VALIDATION THROUGH REAL TIME SIMULATION OF A CONTROL AND PROTECTION SYSTEM APPLIED TO A RESONANT EARTHED NEUTRAL NETWORK

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ABSTRACT

Real time hardware in the loop simulation systems are powerful analysis tools to validate new smart solutions to be standardized and implemented in distribution systems. In this paper the modelling and real time simulations performed to test the behaviour of a resonant grounding system and its associated real protection and control devices are described. The target of the tests performed is to validate adaptive tuning process and arc flash self-extinction.

INTRODUCTION

With the aim of improving the performance of the electrical power grids at generation, transmission and distribution levels, protection and control systems, IEDs (Intelligent Electronic Devices), are being developed and installed with the idea of achieving the optimum energy supply quality with the fewest number of supply disruptions and the highest reliability. This development and implementation of technologies can be involved in different areas such as fault location, network self-healing and fault arc flash self-extinction.

Every new development of protection and control algorithms and devices, as well as every new implementation in the network of an existing device requires an exhaustive validation process. Traditionally development and validation of algorithms have been performed through off-line Electro-Magnetic Transient Programs (EMTP). Additionally, protection and control real devices are tested, in laboratory and in field, by means of current and voltage injection devices. Nevertheless, further steps have been taken to permit a higher level of interaction between the simulation tools and IEDs under test, which is called *“hardware in the loop”*. The objective of these closed-loop testing is to perform a wide range of tests, reaching extreme case operation, unable to be tested otherwise, allowing the correction of malfunctions as well as devices validation.

One of the main tools used to perform *“hardware in the loop”* testing is the RTDS (Real Time Digital Simulator), which is a fully digital electromagnetic transient power system simulator able to simulate transient phenomena in the modelled power system in real time. Therefore, since the simulation runs in real time by RTDS processors, a real IED, connected in closed-loop through analogue and digital inputs and outputs, interacts on-line with the power system model. The controlled and flexible environment of the digital simulation allows protection and control equipment to be subjected to virtually all possible faults and operating conditions. The closed-loop interaction of the protection system with the network model provides insight on both the performance of the relay scheme as well as its effect on the modelled power system.

In this paper, the modelling and real time simulations performed to test the behaviour of a resonant grounding system and the associated real protection and control device, as the needed validation prior to the implementation of the system in the distribution network, is described. As it is explained in following sections, the resonant grounding system comprises of a variable inductance, connected to the neutral point of the transformer, which is called Arc Suppression Coil (ASC) or Petersen Coil.

RESONANT GROUNDING IN DISTRIBUTION NETWORKS

A significant number of faults in power systems involve earth. This makes the power system grounding a very important factor, as it determines the characteristics of the fault magnitudes and, accordingly, the consequences suffered by the network. Traditionally, neutral grounding methods are defined as a criterion by each DSO (Distribution System Operator), being the most commonly used the following:

- Solidly grounded system.
- Ungrounded system.
- Impedance-grounding system.
- Resonant grounding system.

In resonant grounding, also called compensated system, grounding connection is made by a variable single-phase reactance, called arc-suppression coil (ASC), or Petersen coil, see Figure 1.

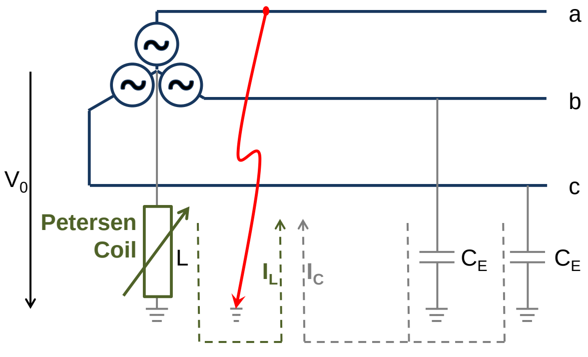


Figure 1. Resonant Grounding

Figure 1 shows schematically the concept of resonant grounding, and the currents flowing under a single line to ground fault in a distribution feeder. In case of fault this coil provides an inductive current that compensates the capacitive one provided by the natural capacitance of the network.

