End-to-End tests of Transmission Line Protection Systems with Single Phase Tripping and Reclosing

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Abstract:

Transmission lines in which single phase tripping and reclosing are applied, are lines that heavily stressed and are also subject to internal and external unbalances. Protection system requirements for these lines are more onerous than for lines with three phase tripping. Therefore, testing these protective relays requires special attention.

End-to-end testing is an effective way of testing the functions of the protective relays and validating their performance. Before a transmission line is put in service in the Peruvian power system, end to end tests are required to validate the complete protection schemes.

In this paper we describe the end-to-end tests required, the methodology used in order to make them, and the expected results.

1. Introduction

The testing of transmission line protection systems, has evolved over the years. Presently, end to end testing using GPS synchronization has become sufficiently easy to perform that it can be routinely applied to complex communications assisted protection systems.

End-to-End testing involves the injection of oscillographic records (in COMTRADE format) with the objective of testing protective relays at both ends of a line simultaneously. The test equipment at end is synchronized by GPS, so the test signals are correctly phased at each terminal with respect to the other, proving correct operation of protection relays, teleprotection schemes, the trigger circuit, phasing of the trip circuits, and switches.

Figure 1 shows the scheme for testing End-to-End in a transmission line.

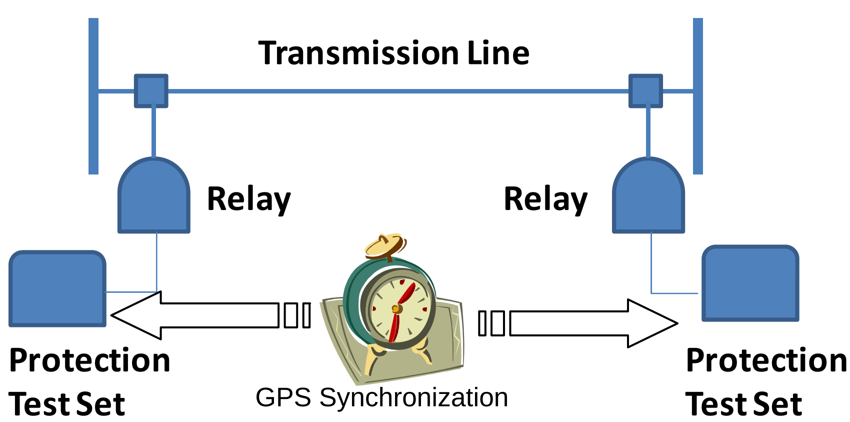

Figure 1. Scheme for End-to-End testing of protection systems.

In lines with single phase trip and reclosing, end-to-end testing is particularly important because of the scheme complexity and performance demands. This test is made to ensure the auxiliary systems such as teleprotection and trip circuit are working correctly, and that the protective relaying operating as predicted by planning studies. For this reason, in this paper, some example end-to-end tests are presented, especially for lines with single phase tripping and reclosing.

2. COMTRADE File Generation.

Careful planning leads to successful tests, and an important aspect is the generation of COMTRADE files for injection into the relays. COMTRADE signals are injected into the relays in a playback mode, instead of using real time digital simulation. Therefore the performance (phase selection and tripping time) of the protection has to be predicted and put into the offline simulation.

The test signals (COMTRADE files) must be created with transient simulation software that can include load flow conditions, and the dynamic behavior of a system [1]. These are important factors that can challenge the performance of transmission line protection systems.

Transient offset of fault currents are also modeled, but capacitor voltage transformers and current transformers are not modeled in detail, only as ratios of primary to secondary values. If CT saturation is a concern, this could also be modeled in the transient simulation. Many test equipments have the option to generate COMTRADE files, and these can also be used for testing.

Because there are many digital relays, which use different technologies, such as polarization, memory, sample rate, filtering, etc. Standard values of pre-fault conditions and sample rate are helpful for consistency when generating COMTRADE files.

COES chooses
Pre-fault time = 0.5 sec
Sample rate = 5 kHz

Prefault power flow depends on the type of test. Nominal continuous rated levels for fault clearing, and short time rated extreme levels for zone 1 security and power swing tests.

In addition, COES may model the inertia of the system behind the weaker line terminal, and assumes an infinite bus behind the stronger terminal. This type of model is important when considering the impact of power swings on protection systems [2].

3. Typical line protection schemes in the Peruvian power system.

Figure 2 shows a typical configuration of a double circuit line on which the protection was subjected to end-to-end testing.

