Setting Out-Of-Step Blocking or Tripping Using Dynamic Simulations

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Abstract:

As transmission lines become more heavily loaded, power swings become more significant with respect to the setting of distance relays. In some cases it may be necessary to apply power swing blocking on the distance protection on some circuits while tripping other circuits to control the point of system separation.

Dynamic power system simulations may be used to determine the time varying impedances presented to transmission line protection to optimize the relay settings. If detailed models of the relays are built into the same software as the power system simulator the process of optimizing the settings is significantly enhanced.

In this paper we first describe a power swing event that separated the North-Center area and the South area of Peru. We then present some examples from a study of the Peruvian Power System dynamic performance (including the relay models) in order to set the blinders of power swing blocking in distance relays, and to determine optimum separation locations.

1. Introduction

Long, heavily loaded transmission lines that interconnect power systems are susceptible to power swings; these oscillations can be produced after an event such as a fault or changes in the topology of the power system. The power swing oscillations happen because the system moves from one stable equilibrium point to another stable equilibrium point after an event.

There are stable oscillations and unstable oscillations, when the system has unstable oscillations the system can lose synchronism and we can say that the system is in an Out-Of-Step condition. These phenomena can be plotted with respect to a distance relay characteristic as shown in Figure 1 and as described in more detail in [1].
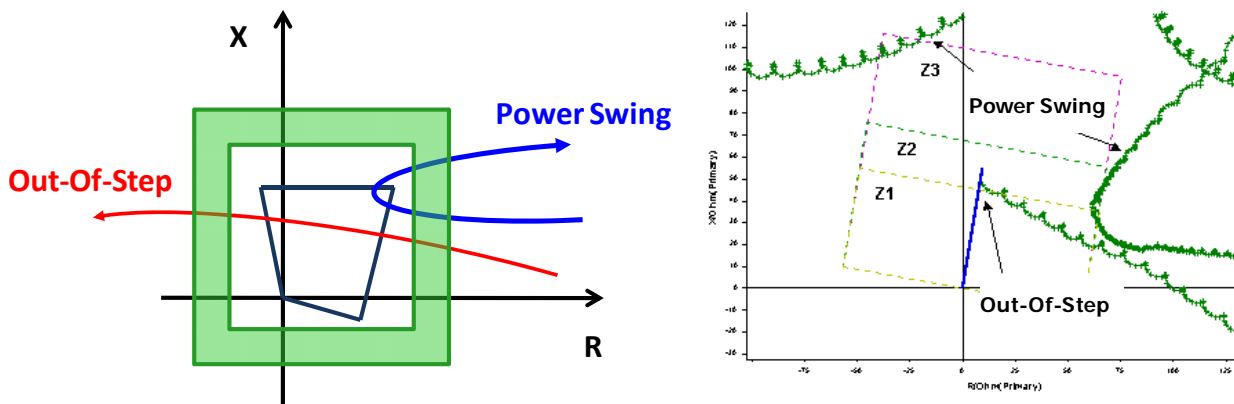

Figure 1 - Apparent impedances presented to distance relays during power swings

If precautions are not taken to prevent undesirable protection operation during stable power swings, unnecessary outages or blackouts may result. In addition, in the case of out-of-step conditions it is sometimes necessary to optimize the system separation point.

The system simulations reported in this paper use software that includes a dynamic model of the power system and of the relays [2]. Note that although the software is capable of performing transient simulations as well as dynamic and steady state simulations, the relay models described in this paper are only used for determining dynamic performance with time varying phasors. The relay response to non fundamental frequency phenomena such a series capacitor subsynchronous oscillations is not within the scope of this paper. The study reported in this paper is a specific example of the process presented in [3], and contrasts with the system simulations [4] that used a system simulator which created test signals for injection into the relay hardware.

It is usually considered that a power swing is a three phase phenomena, however in power systems where single-phase tripping and reclosing is used, a power swing can appear in two phases during the reclosing dead time.