As it is deduced from Figure 1, total fault current is the result of the sum of capacitive and inductive components (and a small resistive component), which are dependent, respectively, on the capacitive impedance of the distribution network and on the inductive impedance connected to the neutral point through the Petersen coil. Therefore, if the Petersen coil is able to provide an inductive current equal in magnitude to the capacitive component aforementioned, which is the resonant point, the resultant fault current will be almost zero. In that case, if the fault is not permanent, the fault arc flash self-extinction is possible avoiding the de-energization of the affected feeder.

Thus, the final objective of this scheme is to achieve transient faults clearance in distribution feeders without the need to trip the breaker, thus keeping continuity of supply, thanks to the fact that fault current total magnitude is reduced down to extremely small values.

In order to make it possible to adapt the inductance of the Petersen coil to different locations of distribution networks, according to their natural capacitance, the inductance of the Petersen coil is variable. Additionally, once installed in a specific location, each network topology variation such as feeders reconfiguration or lines out of service due to maintenance works, involves a variation in the capacitance of the network, according to which Petersen coil inductance needs to be tuned.

The study described in this paper analyses, models and validates a Petersen coil configuration which includes the following main elements in order to optimize the described arc extinction process:

- Variable inductance (ASC). The value of the inductance (that is, the inductive current provided) can be varied within a specific range through the action of a motor which can be managed either manually or automatically by the ASC Controller device.
- ASC Controller device. This IED manages the ASC tuning process. It receives analogue and digital inputs from which it calculates the natural capacitance of the network where the ASC is connected (as well as its variations depending on network topology at each moment) and the desired inductance value at which the ASC has to be tuned. This controller sends “current higher” and “current lower” signals to the motor which actuates on the ASC to move its core, in order to set its inductance to the calculated tuning point. Additionally, this IED includes fault detection functions able to identify the faulted feeder through different algorithms (admittance, wattmetric and directional).
- Injection device. Under the supervision of the controller device, a reduced current is injected in the neutral point, so as the resultant voltages and currents are used as inputs in the tuning process.
- Parallel resistance. This resistance provides a reduced active component in the fault current flowing through the faulted feeder which allows the aforementioned fault detection algorithms to identify the faulted line.

Figure 2 shows the described elements and their interaction.

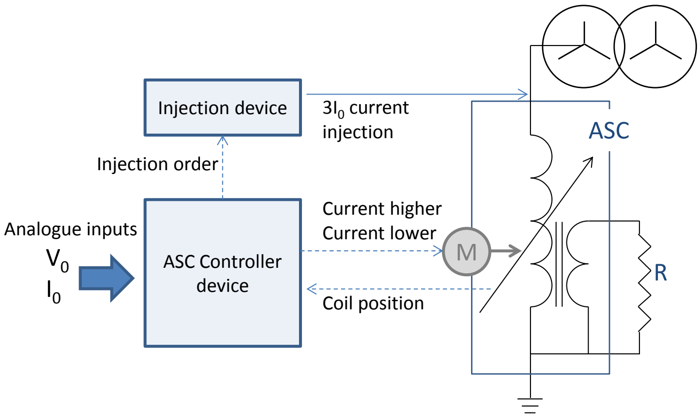


Figure 2. Petersen coil studied implementation

The validation of the whole Petersen coil implementation (ASC + IED) regarding tuning process, fault detection and fault arc flash self-extinction, requires a test platform which allows to integrate on-line and in real time the power system variables (V, I), the outputs generated accordingly by the IED and the corresponding reaction of the power system, in a closed loop.

MODELLING AND HARDWARE IN-THE-LOOP VALIDATION THROUGH REAL TIME SIMULATION

This section describes the validation test performed in the RTDS laboratory. For the tests, the power system, the arc suppression coil and the injection device are modelled in detail in RTDS-RSCAD, whereas the real IED is connected to RTDS and voltage and current amplifiers. Figure 3 shows the RTDS laboratory.

Figure 3. RTDS laboratory validation

RSCAD Modelling

The modelling of the power system, as well as the Petersen coil, is carried out in RSCAD, the Real Time Digital Simulator software. The model includes distribution lines, power transformers, Petersen coil, circuit breakers, the mechanical equipment used to move the coil core and the injection device.

