Fault Experiences in Transmission Lines with Series Compensation

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Prepared by

Yofre Jacome, Humberto Galoc, Francisco Torres

COES SINAC

Perú

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Abstract:

In this paper we are going to show the experiences get during the operation of an important transmission lines that have series compensation in the Peruvian power system. These lines are very long and go through the Andes, because of that are exposed to lightning that produce single phase, phase to phase faults, and cross country faults.

Another important issue is that these lines interconnect a strong system with a weak system, leading sometimes to the collapse of the weak system.

1. Introduction

The North-Center area (SICN) of the Peruvian power system is interconnected with the South area (SISUR) with a link that has two parallel lines as it is shown in Figure 1, this link is 600 km long, and in the middle of the link there is a substation called Cotaruse.

This link is very important for the Peruvian Power System, and has Series Compensation in the middle of the link, in order to increase the transmission capability. However, because this link goes through the Andes, is nightly exposed to lightning and faults.

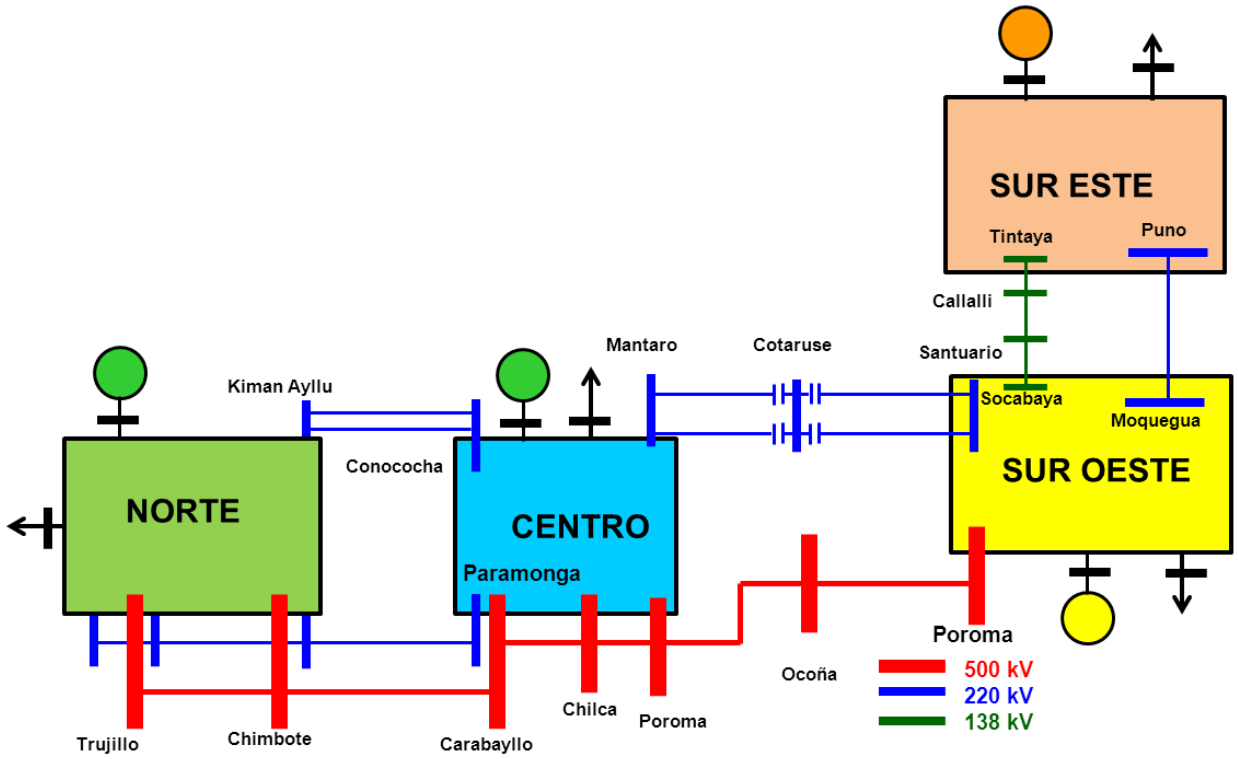

Figure 1. The Peruvian Power System

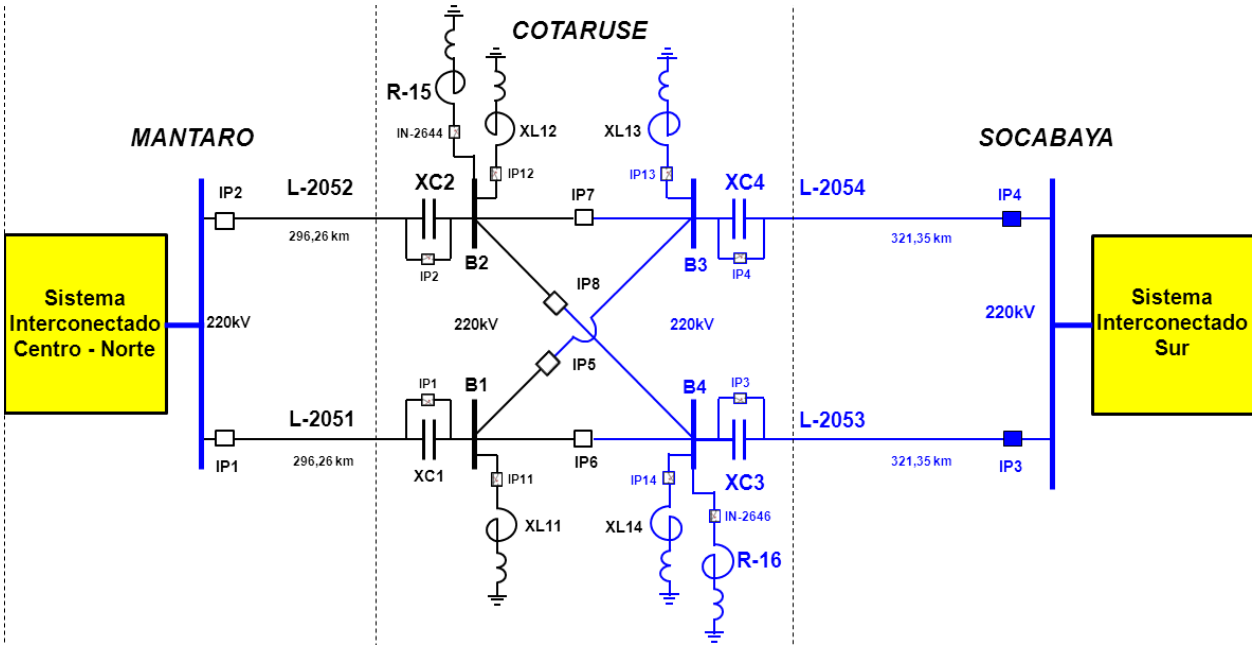

Figure 2. Interconnection between the North-Center Area and the South area

The lines in this link have had several faults, and because the special configuration of these lines, in this paper are shown three important events that happened in these lines. The first one is a Sub harmonic overvoltage due to faults in external lines, the second one is temporary overvoltages in a line due to a fault in the parallel line, and the third one power swing due to faults in these lines.