2. A trip during a power swing.

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 2, this link is 600 km long, and in the middle of the link there is a substation called Cotaruse. In January 10 of 2010, during a lightning storm, there was a phase to phase fault in the line L-2053, and a simultaneous single phase to ground fault on the line L-2054 as is shown in Figure 2. The power flow before the fault was from Mantaro to Socabaya.
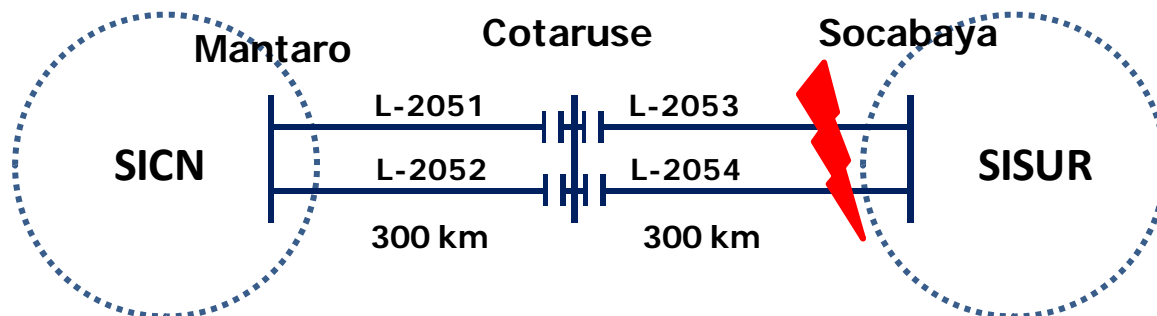

Figure 2. Interconnection between the North-Center Area and the South area

Circuit L-2053 tripped tree-phase with no reclose by a line differential relay (87 L), while L-2054 tripped single phase by a line differential relay (87 L) and started a reclose cycle. During the dead time (reclose in progress) the North-Center area was interconnected to the South area through two phases instead of six, starting a power swing as is shown in Figure 3. It is usually said that a power swing is a three phase phenomena, but in cases of single phase tripping and reclosing, a power swing can happen during the dead time of a single phase trip as in this case.
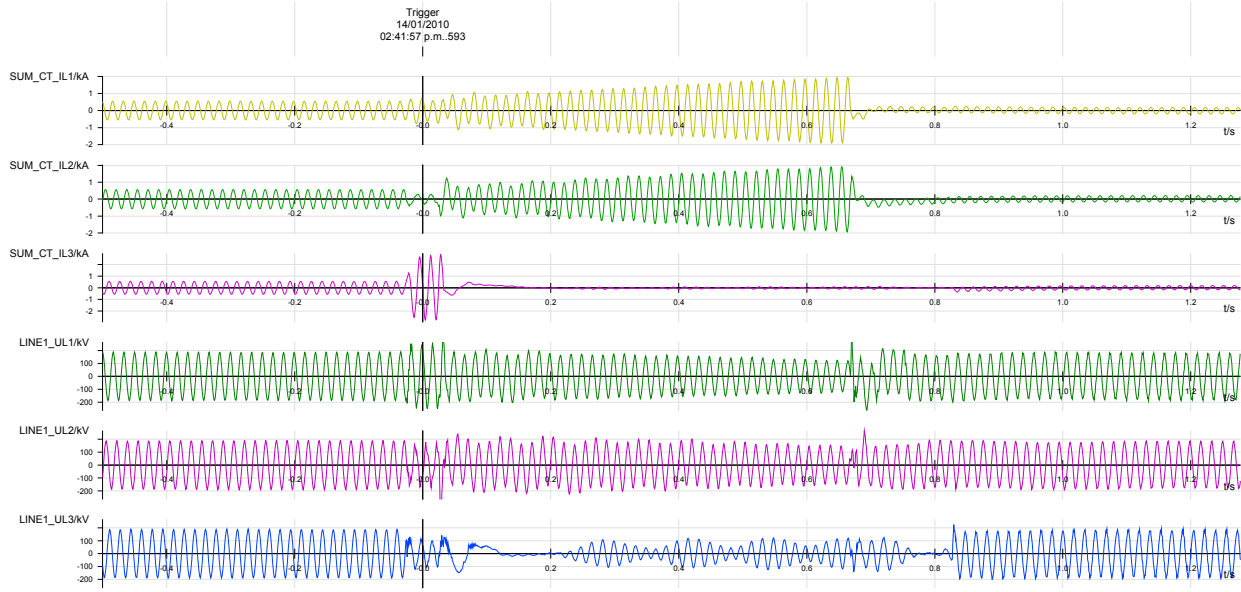
Figure 3. Power swing in L-2054 during the dead time of the reclosing.

