

## NEW HARDWARE IN THE LOOP TESTS FOR EARTHFALT CONTROL AND PROTECTION SYSTEMS

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### ABSTRACT

*This paper presents the experience using a Real Time Digital Simulator (RTDS) for developing and testing of new control and protection algorithms for compensated networks.*

*Due to the rapid change of power distribution networks in recent years, it is no longer enough, only to observe the reaction of a protection relay to a recorded event. In most cases, the supply from the secondary side, for example from a large distributed generating facility, is no more neglectable. In today's very symmetrical networks, also the behavior of controllers for Petersen-Coils is complete different.*

*In this paper the experience of designing a RTDS and using it for development, type test and repetition-tests of a system with two Petersen-Coil-Controllers, an earthfault-protection-system for 32 feeders, two bus-bars each with 10 feeders, two continuously tuneable Petersen-Coils and two thyristor-controlled zero-sequence current injections will be presented.*

*Especially the benefits during the development and the improvements of the quality of the type-tests will be presented in detail.*

### INTRODUCTION

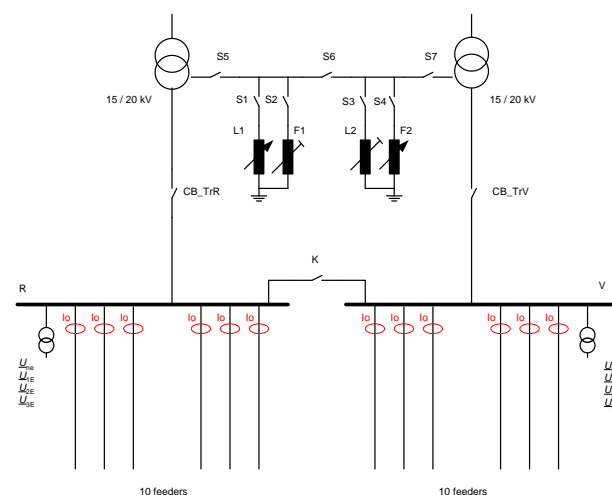
In the past, analogue models were used for the testing of control and protection systems during the development and even for the final type tests. To receive reproducible results, it is necessary to realize real parameters of the network. In today's meshed networks, this mostly requires additional investment. In analogue models, also the change between different network configurations involves a lot of cost-intensive work.

In contrast, with a RTDS it is very easy to model the network very near to its real behavior in real time. Therefore it is possible to test the control and protection system and also the reaction of the network. The simulated network can be meshed, including large distributed generating facilities or other protection systems. Using a RTDS, the whole control or protection system is checked, not only the algorithm.

The use of the RTDS will be explained based on the requirements of ENEL Distribuzione, who asked for a real time digital simulator to perform the type tests on a batch of advanced Petersen-Coil control systems installed in the ENEL MV network.

### CONFIGURATION

For the following standard substation according to *Fig. 1* with two bus-bars, two tuneable Petersen Coils 60 A ... 375 A, two fixed coils 80A ... 200 A and a combined wattmetric increase (serial and parallel impedances) a combined Earthfault Detection and Control System (EDCSys) was developed.



*Fig. 1: One line circuit diagram of a standard substation*

The EDCSys [2] shown in *Fig. 2* is designed to

- control up to four Petersen Coils
- tune the Petersen coil either by changing the coil position respectively by using the Current Injection with two Frequencies (CIF)
- control the Peterson Coils in case of very symmetrical networks with neglectable natural asymmetry.
- supervise up to 32 feeders on earth faults using the admittance method, the wattmetric method and an intermittent earth fault detection algorithm.

The two bus bars can be coupled in the substation or in the field. The automatic detection of the external coupling needs extra handling, as the zero-sequence voltage is very small.

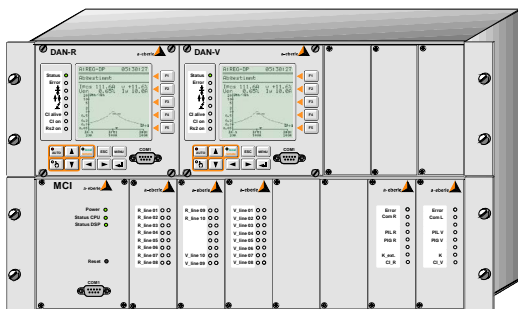


Fig. 2: Earthfault Detection and Control System EDCSys

An injection with two frequencies and variable injected current amplitude, as shown in Fig. 3, is used for the calculation of the actual tuning of the Petersen Coil [1]. For small networks a reduced current injection as depicted in Fig. 4 is necessary, in order not to generate earth fault signalization. All components of the current injection controller are placed in the motor-drive of the Petersen Coil and are connected to the EDCSys only via a RS485 communication.