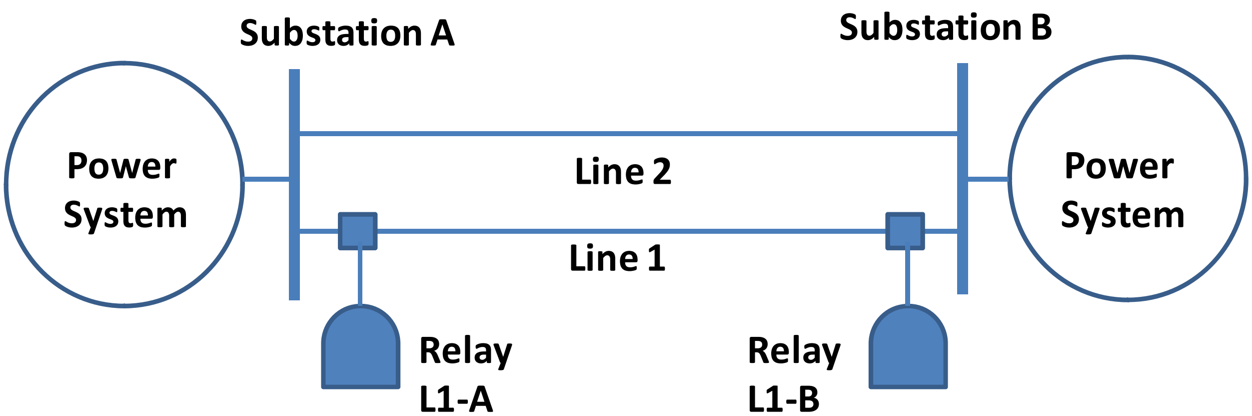

Figure 2. Typical Configuration of a double circuit line.

Protection schemes for 220 kV and 500 kV transmission lines in the Peruvian power system, have two redundant protection relays, whose main functions are differential line protection (87L), distance protection (21) plus ground directional overcurrent (67N) and automatic reclosing (79).

The protection schemes using distance protection and directional overcurrent are directional comparison Permissive Overreach Transfer Trip (POTT) and Permissive Underreach Transfer Trip (PUTT). Traditionally, directional comparison blocking schemes are not used in Peru.

Since the differential protection and directional comparison schemes both perform the same single phase tripping and reclosing functions, they are tested independently. Example tests for the directional comparison schemes are described in the following section.

4. End-To-End Tests in Lines with Directional Comparison Protection.

Ten example sets of tests are presented in the following subsections. Except for test 6, all tests are simulated on Line 1 of Figure 2. This is a 110 kV line with a primary impedance of 23 Ohms used as an example. Test 6 is a cross country fault involving both lines of Figure .2

4.1 Test 1: Zero ohm Fault at 50% of the Line in phase "S".

This test is made to check the functionality of the relays, the trip circuit and the phase selection.

The impedances seen for the distance protection relays are as shown in Figure 3.

<u>The desired result:</u>

Substation A: Zone1 fault detection, single phase “S” tripping, and subsequent successful reclosing.

Substation B: Zone1 fault detection, single phase “S” tripping, single phase and subsequent successful reclosing.

This test is simulated with low Zero Ohms and is repeated in phases "R and T" to demonstrate correct tripping and reclosing of all three phases.

Figure 3 shows the modeled responses of the relays at both ends of the line. Note that the zone 1 elements at both terminals has been set to reach significantly less than 80% of the line to prevent overreach under the condition of the parallel line out service and grounded at both ends.