2. Sub harmonic Overvoltage due to faults in external lines

On 18.03.2007, there was a cross country fault in the lines L-2053 and L-2054 caused by lightning. In the line L-2053 there was a three phase fault tripping and opening in both ends. In the line L-2054 there was a single phase to ground fault in phase “C”, tripping and opening only the phase “C” of the line L-2054. During the dead time of the line L-2054, in the line L-2051 there was sub harmonic overvoltages, which were recorded in the Cotaruse substation. This overvoltage produced the operation of the overvoltage protection in the line L-2051 tripping and disconnecting it.

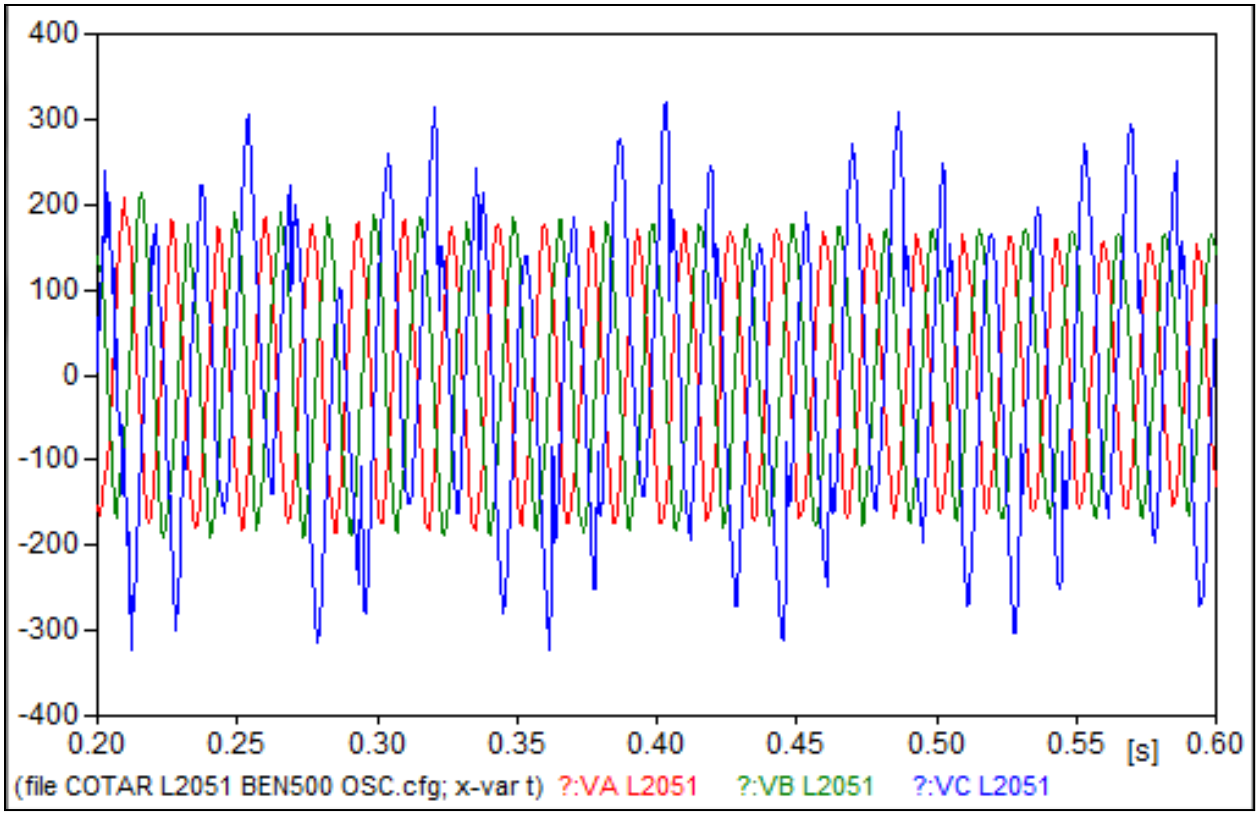

Figure 3 : Sub harmonic Overvoltage recorded on 18.03.2007 in the line L-2051 in Cotaruse Substation

With the tripping and disconnection of the lines L-2053 and L-2051, the North-Center area was linked with the South area only for the lines L-2052 and L-2054. Because the high power flow in these lines, the system when to an out of step condition. After 8.5 seconds both areas were separated by the tripping of the distance protection.

The issue in this case is to explain the sub harmonic overvoltage. After the opening of the breakers (figures 4 A and 4 B), the series capacitor remain with charge and with a maximum voltage, that happened because the electric arc in the breakers are extinguish when the current cross by zero. The energy in the series capacitor the oscillate in the R-L-C circuit which is still connected from Mantaro Substation, and in this configuration a sub harmonic oscillation about (14 to 20 Hz) began (figure 3).