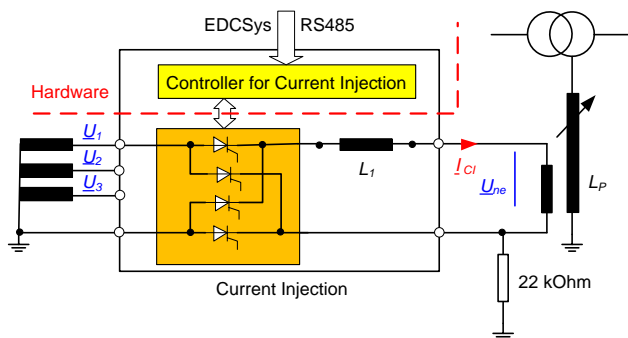


Fig. 3: Current Injection with a thyristor-switch with variable ignition

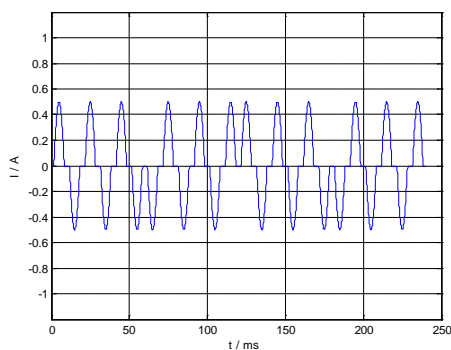


Fig. 4: Reduced injected current for small networks

For the high impedance earth fault detection using the admittance method, it is necessary to get reference-values of the admittance of each feeder. For the calculation of the admittances it is necessary to inject the two frequencies for a short time and to measure at that time the corresponding zero-sequence values of voltages and currents. Due to this requirement a simple replay of a transient record, as it is

usual for tests of short circuit protection relays, is not possible for the test of protection systems which are using the admittance method.

For the test of the control function as well as for the test of the admittance method, it is necessary to inject a current in the zero-sequence system and to measure the reaction of the network for the further calculation. Therefore the following components must be simulated:

- Substation according to Fig. 1
- Current injection according to Fig. 3 without the Current Injection Controller, which is connected via RS485. The group of digital signals for the firing of the thyristors is one of the interfaces between real hardware and simulation.

From the perspective of the model, the following signals are necessary to communicate with the Device Under Test (DUT):

- 5 Voltages 100 V
- 12 Currents 1A
- 2 small DC-voltages for the actual coil-position
- up to 48 relays for the switch replication
- 48 opto-coupled binary inputs for the thyristor firing and the commands to the Petersen Coils

Further requirement for the tests is, that a large number of situations and reactions of the network must be tested [3][4], for example:

- Simulation of an isolated and compensated network
- Simulation of different types of earth faults
  - single line earth fault
  - double earth faults
  - intermittent earth faults ( isolated networks )
  - restriking earth faults
  - high impedance earth faults up to 20 kOhm
  - low impedance earth faults
- Simulation of different network situations as for example:
  - switching of wattmetric increases
  - switching of fixed coils
  - switching of decentralized coils
  - coupling of the bus bars in the substation
  - external coupling of the bus bars
  - switching of loops in the network
  - autorecloser function of a feeder
  - disconnections of one faulty part of the line
  - switch on of a healthy line
  - switch on of a faulty line
  - switching of a loop with a healthy feeder
  - switching of a loop with a faulty feeder
  - cross-country fault in the same feeder
  - cross-country fault in different feeders
  - ...

For testing these large number of use-cases, it is possible to use either an analogue model or to simulate the network and the current injection with a RTDS.