The ASC Controller device under test generates a response to the different grid situations simulated, according to its control algorithms. The behaviour of this control device and the reaction of the power system modeled are checked with RTDS. Therefore, all the elements involved in the network have to be included in the test, as it is described next.

Power System Modelling: Distribution System and Petersen Coil

Figure 4 shows the general scheme of the grid under test.

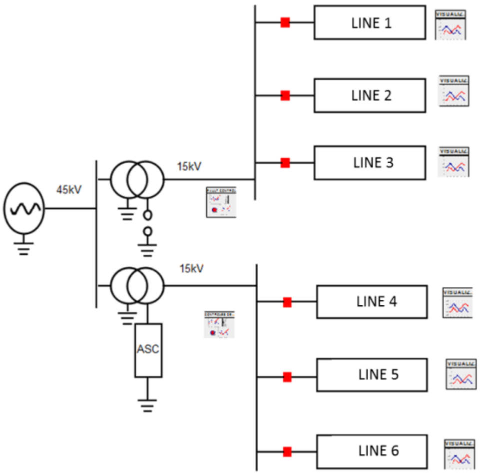


Figure 4 General scheme of the power system

A main part of this modelling process is focused on emulating the behaviour -both electrical and mechanical- of the ASC equipment, so that the control device is able to interact with the grid as if it were in the real facility. Therefore, the RSCAD model includes the mechanical system of the coil, the maximum and minimum position sensors, the parallel resistance connected to the secondary winding, in primary values, the injection device and the current and voltage transformers.

Figure 5 shows a detail of the modelling of the resonant grounding components.

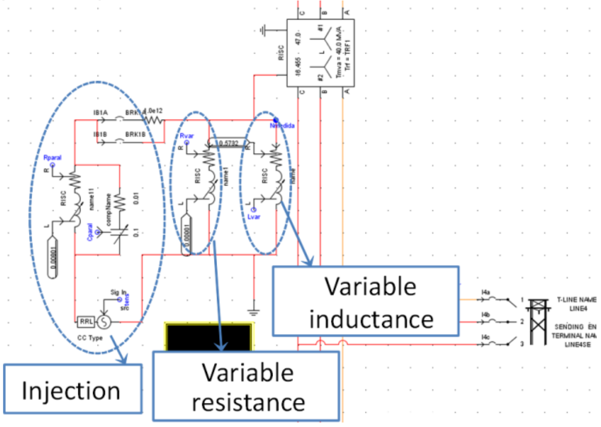


Figure 5. Complete model of ASC

Electric Arc Model

One of the most notable tests that the simulator allows to carry out is to check if the resonant grounding is able to self-extinguish the electric arc generated under transient faults in the power system. Whit this aim, a detailed model of fault with electric arc is developed in RSCAD.

According to the theory related to electric arc generation, in case of low current arcs, like the one that is generated in isolated neutral networks, the electric arc model is based on the modification of the arc length along time. Since fault current magnitude is low in this case, the electric arc is not stable; being its length increased over time and, therefore, its resistance grows as well. This phenomenon finishes with the arc extinction. This electric arc model is included in RSCAD, integrated in the fault model.

Unbalanced situations in the natural capacitance of the grid

So as to prove the capability of the controller device to detect changes in the natural capacitance of the grid, which are caused by changes in the network topology, some variable capacitors are set in parallel with the distribution lines. The values of capacitance can be varied by the user in order to check if the control device performs the tuning process correctly.

Information flow

In order to achieve that the controller device "believes" it is connected to a real power system, emulated by RTDS, information sharing between the simulator and the device under test is necessary. This information flow is done through the exchange of digital and analogue signals, as it is shown in Figure 6.