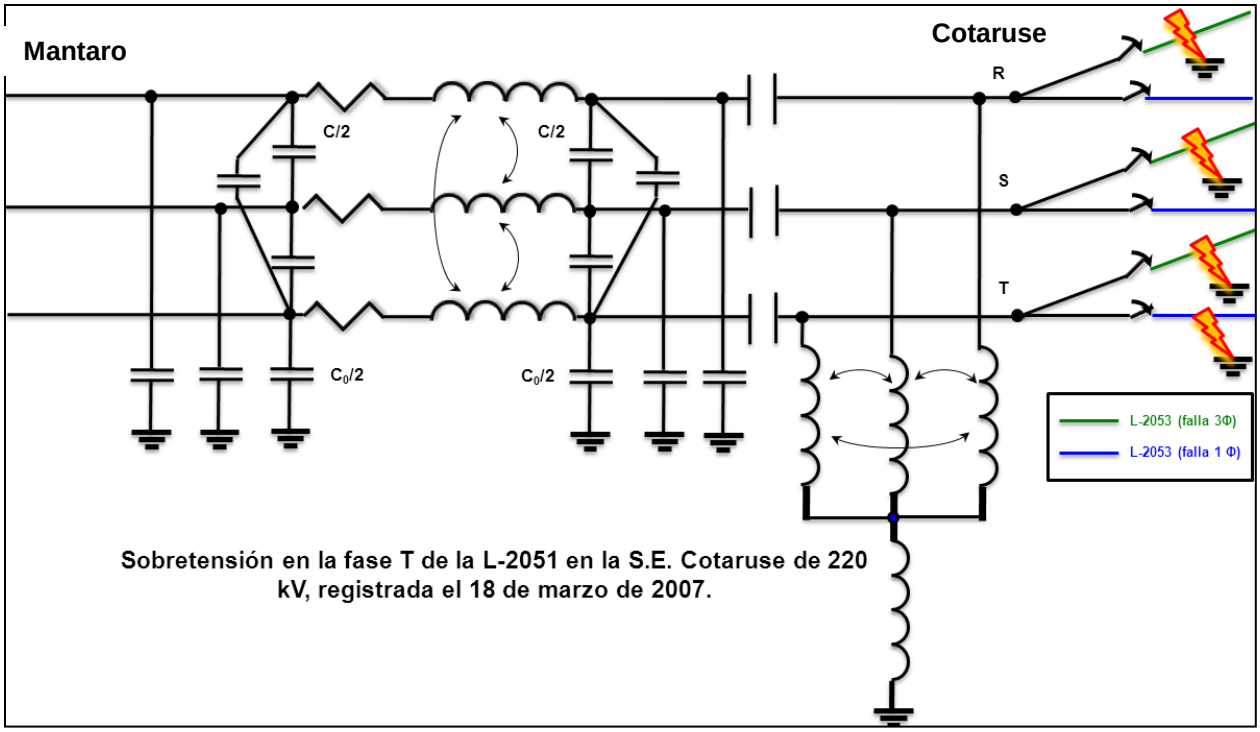

Figure 4A Line, Series Compensation, and Line Reactor

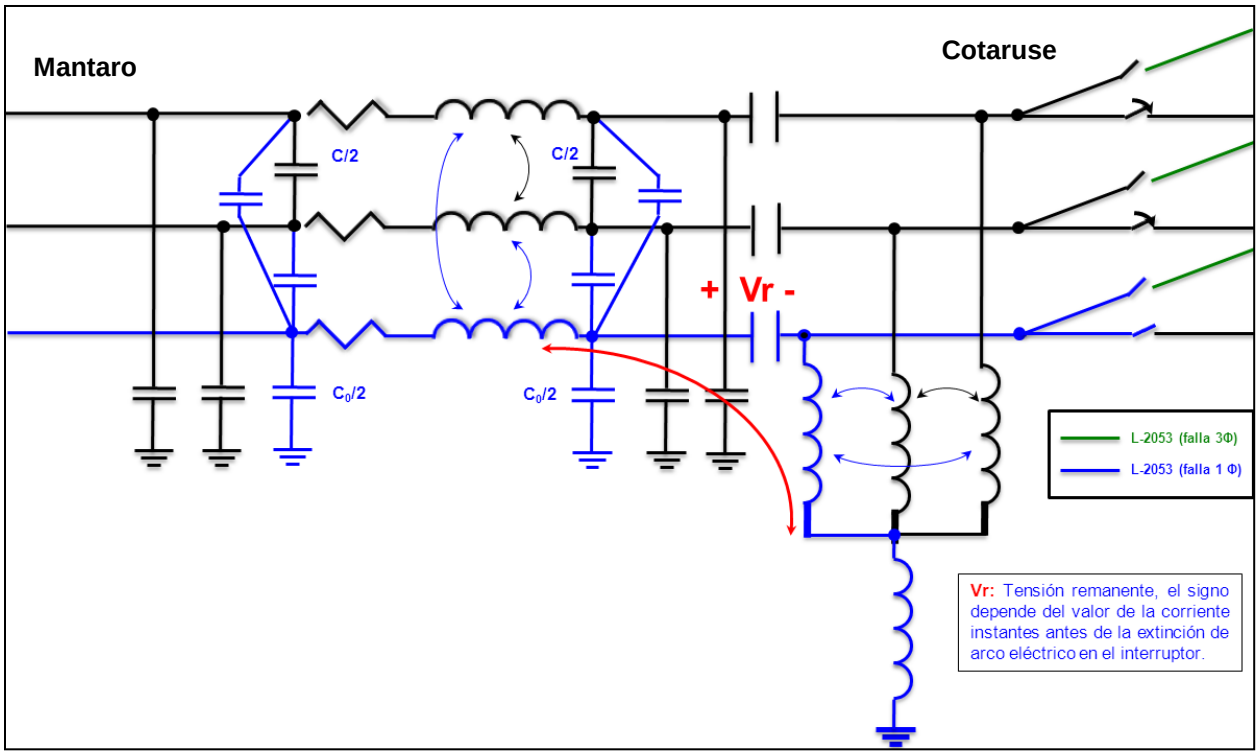

Figure 4B Charging in the circuit R-L-C, after the breaker opening.