## ANALOGUE SIMULATOR

The advantages of an analogue net-model are:

- Possibility to build up very large networks
- Frequency response of the network is continuously
- Accuracy depends on the quality of the models

But there are some disadvantages using an analogue simulator, for example:

- A lot of work must be done to ensure, that the parameters of the model at lower voltages and currents correspond to the real network components, especially for nonlinear components like thyristors
- Some components can be build up only with a large investment - for example: the Petersen Coil with moving core
- It is not easy to change some parameters of a model, for example the losses or the maximal current of a Petersen Coil
- Switching between different configurations of the network needs a lot of time
- It is not so easy to ensure that the ignition time of the arc occurs at reproducible phase angles
- Thermal drift and aging of the components

## RTDS

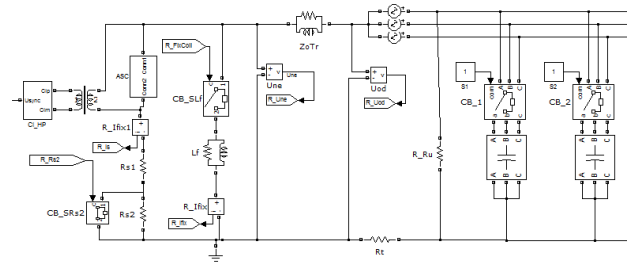
Using an RTDS eliminates a lot of disadvantages of the analogue simulator.

To enable an adequate simulation for the transients of a real network, the cycle time of the RTDS should be less than 50  $\mu$ s, which corresponds to a sample rate of 20 kHz. The resolution of the digital analogue converter should be in the range of 16bit. These requirements for the RTDS were provided by ENEL Distribuzione.

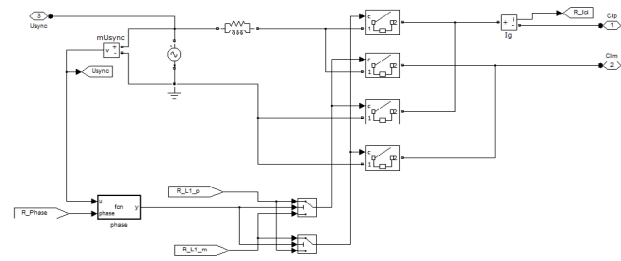
The solution for these requirements was to use a fast PC off-the shelf as "Target PC" equipped with a fast 16 channel DA-converter with 16 bit resolution and a digital-IO interface with 48 relays and 48 fast optocoupled binary inputs. For the simulation the software xPC-Target in combination with Simulink and the toolbox SimPowerSystems from MathWorks were selected. Accurate analogue power amplifiers from OMICRON were used for the conversion from the DA output with  $\pm 10$ V to the secondary level of 100 V respectively to 1 A.

The network and the current injection was built up with the standard blocks available in the SimPowerSystems. Two examples are depicted in *Fig. 5* and *Fig. 6*.

For some special components, as for example the tuneable Petersen Coil, Simulink was used. The problem for the realization of this model is the short word: "tuneable". The inductivity of the Petersen Coil must be changeable especially during the whole simulation time.



*Fig. 5: Part of the simulated network with the Petersen Coil and the current injection*



*Fig. 6: Submodel of the current injection from Fig. 3*

The workflow for a test is as follows:

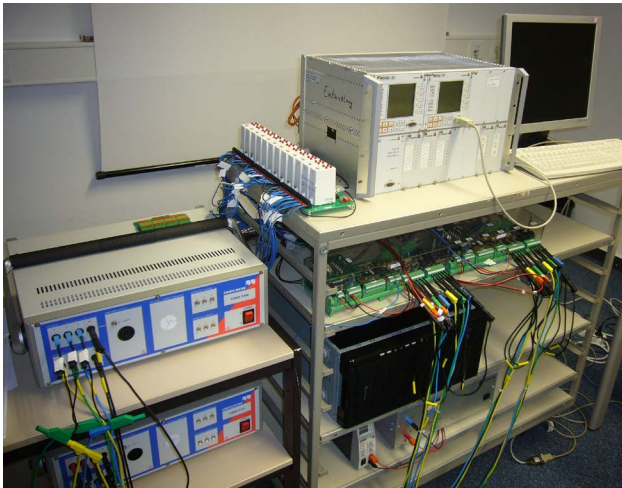
- 1) Configuration of the network, definition of the initial values and the definition of the changeable parameters are done in SimPowerSystems
- 2) This model is then compiled to an executable program
- 3) The executable program is downloaded to the Target-PC via Ethernet. On the Target-PC a real time operating system (RTOS) is running. The RTOS is part of the xPC-Target software from MathWorks
- 4) The simulation on the Target-PC is started
- 5) Parameters of the simulation on the Target-PC can be modified remotely via Ethernet with Matlab commands
- 6) Required test-sequence can be started via Matlab commands or Matlab scripts
- 7) The reaction of the EDCSys can be supervised with different methods:
  - Display of the EDCSys
  - Via the binary inputs of the Target-PC, using the RTDS as recorder
  - Via RS232 connected to the EDCSys and reading the measurements and states of the EDCSys
- 8) The closed loop version via RS232 enables to generate very easy automatic supervised test sequences
- 9) If the reaction is ok, the next test can be started