The impedance measured during the power swing is shown in Figure 4. This figure shows that the impedance measured by the relay changing at a rate of change of 164 Ω/sec to 100 Ω/sec. Finally the impedance entered into the distance characteristic, tripping the line at Cotaruse Substation and sending a Direct Transfer Trip to Socabaya Substation.
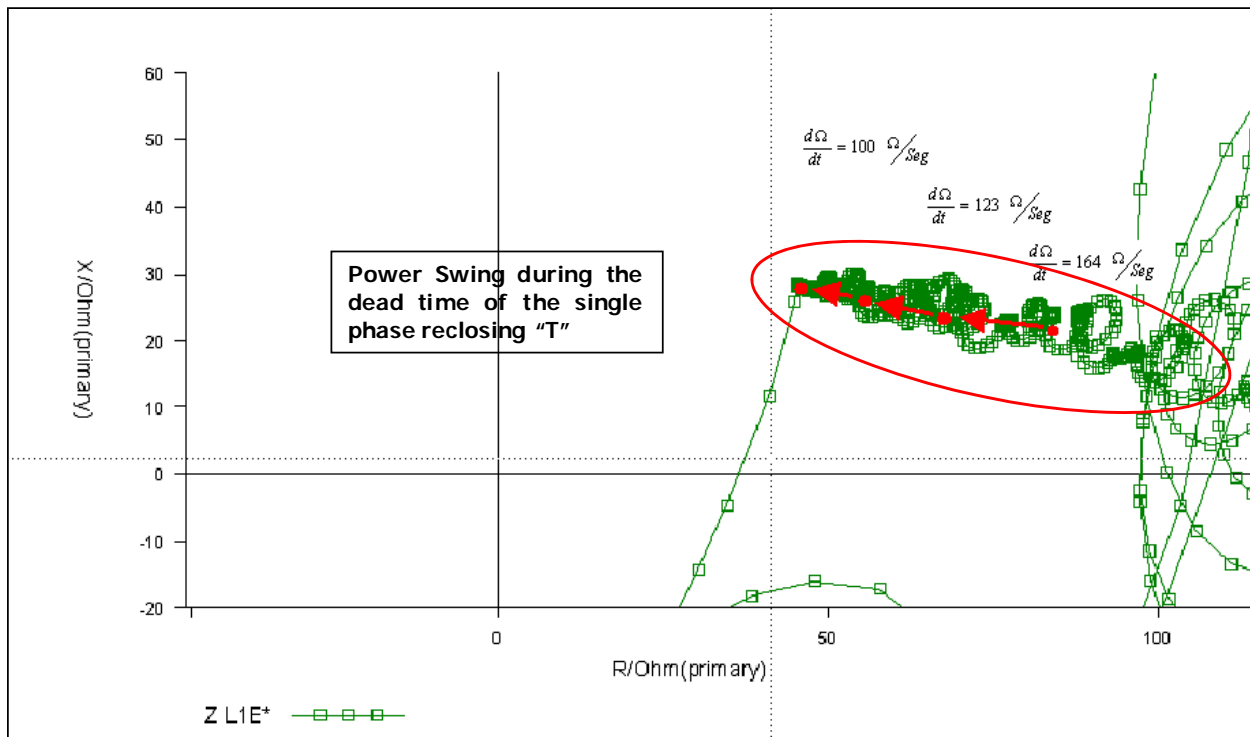

Figure 4. Impedance measured from the Cotaruse terminal during the power swing.

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Finally, after L-2054 tripped, the South area collapsed. Although in the system there is a load shedding scheme, some other generation problems caused a blackout of the South area.

3. Dynamic simulations in order to set the distance relays

After the event, as a part of an overall protection study of the Peruvian Power System [5], dynamic simulations were made in order to find the settings of the Power Swing Blocking and the settings of the Power Swing Tripping (out-of-step) functions of the various line protections.

The simulations were made not only in the lines of the link between Mantaro – Socabaya but also on many other backbone transmission lines. The simulations allowed the identification of various power swing blocking and tripping locations.

I)   Analysis of the lines between Mantaro – Cotaruse:

In order to find the setting for the lines between Mantaro – Cotaruse, some simulations were made for the lines Mantaro – Cotaruse. The cases analyzed were three phase faults near Mantaro and three phase faults near Cotaruse. Three phase faults are the most severe faults. The three phase fault were applied during 100ms, and cleared with the tripping of both ends of the line.

For the first case, three phase faults near Mantaro on Circuit L-2052 cause a power swing, but the swing is stable. The apparent impedances presented during the oscillations do not enter in the distance protection zones and the rate of change of the impedance is relatively slow, in the region of 154 Ω/sec.