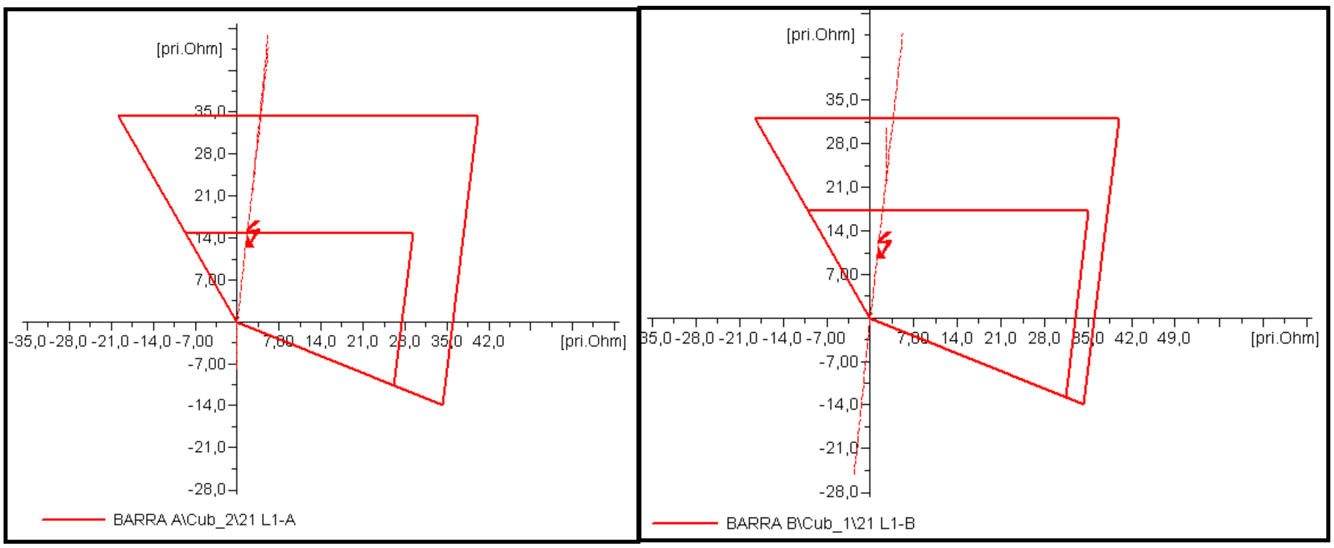

Figure 3. Fault al 50% of the line in phase “S”, seen for both ends.

Figure 4 shows the COMTRADE test current and voltage signals injected into terminal A of the line. Note the pre-fault load flow, transient offset of the current in the faulted phase, high frequency transients in the faulted phase voltage and dc offset in the faulted phase recovery voltage after the fault is cleared. The secondary arc voltage (after the primary fault is interrupted), is not modeled.

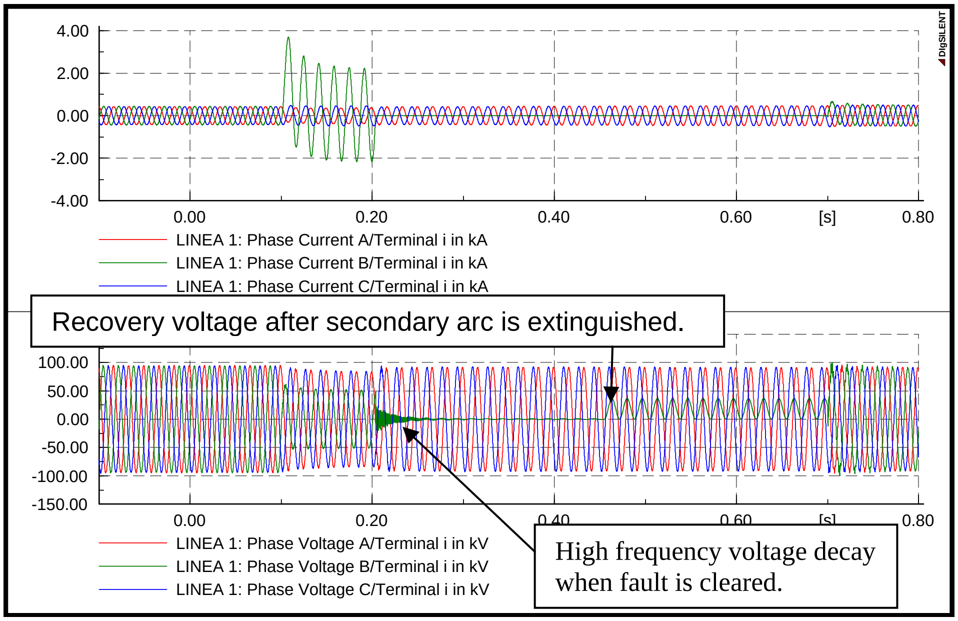

Figure 4. Single phase fault at 50% of the line in phase "S", seen in Substation A- Line 1.

4.2 Test 2 : Zero ohm phase to phase fault at 50% of the line in phases "RT"

This test is made to check the functionality of the relays, and the three phase tripping without reclosing. Figure 5 shows the currents and voltages injected into terminal A.