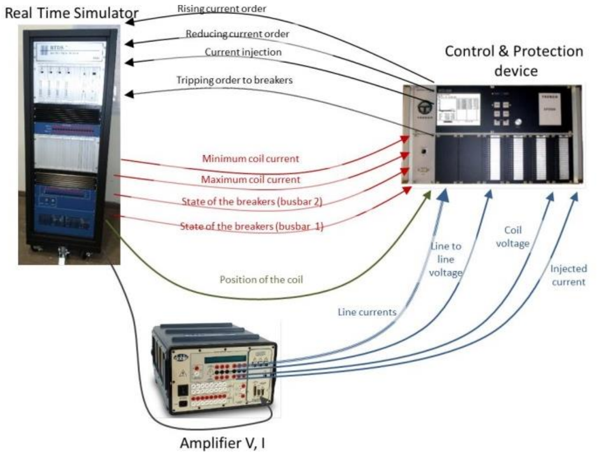


Figure 6. Signal exchange between RTDS and the controller device

The signals involved into the information flows are:

- From the RTDS to the controller device, through the signal amplifiers: neutral currents from lines 4, 5 and 6, neutral point voltage, reference voltage of the distribution network and current injected into the neutral point.
- From the RTDS directly to the controller device: current position of the coil, maximum and minimum position contact status, circuit breakers in lines 4, 5 and 6 contacts status.
- From the controller device to the RTDS: order for increasing or decreasing the inductance of the ASC, injection device activation order and trip signals to the circuit breakers of lines 4, 5 and 6.

Performance Tests

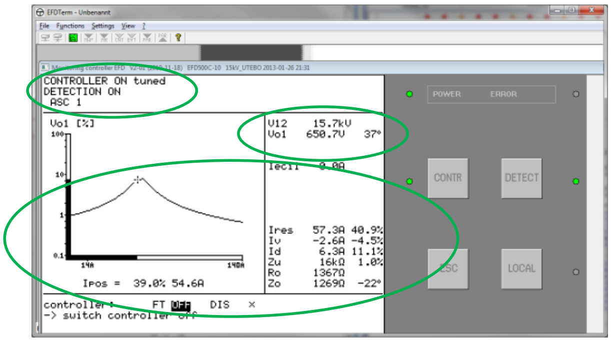
Once the whole system is modelled in RSCAD, a series of tests are done with the aim of check the performance of the controller device and the resonant grounding method in the grid.

The simulator allows doing tests that in the real grid may not be done due to the risk for the installation. Moreover, the simulator provides results of these tests in the same instant that they have been carried out, thanks to the oscillography offered by the software.

The main tests performed are described next:

Start-up and initial tuning process according to the capacitance of the network

At the start-up, the controller device orders a series of current injections into the neutral point of the grid so as to calculate the capacitance of the network. Based on the results obtained and the compensation defined by the user, the IED calculates the position of the coil and sends the corresponding order to the ASC.



```
CONTROLLER ON tuned
DETECTION ON
 ASC 1

V12     15.7kV
Vo1     650.7V    37°
Iecl1     0.0A

Ires    57.3A  40.9%
Iv      -2.6A  -4.5%
Id       6.3A  11.1%
Zu       16kΩ   1.0%
Ro      1367Ω
Zo      1269Ω   -22°

Ipos =  39.0% 54.6A

controller:      FT OFF   DIS   ×
-> switch controller off
```

Figure 7. Initial tuning of the coil

In this case, the IED settings are established in 95 % of capacitive current compensation. This compensation level agrees with a neutral current of 54.6 A from the inductance, as shown in the Figure 7. The values of line to line voltage in the network (V12), neutral voltage (Vo1) and resonance current (Ires) are shown as well. Besides, the control device provides the resonance curve of the current respect the neutral voltage.

Detecting and clearing a single line to ground (SLG) fault

A single line to ground fault in one of the feeders is simulated in order to check the reaction of the whole system. The signals shown in Figure 8 are –from the top to the bottom- the phase currents, the tripping order, the current through the neutral, the fault duration and the faulted line breaker status. It can be seen in Figure 8 the increase of the current through the neutral in presence of a SLG fault.