3. Temporary overvoltages in a line due to a fault in the parallel line

On 15.02.2012 at 15:11:27.250 hours, a single-phase to ground fault occurred in phase "S" of the line L-2052 and about 60 ms after a single-phase to ground fault occurred in the phase "S" in the parallel line L-2051 (figure 5). According the fault locators, the faults were at 24.4 km from the Cotaruse substation. The Power flow in the link Mantaro – Socabaya before the fault was about 329 MW measured in the Socabaya substation.

On 18.03.2012 at 17:24:40 hours, a single-phase to ground fault occurred in phase "R" of the line L-2052 and about 75 ms after a single-phase to ground fault occurred in the phase "R" in the parallel line L-2051. According the fault locators, the faults were at 28 km from the Cotaruse substation.

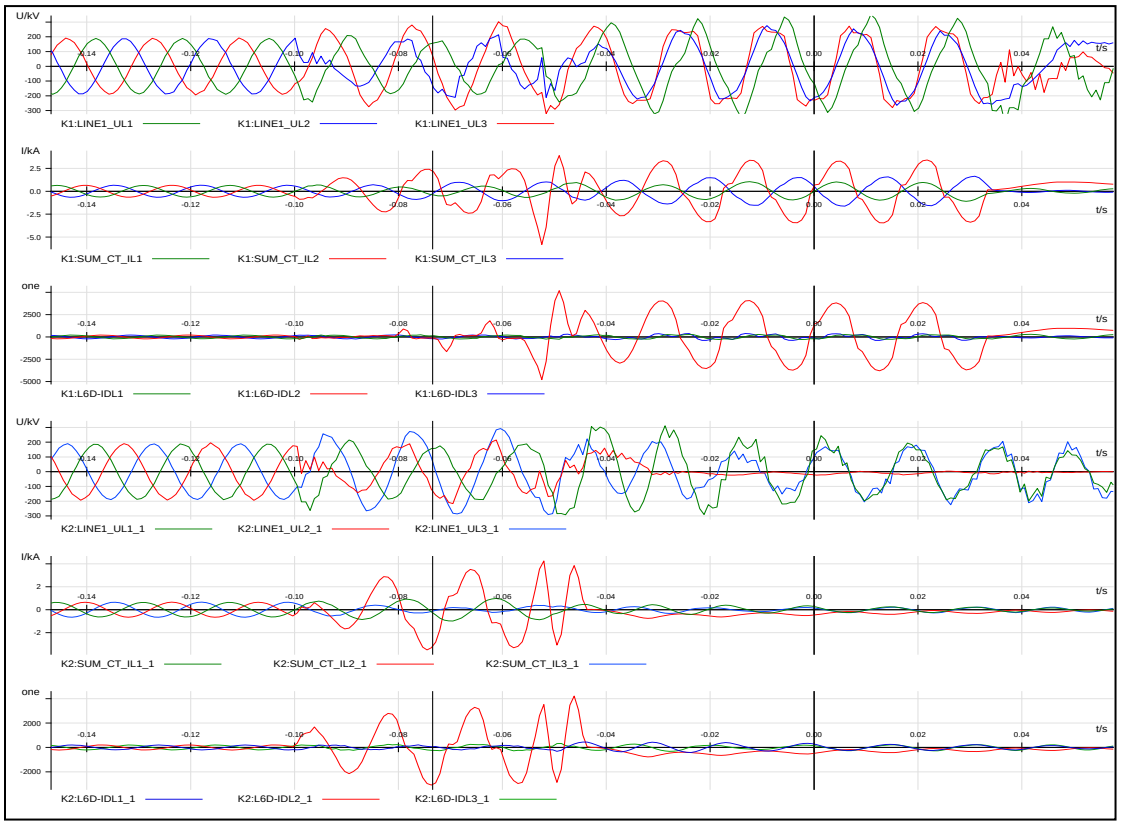

Figure 5. Fault Record of the lines L-2051 y L-2052 in Cotaruse Substation from the faults on 15.02.2012