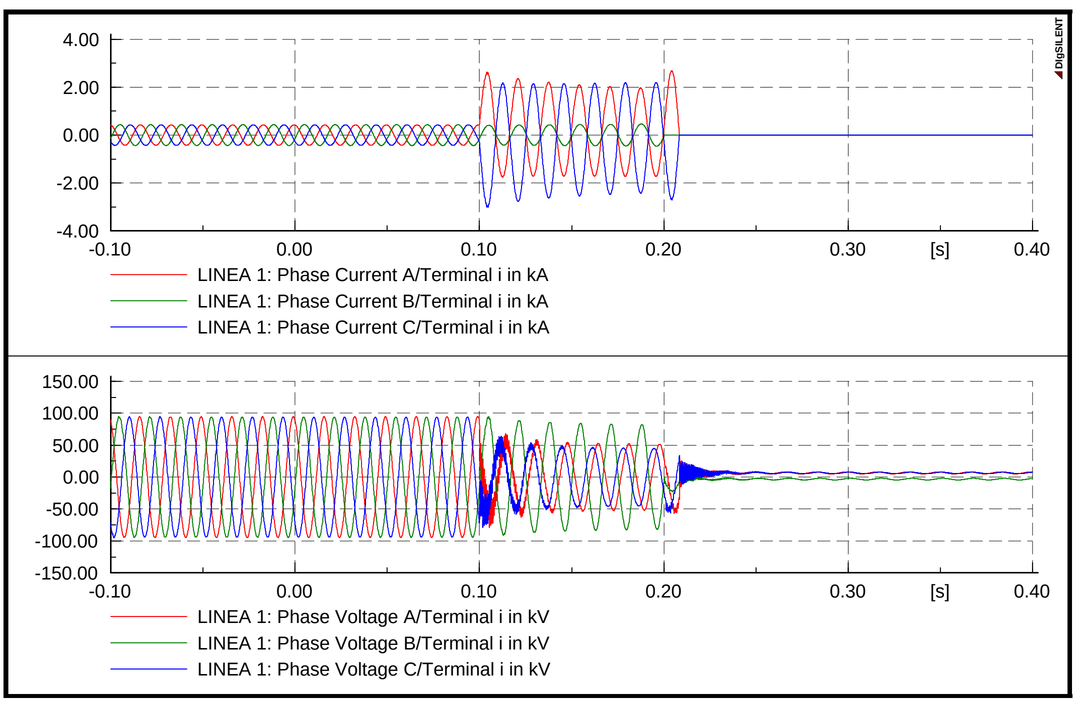

Figure 5. Phase to Phase fault at 50% of the line in phases "RT", seen in Substation A- Line 1.

The desired result:

Substation A: Zone1 failure detection, three phase tripping.

Substation B: Zone1 failure detection, three phase tripping.

4.3 Test 3 : Zero ohm fault at 1% of the line in phase “R”

This test is made to check the teleprotection scheme.

The impedances seen for the distance protection relays are as shown in the Figure 6. It can be seen that the distance relay at Terminal A is not only detecting faults in phase RN, but also, the relay may detect faults in other fault loops in zone 1, for this reason it is important that the faulted phase selection be determined.

The desired result:

Substation A: Zone1 failure detection, single phase “R” tripping, teleprotection signal sending, and subsequent successful reclosing.

Substation B: Zone2 failure detection, teleprotection signal reception, single phase “R” tripping, single phase and subsequent successful reclosing.

This test can be repeated in phases "S and T" to confirm all fault loops are correctly selected and tripped.

4.4 Test 4 : Zero ohm fault at 99% of the line in phase “T”

This test is made to check the teleprotection scheme.

The impedances seen for the distance protection relays are as shown in Figure 7.

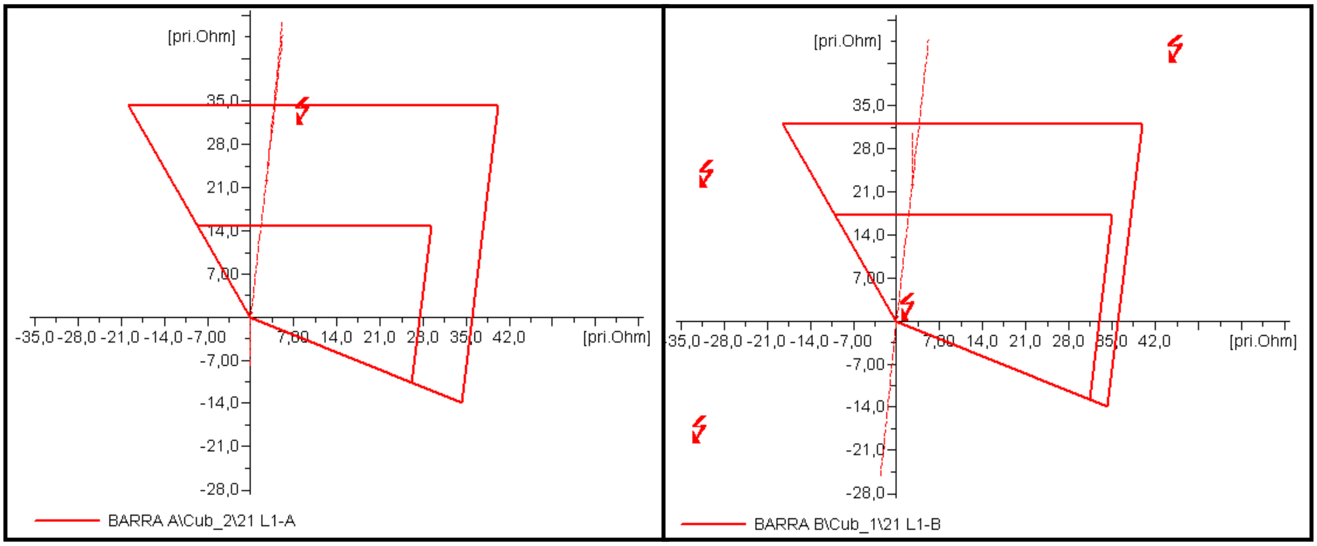

Figure 7. Fault al 1% of the line in phase “R”, seen for both ends.