During the simulation the on/off switching of feeders can be done very easy via Matlab-commands. As these commands change only the "tuneable" parameters of the model, a recompilation and download of the new model is not necessary during the simulation.

Using the RTDS it is also possible to write selected channels in realtime to a file on the harddisk. This enables

additional accurate evaluations after the simulation.

In *Fig. 7* the complete EDCSys with the two current injection controllers and the RTDS with the three power amplifiers, the 48 binary inputs and the 48 relay outputs is depicted.



*Fig. 7: Complete system: EDCSys with 2 Current injection controllers and the RTDS with power amplifiers*

## EXPERIENCES

The overhead of the RTOS is about 5  $\mu$ s. The calculation of the network takes about 5 to 15  $\mu$ s, depending on the size of the selected network. Also the output of the 16 DA channels poses no timing problems. Only in case of the binary input and output, the necessary time for one transferred bit must be taken into account very carefully. In our case the numbers of digital IOs should be reduced as much as possible.

The selected discrete fixed-step solver of Simulink influences the required simulation time, too. The choice of the solver also has influence on the accuracy and the numerical stability of the RTDS. In our case we had no problems with the standard selected ode3 solver (Bogacki-Shampine).

With the RTDS it is now possible to set up the parameters of the models very easy, according to the requirements, for example the quality of the coil or maximal current through the Petersen Coil. This was not possible with the previous used analogue network model.

With the RTDS, to change a network-configuration only means to download a new file. This takes only few seconds. Compared with a reconfiguration of the analogue model, which could take hours, this is neglectable and reduces also dramatically the possibilities to make errors due to reconfiguration.

The switching operation, the setting of the fault conditions and the start of the fault in the network can be done via Matlab-commands from the PC connected to the RTDS via Ethernet. In parallel, the measurements and the state of the binary IOs of the EDCSys can be also read out directly from EDCSys. Therefore it is very simple to write scripts in Matlab defining the network switching sequences and to supervise the reaction of the EDCSys. This enables to generate a complete and fast automatic type test for the EDCSys. This test-sequence can be started after any modification in the firmware and enables to detect side effects in case of changing software-modules. Comparing to the long lists of different use-cases, this possibility increases the speed and quality of the development.

Test-scripts for one use-case can be written parallel to the development of a software-module. Therefore the development is changing to a test-driven software development, which increases the quality. Additionally this hardware in the loop testing also promotes the model-based software development, which increases the software quality once more.

Another advantage of the RTDS is, that it is possible to generate ignition of an earth fault or switching of a feeder with reproducible phase angles. Especially for the evaluation of transient relays this behavior is very important. With an analogue simulator this is not possible or needs high investment.

## CONCLUSION

This paper shows, that the use of an RTDS reduces the development time and improves the quality of the software dramatically.

With the RTDS it is easy to change configurations of the network and this change of configuration is equivalent to a download of a file via Ethernet. Parameter changes of components can be done also very easy during the simulation and can be automated. Therefore more use-cases can be checked already during the development of modules, which increases the quality of the firmware.

Due to the possibility to automate the testing, it is easier to detect side effects during the development cycle. Finally, even the type test can be improved and could be faster. The option of changing parameters of the models makes it possible to test configurations, which cannot be realized with analogue simulators. Therefore it is possible to cover much more use-cases with the RTDS, than with the analogue simulator.

Using an RTDS enables to test complex algorithms in a closed loop configuration. This is needed for algorithms, which evaluate reactions of the system on artificial injected test signals.

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