Figure 5 shows the apparent impedances seen by the protection systems on the unfaulted circuit L-2051 before, during and after a three phase fault at the Mantaro terminal of Circuit L-2052 cleared at both terminals after 100ms. It can be seen first that the load impedances are seen far beyond the reach of the distance characteristics. During the fault the impedance jumps in to the zone 3 characteristic of the Cotaruse relay. After clearing the fault in 100 ms the system oscillates and the relays detect the oscillations as a power swing. It is important to note that because the fault was near Mantaro, the series capacitor was not by-passed.
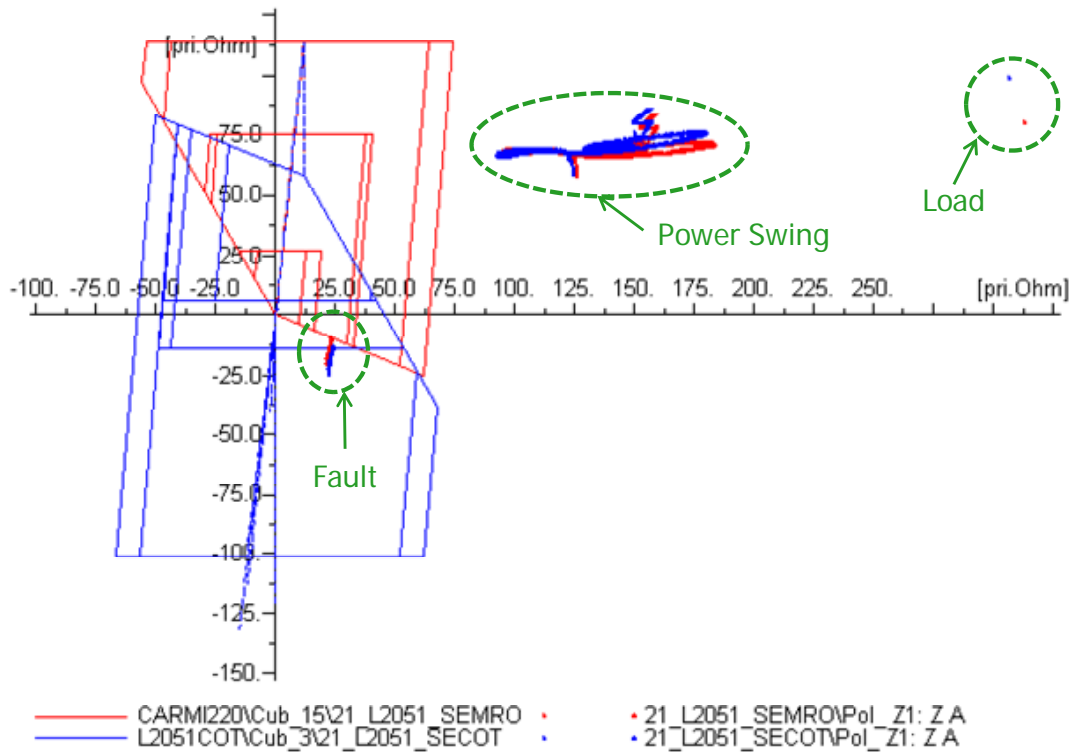
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Figure 5: Power swing in the lines Mantaro – Cotaruse (reference Mantaro Substation).