<u>The desired result:</u>

Substation A: Zone2 failure detection, teleprotection signal reception, single pole phase “T” tripping, single phase and subsequent successful reclosing.

Substation B: Zone1 failure detection, single pole phase “T” tripping, teleprotection signal sending, and subsequent successful reclosing.

This test can be repeated in phases "S and T" to confirm all fault loops are correctly selected and tripped.

4.5 Test 5 : Evolving faults, first zero ohm single phase fault in phase at 50% of the line in phase "R", and then zero ohm single phase fault at 50% of the line in phase "S".

This test is made to check if the protection relays stop the reclosing sequence if a fault occurs during the dead time.

The test current and voltage signals are shown in Figure 8.

<u>The desired result for the first fault (Phase R):</u>

Substation A: Zone1 failure detection in phase "R", single pole phase "R" tripping, single phase reclosing initiated.

Substation B: Zone1 failure detection in phase "R", single pole phase "R" tripping, single phase reclosing initiated.

<u>The desired result for the second fault (Phase T):</u>

Substation A: Zone1 failure detection in phase "T", block of the reclose in progress, three phase tripping.

Substation B: Zone1 failure detection in phase "T", block of the reclose in progress, three phase tripping.

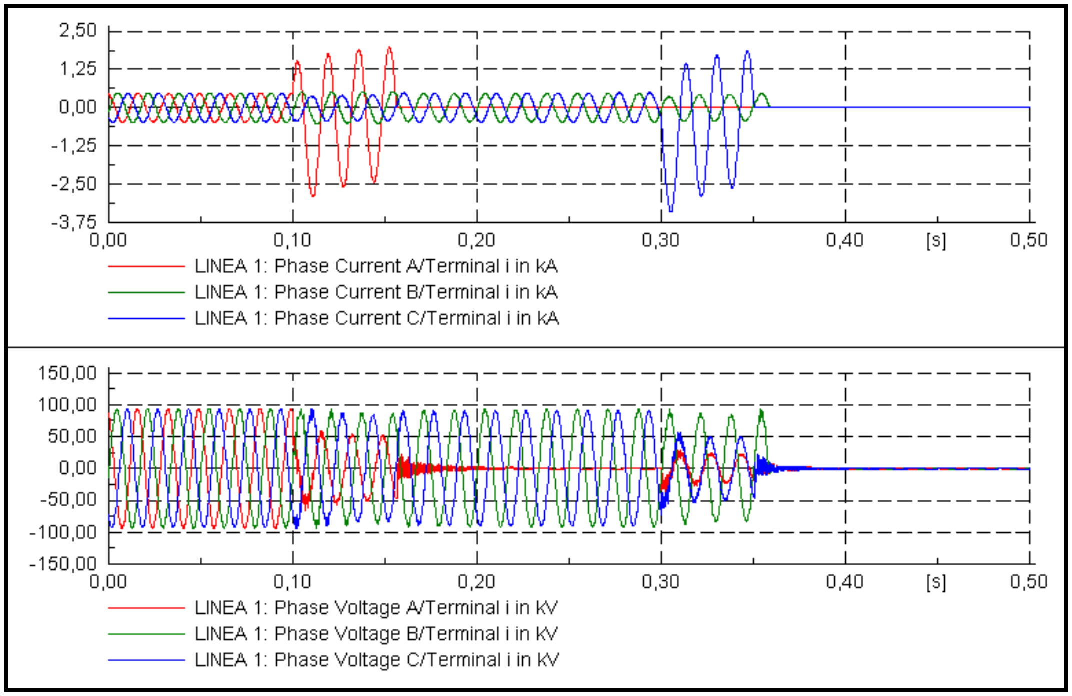

Figure 8. Evolving fault, seen from Substation A.

4.6 Test 6 : Cross country faults, simultaneous zero ohm faults in both lines in different phases (Line 1 phase S, Line 2 phase T). Fault location on both lines is 80% from Terminal A.

This test is made to check if the protection relays do a correct fault selection, and to check the behavior of the loop phase selector. The relays must do a single phase trip and reclose. Figure 9 shows the apparent impedances presented to the relay on Line 1 at Substation A.

<u>The desired result for Line1:</u>

Substation A: Zone1 failure detection in phase “S”, single phase trip, and successful reclose.

Substation B: Zone1 failure detection in phase “S”, single phase trip, and successful reclose.

