify the layout of the results automatically.

OFF REAL-TIME SIMULATIONS AND TEST OF A SIMULATED RELAY

The schematics displayed in Figure 4 shows how both differential relays have been implemented in a Matlab simplified model. The main parts of the relays appear : analogic currents summation, signal filtering, threshold calculation, fault detection, local tripping decision making, remote tripping signal emission. Time delay due to communications between the relays through a pilot wire is modelled by a lag function.

The relay computes a linear combination of the phase currents at each end of the conductor.

$$\sum I = Ia + k\ Ib + k'\ Ic$$

The “slave relay” sends continuously the value of the linear combination to the “master relay” located at the other end of the cable. This relay calculates the difference between the linear combination of currents at the receiving and sending ends. There is indication of a fault if this difference exceeds the tripping threshold made of the sum of two values :

- the first one depends on the value of the currents at both ends and takes into account the CT errors,
- the second one is constant and avoids nuisance tripping due to shunt capacitive currents in case of an external fault.

The tripping criteria is therefore :

$$\left|\sum Is - \sum Ir\right| > \alpha\left(\left|\sum Is\right| + \left|\sum Ir\right|\right) + Io$$

Once the tripping decision is made by the master relay, a remote tripping signal is sent through the pilot wire to the “slave relay”.

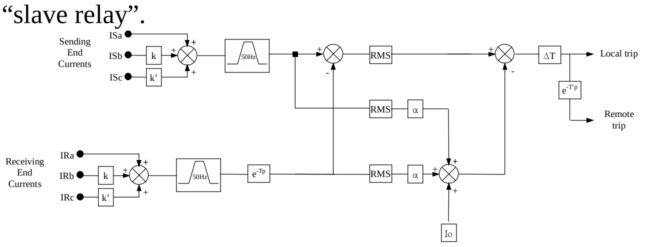

Figure 4.Simplified differential relay operating diagram

An example of ARENE and Matlab simulations results is shown in Figure 5. The study case is the apparition at t =100 ms of a bolted single phase to ground short-circuit on the protected cable. The first three curves represent the currents at the cable end on the substation side. The next three are the currents received on the other end (producer side). An overcurrent appears, which should make the simulated relay trip. The results appear on the bottom curve, showing that the relay stabilises in 35 ms and does trip under these conditions.

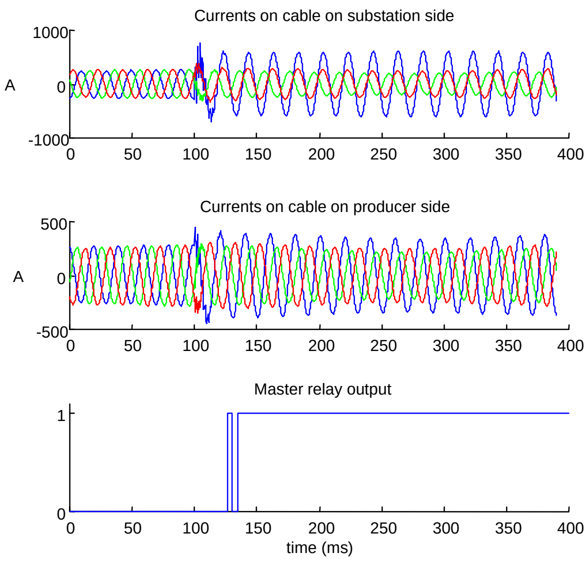

Figure 5.Off-real time simulated differential relay response in case of a single phase to ground fault

An extensive off real time study has been performed to get a selection of around 150 cases to be real time tested. Since the differential relays input is a linear combination of the three phase currents, their behaviour is supposed to be “unbalanced”. For each type of fault, the phases that would give the least sensitivity while affected by the fault have been determined. These tests indeed revealed that the sensitivity could be reduced by half according to the faulted phases. The obtained theoritical sensitivity is :

- 50 Ω for single phase to earth faults
- 40 Ω for double phase faults
- 140 Ω for three phase faults