For the second case (see Figure 6), a three phase fault was simulated on Circuit L-2052 on the line side of the series capacitor near Cotaruse substation for 100 ms. Again, first we see the load impedance far away from the distance characteristic. In this simulation, during the three phase fault initially (due to voltage inversion) the impedance is seen by the relays of L-2051 in Cotaruse in Zone 3, and in Reverse zone in Mantaro., Within half a cycle, the MOV of the series capacitor of the line L2052 conduct and three cycles later the series capacitors are by-passed so the fault impedance seen by the relays change their position. After clearing the fault, the system oscillation is not stable, producing an out-of-step condition.
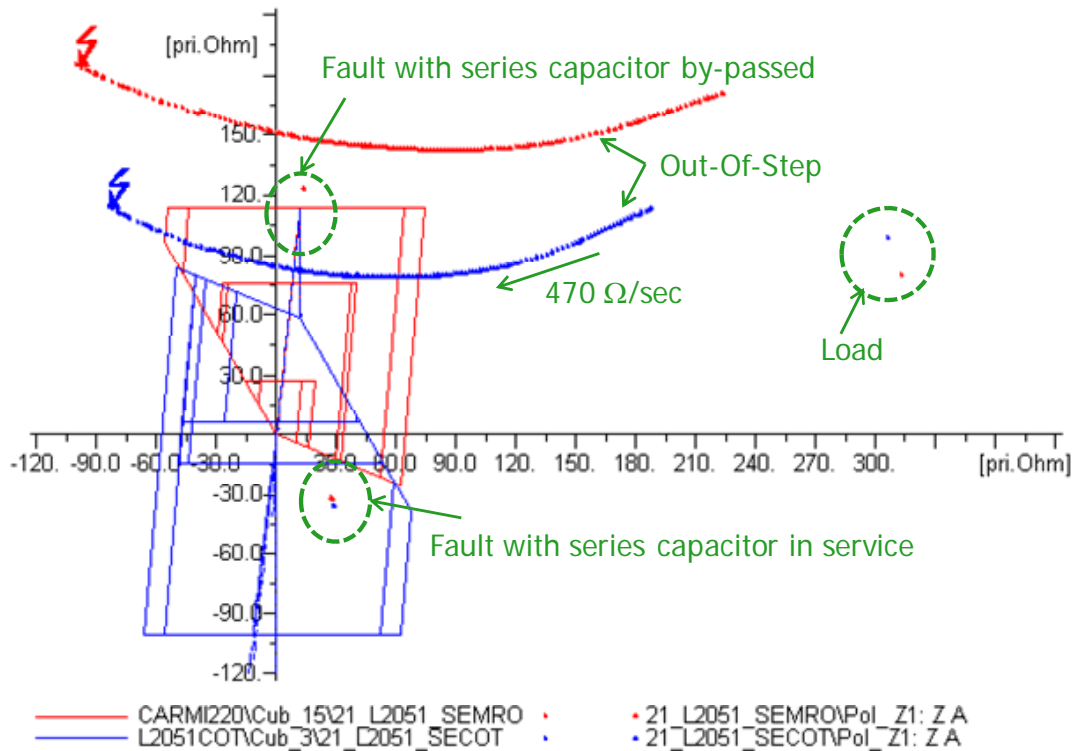
Figure 6. An Out-of-step in the lines Mantaro – Cotaruse (reference Mantaro Substation).

From these simulations we can conclude that in these lines we must set the Power Swing blocking. We do not trip this line under Out-Of-Step conditions because if we trip this line under Out-Of-Step condition, the lines between Cotaruse – Socabaya are going to be energized from Socabaya injecting around 140 MVAR capacitive, so it will cause and overvoltage in south area.

Some protection relays have options to block during power swings if one of three (1 of 3), Two of three (2 of 3) or three of three detect (3 of 3) phases detect a power swing. Because these lines have single phase tripping and reclosing, it was advised that the relay must be set with 2 of 3 options. The 1 of 3 option is not recommended, because there could be a single phase fault with changing impedance (such as a fault produced by a tree), and in this case the power swing blocking can be undesirably activated.

II)   Analysis of the lines between Cotaruse – Socabaya:

For the lines between Cotaruse – Socabaya, the cases analyzed were similar to the lines between Mantaro – Cotaruse, the faults analized were three phase faults (cleared in 100 ms) near Cotaruse and Socabaya.

For the first case (Figure 7), three phase fault near Cotaruse, the electric center of these oscillations are in the lines Cotaruse – Socabaya, and after the fault, the system loses synchronism. Therefore, in this line we must block under stable power swing conditions, and trip