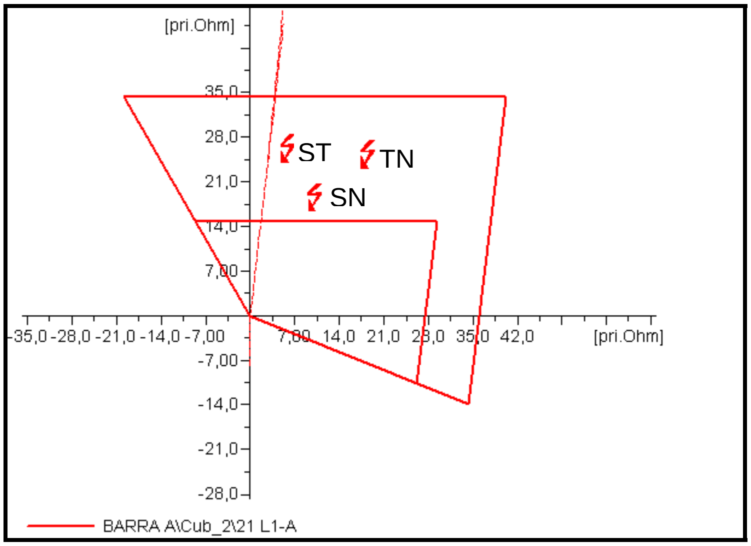

Figure 9. Impedance seen by the distance relay in Line 1, Substation A.

It can be seen that, the relay of Line 1 in Substation A, may trip three phase because the impedances are seen in multiple phases in Zone 2. So the relays must have options to choose whether the leading phase, the lagging phase, phase to phase loops or all loops are going to evaluate in order to trip. Depending of the algorithm of the relay it can be set to choose all loops or only phase to ground loops. It is important considering the power flow, because this can change the impedance seen by the relay. Simulations and tests with power flow enable the correct phase selection options to be chosen. In this case phase selection using the leading phase was adopted.

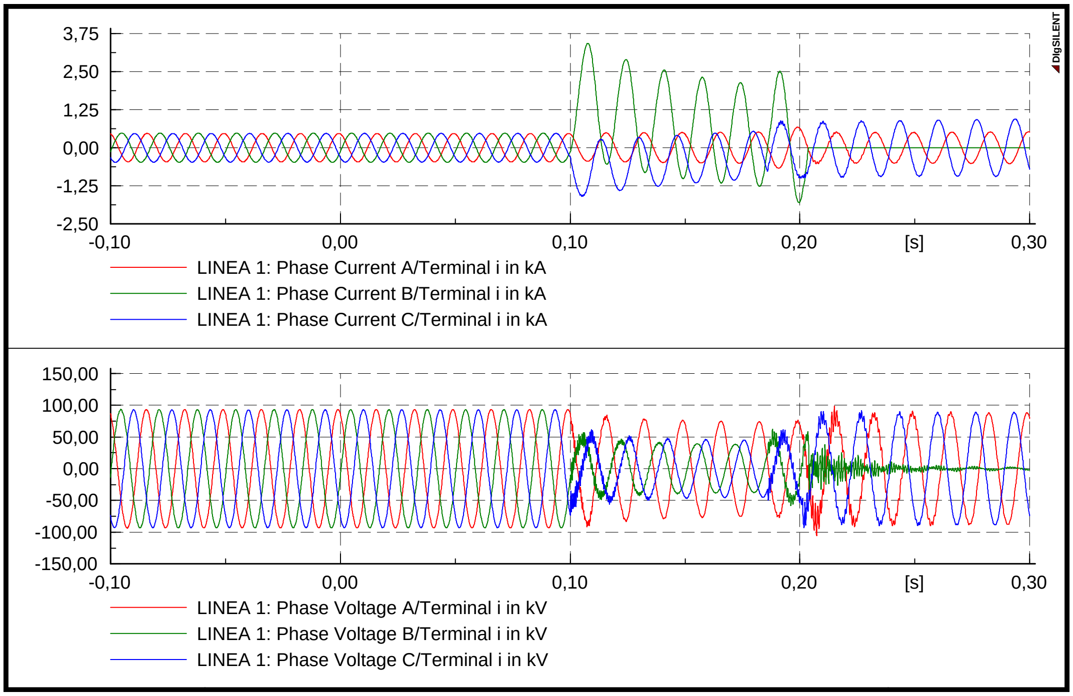

Figure 10. Cross Country fault, seen from Substation A (Line 1).

This test can also be repeated with faults in other locations to check correct operation for cross country faults at the full range of locations.

4.7 Test 7 : Fault at 101% of the line in phase "R", with 50 Ohms fault resistance.

This test is made to check the load compensation algorithm and security of Zone 1 of the protective relays, the simulation must be made for the worst conditions (high load flow, and the parallel line out of service and grounded at both ends).