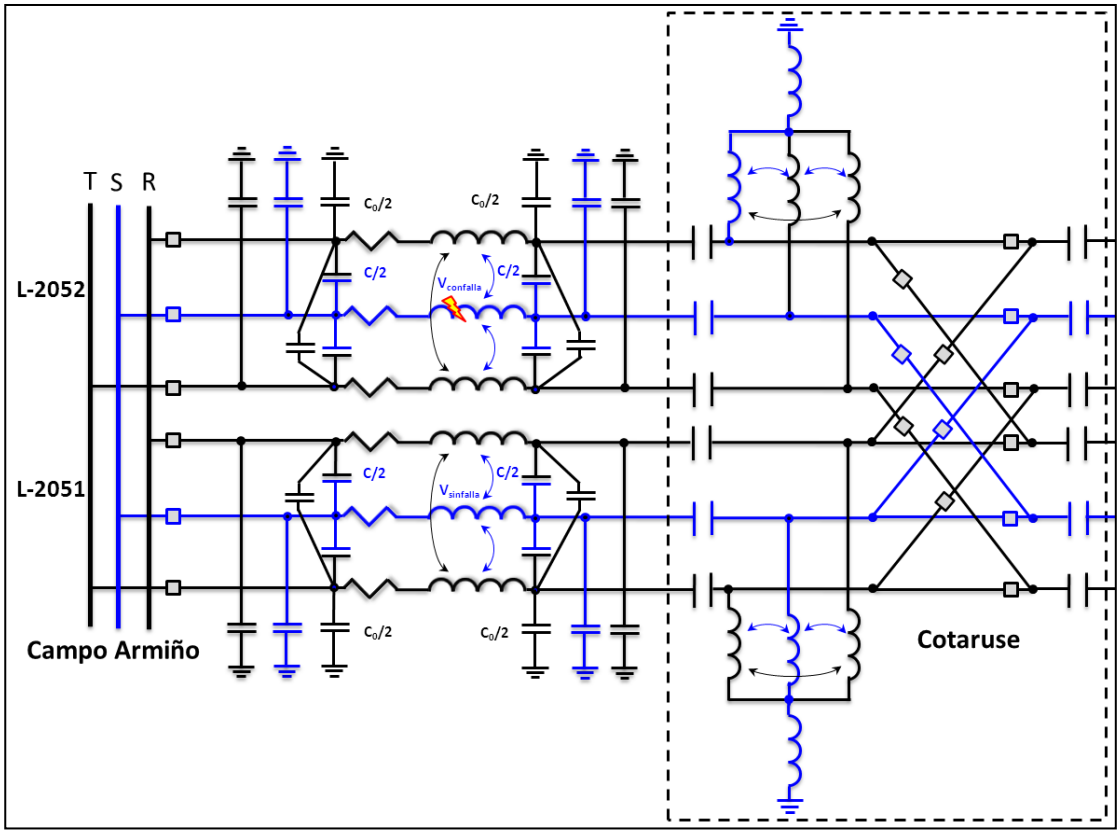

Figure 6. Simplified representation of the lines L-2051 and L-2052 (Campo Armiño – Cotaruse)

3.1 the Origin of multiple faults

The probability of the occurrence of a fault in the line L-2051 caused by lightning after 60 ms of the occurrence of the fault in the line L-2052 is minimal, due to the low probability that there where consecutive lightning with a time difference of 60 ms.

During the fault analysis, a simulation with ATP was made in order to determinate the origin of the faults. In the simulation (figures 7 and 8) during a fault in the line L-2052 in the same phase of the parallel line L-2051 an over voltage appear, this overvoltage is about 335 $Kv_{Phase\text{-}Ground}$ (2.63 p.u), which could break the insulation of the line. This overvoltage can make to operate the MOV that are installed in the transmission line, and when the MOV are conducting a differential current can appear in the differential protection relays. The value of the differential current depends of the MOV conducting during this temporary overvoltage as is shown in the figure 9.

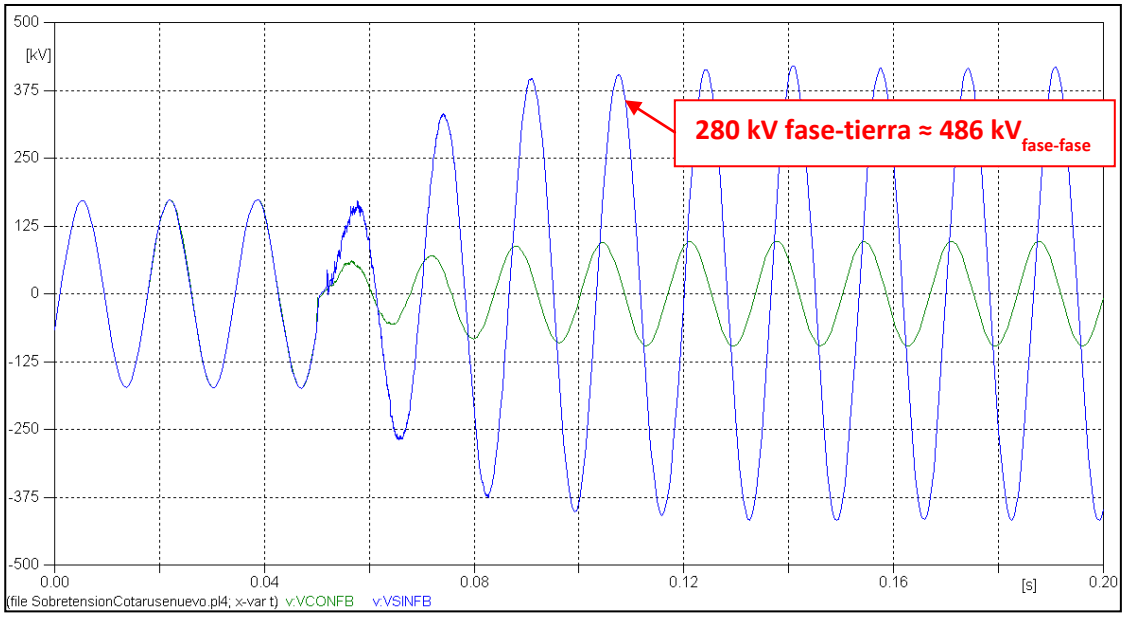

Figure 7: Overvoltage in the line L-2051 due to a single phase to ground fault in the line L-2052 with Rf = 35 Ω, located at 24,4 km from the Cotaruse Substation (v:VCONFB, voltage in the phase "S" fault location in line L-2052; v:VSINFB, voltage in the phase "S" in the fault location of L-2051)