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under Out-Of-Step condition. We can see that the relays initially detect the load far away from distance characteristic, during the three phase fault on L-2054 initially the impedance is seen by the relays of L-2053 in Cotaruse in Zone 2, and in reverse zone in Socabaya, the MOV of the series capacitor of the lines conduct and the series capacitors are by-passed so the fault impedance seen by the relays change their position. After clearing the fault, the system oscillates producing an out-of-step condition.
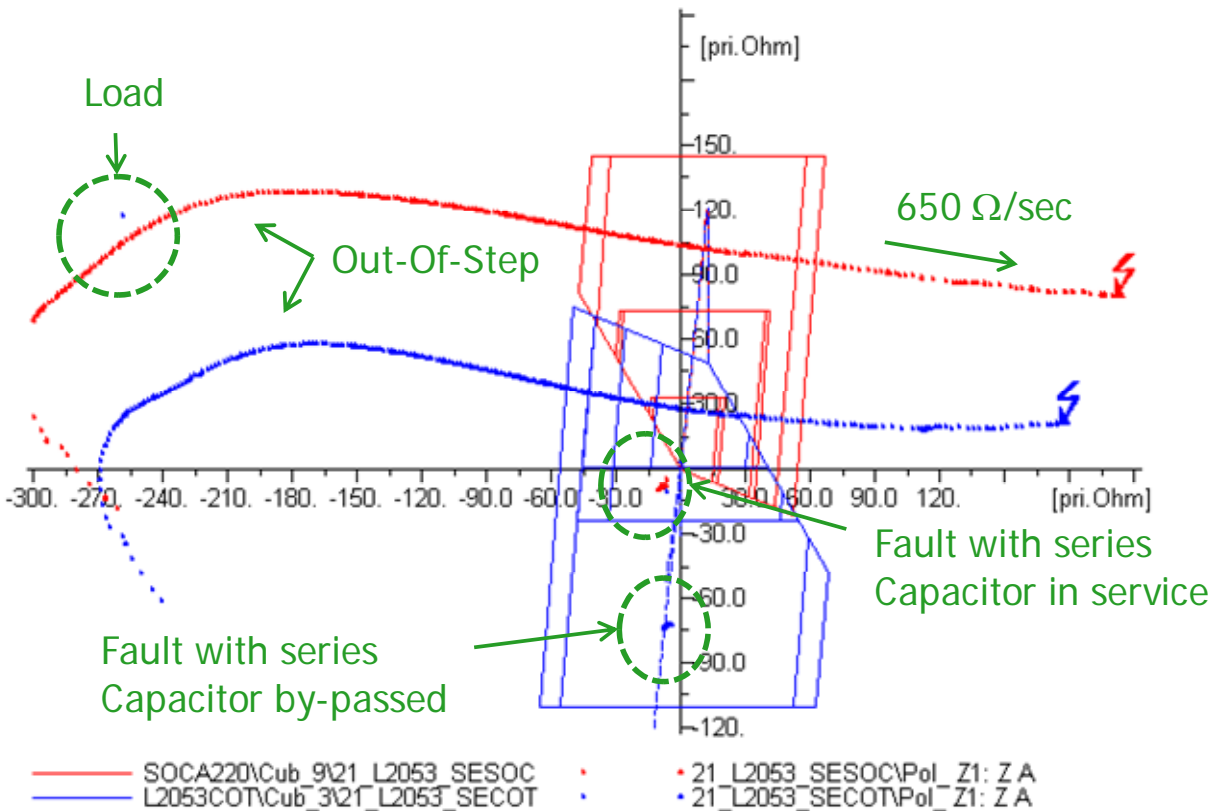

Figure 7: Out-Of-Step in the lines Cotaruse – Socabaya (reference Socabaya substation).

For the second case (Figure 8), three phase fault near socabaya, the system has stable power swings, the rate of change in the impedance during a power swing conditions for this case is 134 Ω/s .
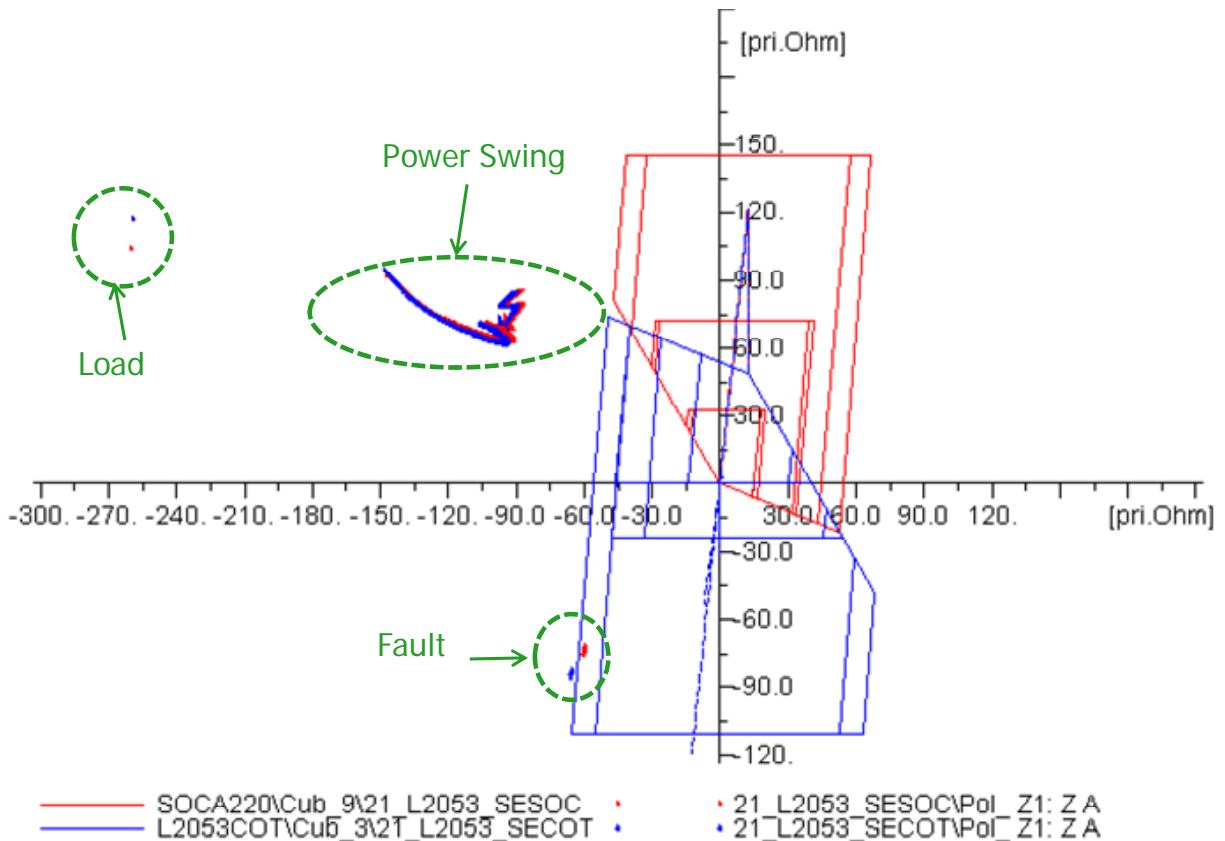
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Figure 8: Power swing in the lines Cotaruse – Socabaya (reference Socabaya substation).