The fault resistance must be evaluated before the test, using simulation tools., This resistance must be such that given a fault condition for high load flow (exporting), the impedance without being compensated by the load effect could enter in zone 1.

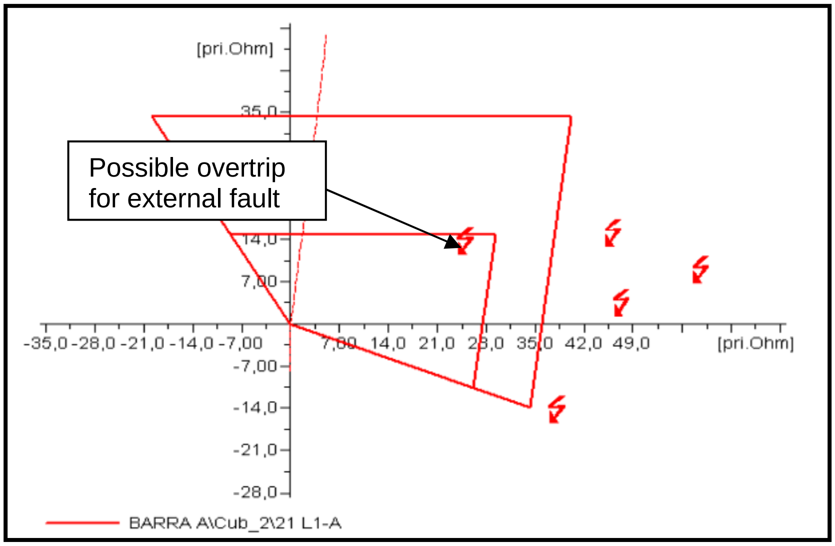

Figure 11. Impedance seen by the distance relay in Line 1, Substation A for a single phase fault at 101% with 50 ohms fault resistance.

<u>The desired result for the first fault (Phase R):</u>

Substation A: Zone 2 fault detection in phase "R", trip with zone 2 time.

Substation B: Reverse zone fault detection in phase "R", no tripping.

4.8 Test 8 : Fault at -1% of the line in phase "T", with 50 ohms fault resistance.

This test is similar to the test 7, but for this test the load flow must be inverted. In this case, since the distance relay may underreach, the test should be performed with the parallel line in service.

<u>The desired result:</u>

Substation A: Reverse zone fault detection in phase "T", no tripping.

Substation B: Zone 2 fault detection in phase "T", trip with zone 2 time.

4.9 Test 9 : Single phase fault at 50% of the line with reclosing and power swings during the dead time of reclosure.

This test is made to check if the Power Swing blocking function is activated during the dead time of the reclosing, blocking the distance functions.

The desired result:

During the dead time of reclosing the relay must activate the power swing blocking function. Note that other protection must also separate the out of step sources, but that function is not being tested in this test.

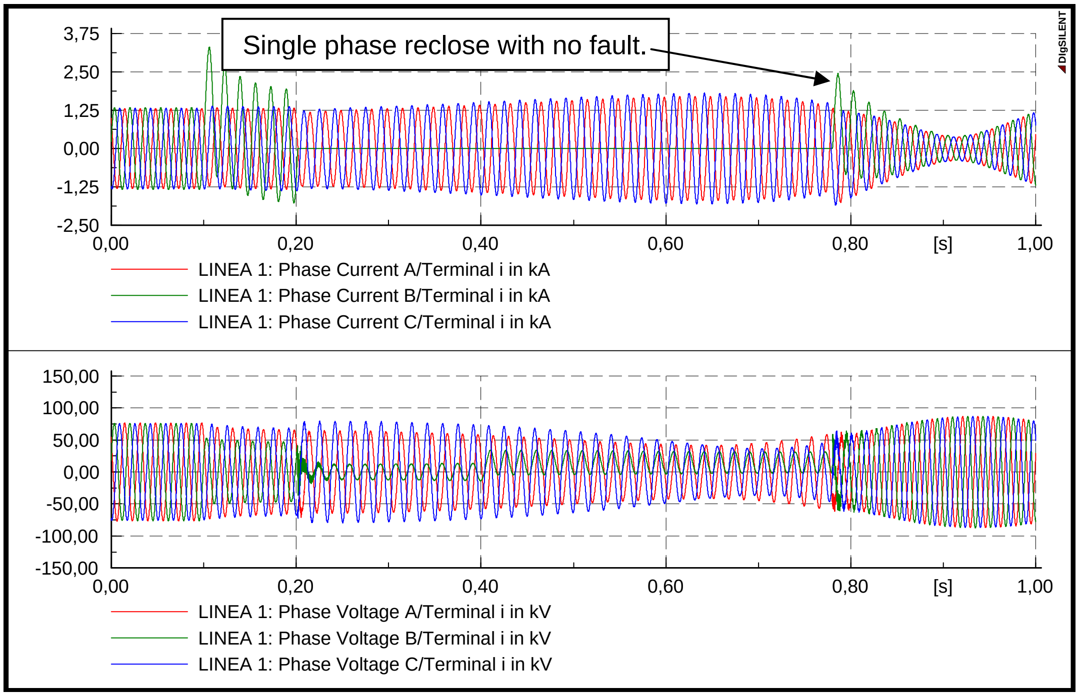

Figure 12. Power Swing during the dead time of reclosing.