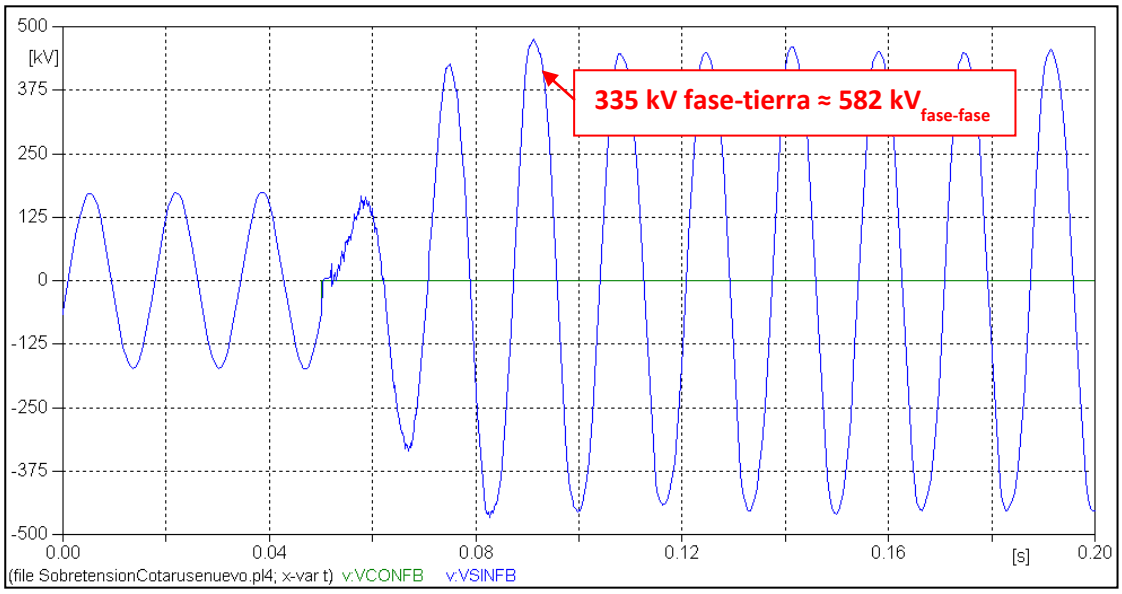

Figure 8: Overvoltage in the line L-2051 due to a single phase to ground fault in the line L-2052 with Rf = 0 Ω, located at 24,4 km from the Cotaruse Substation (v:VCONFB, voltage in the phase "S" fault location in line L-2052; v:VSINFB, voltage in the phase "S" in the fault location of L-2051)

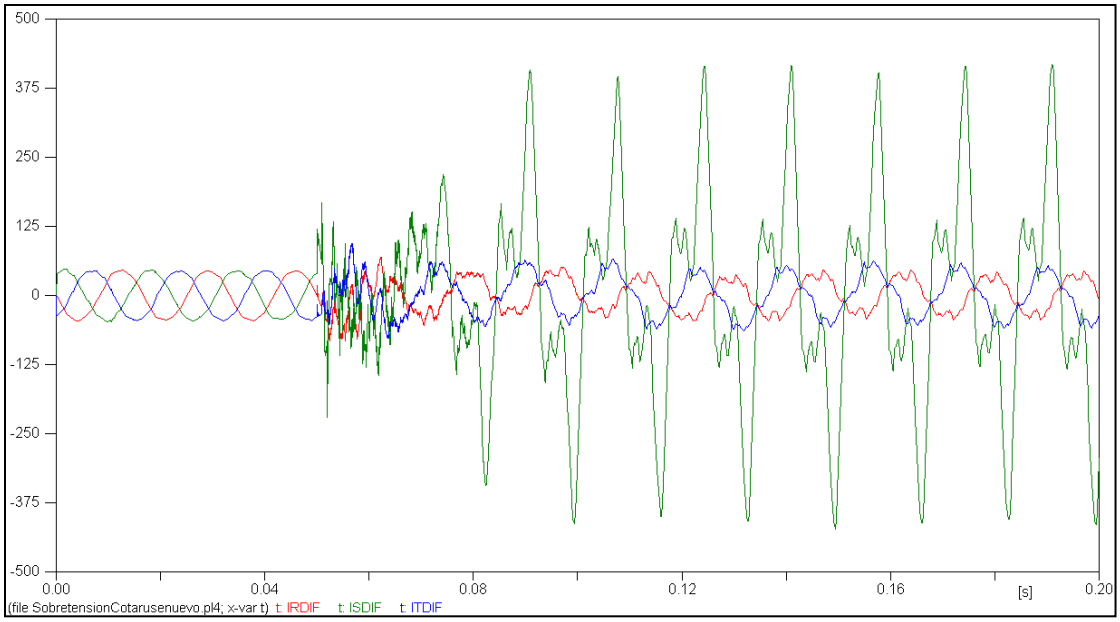

Figure 9 : Differential current due to the MOV conduction due to a single phase to ground fault in the line L-2052 with Rf = 0 Ω, located at 24,4 km from the Cotaruse Substation.

4. Power Swings

The 220 kV interconnection between the north-center area and the south area of the Peruvian power system (link Mantaro – Socabaya), has a stability limit of 460 MW, because the lines are long about 600 km, and these limit is when all the lines and series capacitor are in service. For that reason power swings have been produced between those areas, which have been detected by the protection relays, and in some cases producing the tripping of the lines.

The events that happened are :

4.1 Power swing during a maintenance maneuvers

On 14.10.2011 at 07:45:13 hours, the line L-2054 was disconnected manually for maintenance with 192 MW of load from Cotaruse to Socabaya. As a result of the disconnection, the system began to oscillate, and the power swing was detected by the distance relays RED670 of the parallel line L-2053 (Figure 10).

In the figure 11 the impedance recorded during the power swing is shown.

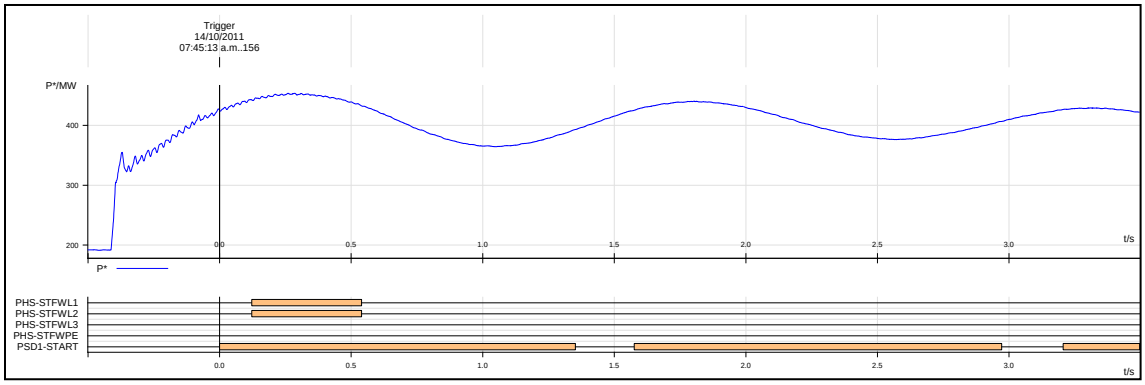

Figure 10: Active power record in the line L-2053 in Cotaruse substation on 14.10.2011.