REAL-TIME TESTS

Presentation

These tests have been run in real-time, with the real current differential relay connected to the simulator. Each part of the relay receives the simulated currents corresponding to the end of the line it is connected to. (see Figure 6)

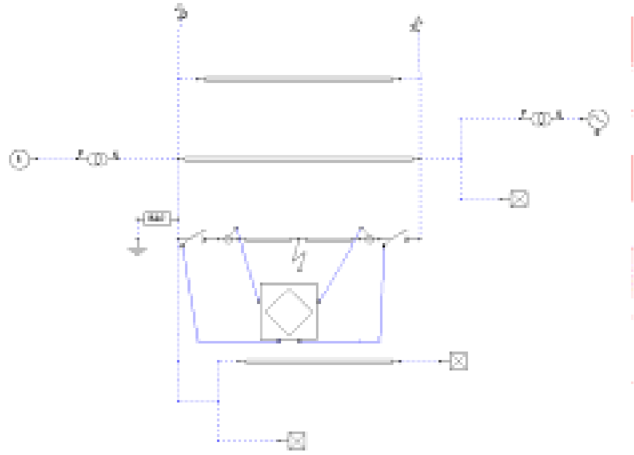

Figure 6.Real time test configuration

In the setting up of the test bench, attention has been given to the modelling of current transformers. Their behaviour has indeed a significant impact on the response of the relays. The main problem that can be encountered in the case of embedded generators interconnected with distribution systems is the risk of CT saturation due to a higher sustained DC component in the phase current. Actual characteristics of the magnetic circuits provided by the manufacturer have been used to create the CT model.

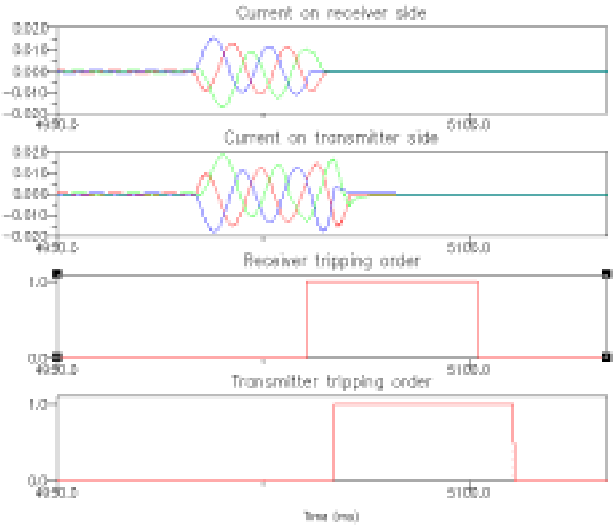

Figure 7. Tested relays response in case of a three phase faults

The real time tests enabled to evaluate the relays time response (breaker opening time excluded) between 50 and 60 ms. Sensitivities obtained through these tests are similar to the theoretical ones for single and double phase faults. However a significant difference can be noticed for three phase faults since the highest fault impedance that could be detected during real time testing was 20 Ω (instead of 140 Ω). This difference can be justified by a lack of information of the exhaustive design of the relay and the use of a simplified Matlab model. It showed nevertheless the complementarity between off real time and real time testing.

CONCLUSION

The easiness to make tests with ARENE and change the parameters of the simulation, the ability of modifying the test-cases on the fly have been demonstrated through this study. Hundred of tests have been done in short time, showing the real gains that this simulator brings in reducing the cost of testing campaigns.

[1] L. Levacher, H. Chabanas, O. Huet, O. Delsol, O. Devaux "A powerful graphical interface for a real-time digital transient network analyzer", *ICDS'97,* Montreal, Québec, Canada, May 28-30, 1997

[2] O. Devaux, L. Levacher, O. Huet, "An advanced and powerful real-time digital transient network analyser ", *IEEE PES Summer meeting,* Berlin, Germany, June, 1997, PE-825-PWRD-2-06-1997