4.10 Test 10 : Single phase at 50% of the line with 70 Ohms of fault resistance.

This test is made to test the directional comparison teleprotection scheme by 67N, the fault has too much resistance to be detected by the distance functions (Zones). Figure 13 shows the apparent impedances presented to the distance relays at both ends of the line. This type of high resistance fault is not expected very frequently, so three phase tripping with no reclosing is accepted for this case.

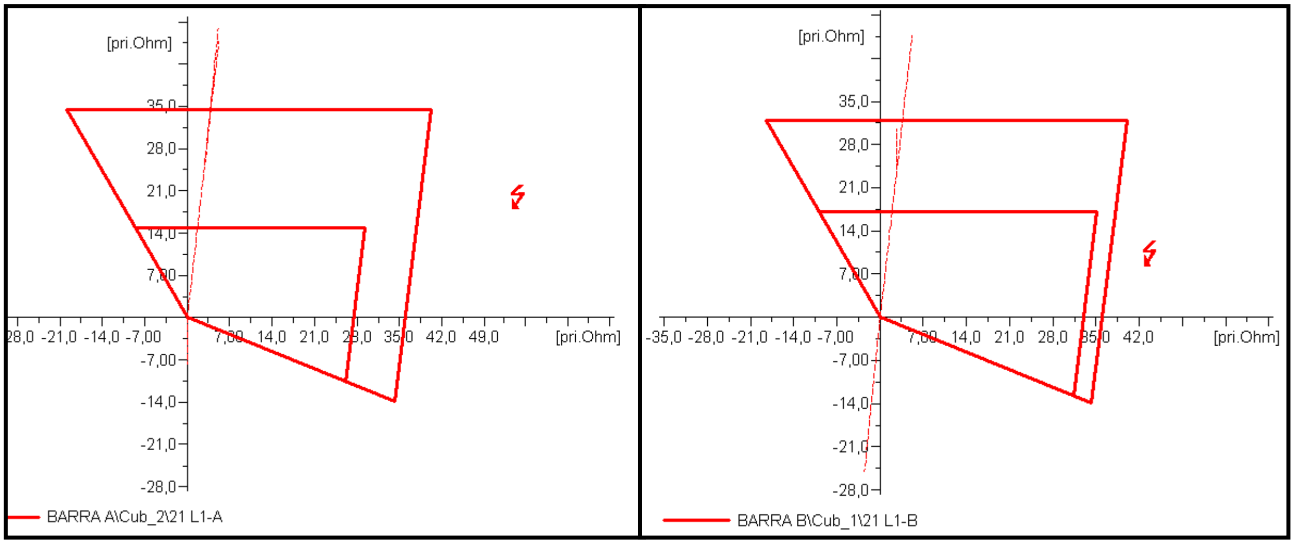

Figure 13: Single phase fault with high fault resistance.

<u>The desired result:</u>

Substation A: 67N Forward detection, three phase trip by 67N directional comparison.

Substation B: 67N Forward detection, three phase trip by 67N directional comparison.

5. Conclusions

i) End-to-end testing is an important tool to test complex transmission line protection schemes. The factors tested by the examples shown in this paper are

- Correct phase selection for faults at all locations
- Correct operation of the teleprotection system
- Operation of the correct phases of the circuit breakers in the substation.
- Security of the zone 1 elements with high load and the parallel line out of service and grounded at both ends.
- Dependability of the zone 2 elements with the parallel line in service and high load
- Correct selection of faulted phases for cross country faults
- Correct operation of the automatic reclosing scheme during evolving faults.
- Security of the system with a single phase open, and power swing in progress
- Correct operation of higher impedance fault detection

ii) The use of software to simulate the behavior of protective relays COMTRADE format test signals is very important during the planning test stage. This helps the planner to understand the important factors that should be considered during the tests.

iii) System models used for the creation of test files should model consider the necessary factors that might affect the operation of the protection system during normal service and under extreme conditions.

6. Acknowledgement

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7. References

1 DIgSILENT Power Factory, “User Manual”, www.digsilent.de

2 Henville C., Folkers R., Hiebert A., Wierkx R. “Dynamic Simulations Challenge Protection Performance”, Western Protective Relaying Conference, Spokane WA October 2003.