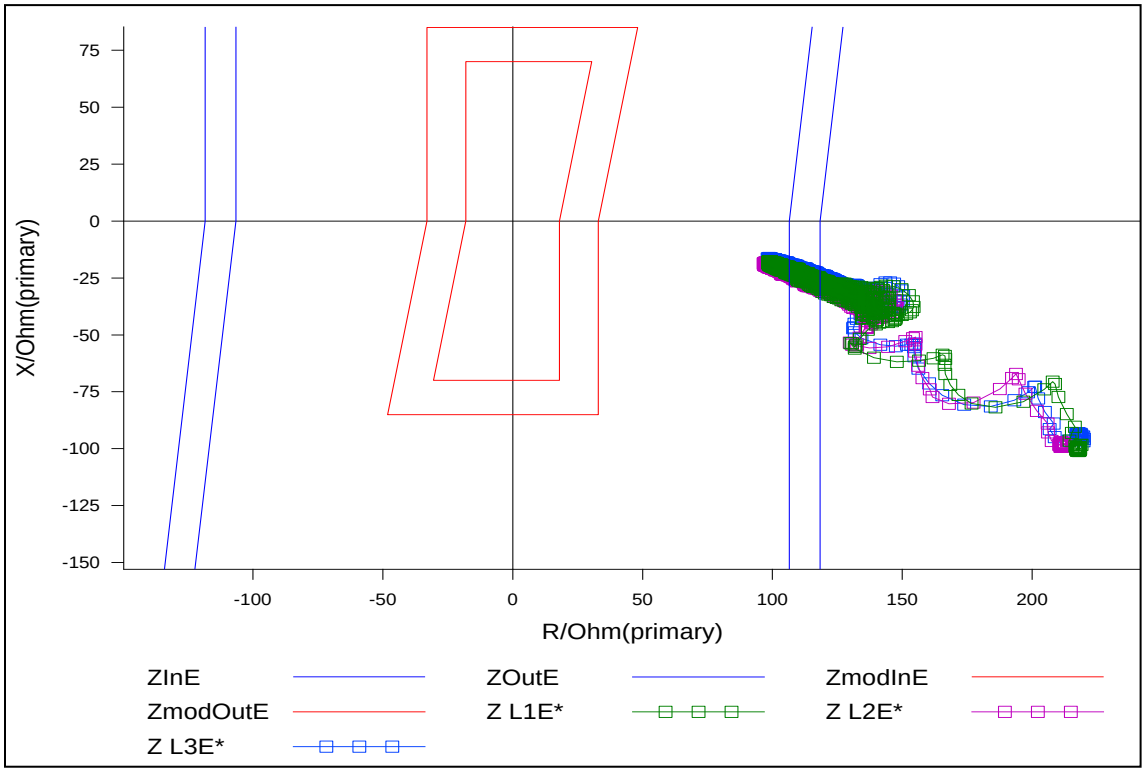

Figure 11 : Impedance during a power swing recorded in the distance relay of the line L-2053 Cotaruse Substation

4.2 Power swings none detected

During the faults occurred on 28.12.2011, 19.01.2012 and 08.02.2012, the relays RED670 did not activated the Power Swing blocking function (68) during the dead time of the reclosing in one line of the link between Mantaro – Socabaya (figure 12). The power swing blocking was not active because the internal logic of the relay was blocked by the distance start (PHS-STPE).

With those events, we found that for some events the power swing function was detected correctly, while for other events function power swing was not detected, causing and incorrect tripping of the distance protection (Figure 13)