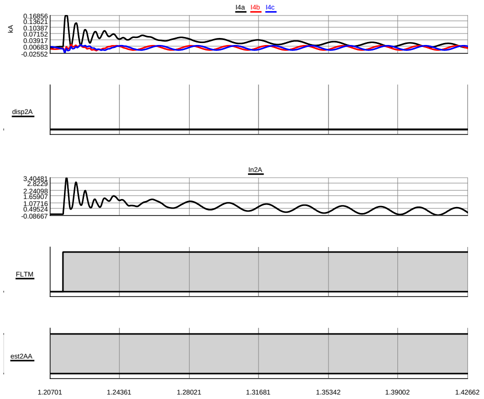


Figure 8. Detail of the signals just after the fault inception

In Figure 9, the same signals are shown, but in this case the instants before fault clearance are included. The tripping order is sent 2 seconds after the fault inception, as it has been set previously by the user in the controller device. Once the tripping order has been received by the breaker, it takes about 100 ms in interrupting the current flow. This time delay depends on the breaker and, for these tests, a standard time has been taken into account.

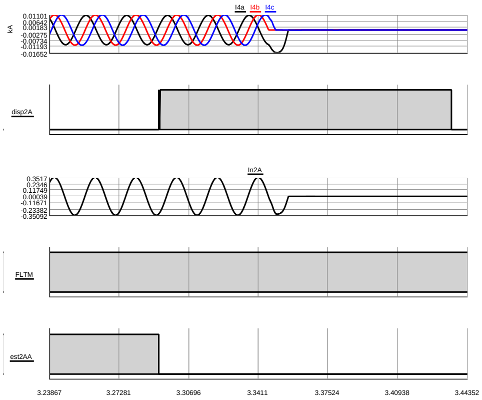


Figure 9. Detail of the signals just before clearing the fault

Electric arc self-extinction under transient fault

The feature of the ASC system related to self-extinction of the electric arc is analysed in this test. The goal of this test is to check if the ASC system is able to achieve fault clearance through the self-extinction of the electric arc, avoiding the tripping of the circuit breaker, thus ensuring the continuity of the electric supply to the distribution lines.

Figure 10 shows the transient fault simulated. The initial current transient disappears over time, due to the extinction of the electric arc generated in the transient fault, as seen in Figure 10. During the entire fault, the breaker remains closed, since no tripping order is received from the controller device.

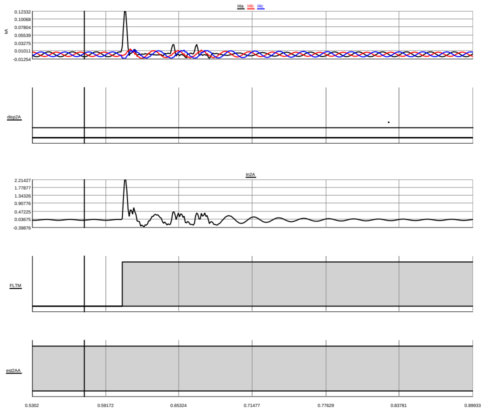


Figure 10. Detail of the signals just after the fault inception

The detail of electric arc current is shown in Figure 11, where it can be observed that after a short high initial current peak, the current in the arc is quickly reduced.

Therefore, the aptitude of the ASC system for compensating the capacitive current of the network and, consequently, to achieve the self-extinction of the arc in case of transient faults has been checked through RTDS.

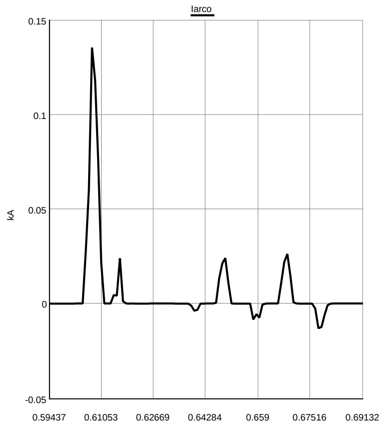


Figure 11. Arc current during the fault

CONCLUSIONS

This study aims to serve as an example so as to demonstrate the big capacity of real time *"hardware in the loop"* simulation, which provide opportunities for developing, testing and validating new equipment and implementation required for the improvement of power systems, which need to face challenges such as high penetration of renewable energies, distribution generation integration and smart grids development.

The particular analysis presented in this paper is the validation of a resonant grounding system, made up of a variable inductance coil (Petersen coil) and its associated protection and control devices.

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