As a result of the simulations, the power swing blocking function was activated on lines L2053 and L2054. Also, the Out-Of-Step tripping was recommended to be activated in these lines. The relays have not yet had the Out-Of-Step protection function enabled, with dependence initially on natural tripping by the impedance characteristic. The Out-of-step protection was activated during this year (2011).

III) Analysis in other lines of the Peruvian Power System

As a part of the overall system protection coordination study, other simulations in other lines were done. It was found that some Out-Of-Step conditions are not detected by the relays under analysis, because the electric center of the oscillations are not in the line under analysis.

For example we show two cases of out-of-step conditions that do not enter in the distance relays characteristics of lines under study.

In the first case (see Figure 9), we analyze a condition where the apparent impedances of the oscillation cross from the first quadrant to the second quadrant. In this case it is possible to implement an Out-Of-Step tripping by increasing the reaches of the reactive blinders in order to detect that Out-Of-Step condition. However in that case only power swing blocking was activated, because there was another scheme that would trip on the out of step condition in the line where the electric center is.
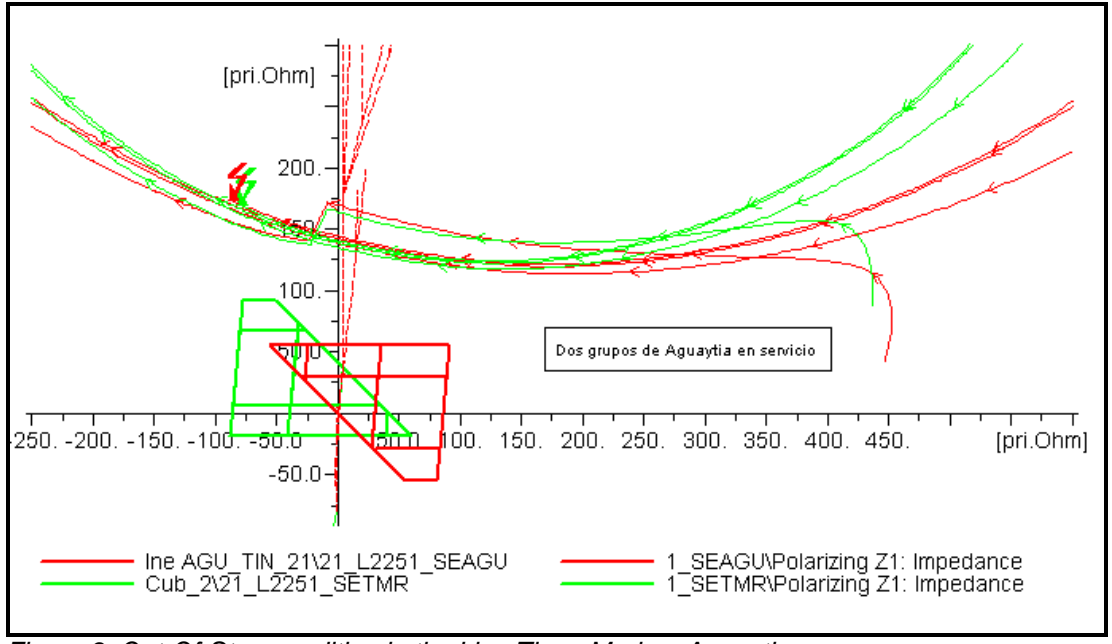
Figure 9: Out-Of-Step condition in the Line Tingo Maria – Aguaytia.