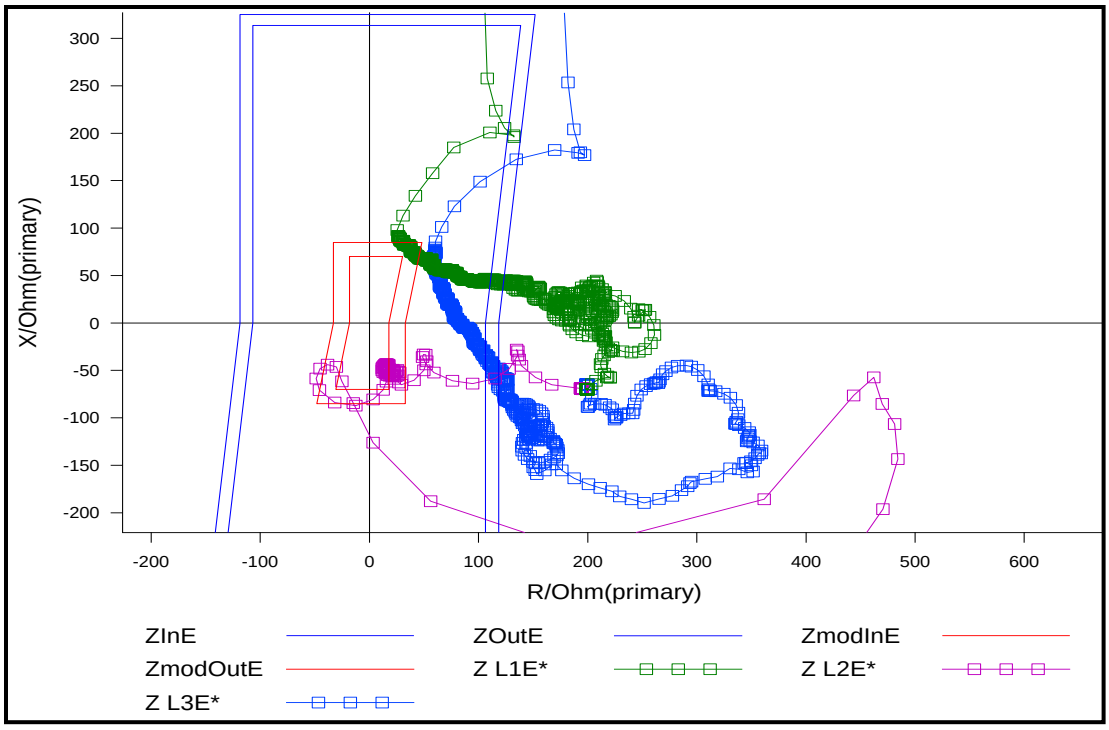

Figure 12 : Impedance during a power swing recorded in the distance relay of the line L-2053 Cotaruse Substation on 08.02.2012

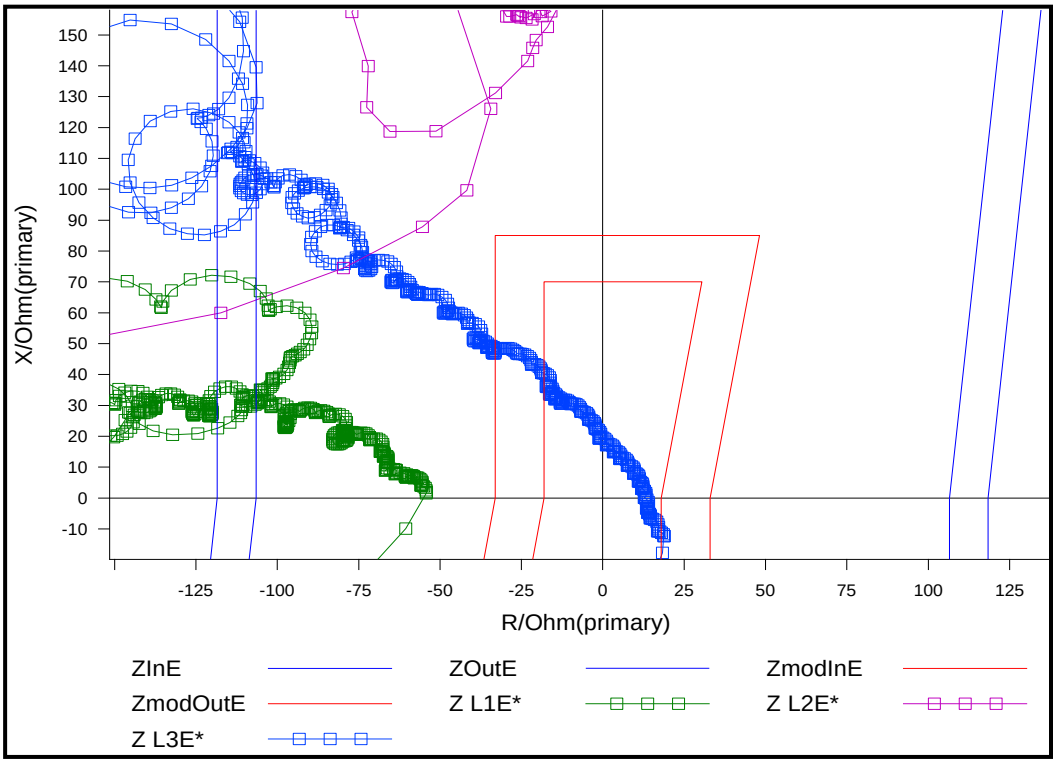

Figure 12 : Impedance during a power swing recorded in the distance relay of the line L-2053 Socabaya Substation on 08.02.2012

5. Conclusions

5.1 Lines with series compensation and shunt reactors are susceptible to sub harmonic over voltages. For that this phenomena must be studied in order to mitigate them.

In Peru in order to mitigate the overvoltage one logic as shown in figure 13 was propose. This logic monitored the overvoltage during the dead time of a reclosing.

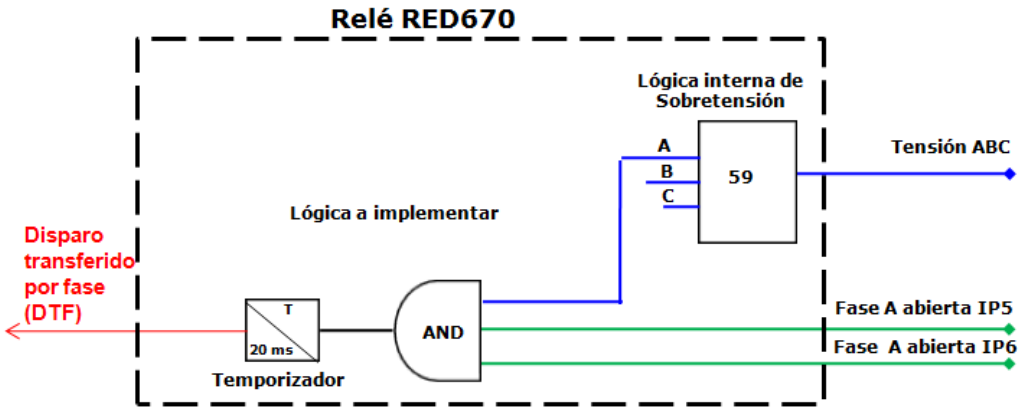

Figure 13. Logic proposed to the Protection relays in the Link Mantaro – Cotaruse – Socabaya.

5.2 In parallel lines with series compensation and shunt reactors, the overvoltage produced during a fault in one line, must be studied. The studies must be used to verify the insulation.

5.3 The parallel lines with high load flow, must count with power swing blocking schemes, that not only work on the traditional scheme which is based in blinders.

6. Acknowledgement

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7. References

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