In the second case (see Figure 10) we analyze an out-of-step case where the apparent impedances of the oscillation do not cross from the first quadrant to the second quadrant but still may enter the zone 2 characteristic of the line under study. In this case it is not possible to implement out-of-step tripping. Only the power swing blocking logic was set. Again, other protections would operate to separate the out of step systems.
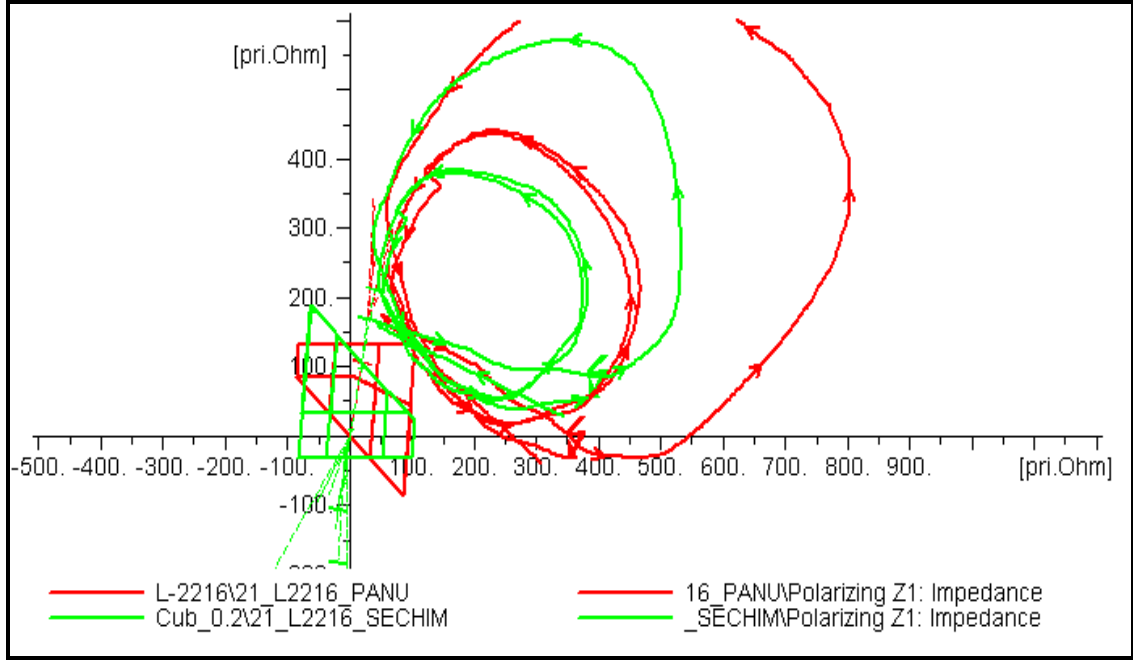

Figure 10: Out-Of-Step condition in the Line Chimbote – Paramonga.

In all the cases analyzed in the Study, the rate of change of the impedance during a power swing oscillation ranged from 100 Ω/sec to 800 Ω/sec.

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4. Conclusions

i)   Power swing phenomena may appear during single-phase tripping and reclosing.

ii)   The use of software to simulate the dynamic behavior of the power system, and the relay characteristics simplifies setting the power swing blocking and tripping functions.

iii)   The simulations identify the rate of change of impedances during a power swing in the Peruvian power system. Rates range from 100 Ω/sec to 800 Ω/sec. Knowing the rates of change of impedance allows the timing of the trip and block functions to be set easily.

iv)   Out-Of-Step tripping must not be applied in all the lines.Separation points should be carefully chosen in order to save the system after out-of-step tripping.

v)   As a result of the analysis of the event in the Peruvian Power System, and the Coordination Study. Power swing blocking and tripping functions were activated.

5. Acknowledgement

6. References

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