An Example Distance Protection Application with Complicating Factors.

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Abstract:

A simple way to set distance relays is to base the setting on percentages of the line impedances. However, when such simplified techniques are used, there are several factors that could affect the reliability of settings under various circumstances. In some cases these factors make it necessary to conduct additional studies to verify these settings under some critical operating conditions that could cause these relays to trip incorrectly. This paper describes an analysis made to the protection of a pair of long (221 km) parallel 220 kV transmission interconnection lines in Peru. It describes the problems that had been experienced before the settings were revised, and the basis for the new settings.

In addition to being an interesting study of complicating factors for transmission line protection, this paper also has an educational component. It demonstrates many of the effects that should taken in consideration during the setting studies such as, mutual coupling of the parallel lines, load flow effects, fault resistance effects. For example, this is a long line with power autotransformers at the remote terminal where a typical setting zone 2 reach had to be reduced from 120% to 100% in order to avoid tripping during faults at the lower voltage level.

1. Introduction

Distance relays are one of the most important protection elements in a transmission line. These relays may sometimes be set based in percentages of the line impedances, for example a typical setting for zone 1 is 80% of the impedance of the line in order to not reach the remote end, the zone 2 can be set at 120% of the impedance of the line in order to dependably overreach the line, Zone 3 sometimes are disabled or set to cover an adjacent line.

Distance relays characteristics may be Mho, Quadrilateral, Offset Mho, etc. In the case of the quadrilateral characteristic or long reaching mho characteristics, additional care may be required to remain secure during heavy load.

In the case of parallel lines, the mutual coupling of these lines can cause distance relays to under reach and over reach. For this reason the relay setting must consider this effect, some relays have algorithms to compensate, but it is necessary to use the current of the parallel line which adds complexity to the installation.

In some countries there criteria that a distance protection can not reach fault in other voltage levels, because fault clearing times in sub transmission levels may be slower than fault clearing times at the transmission level.

2. A wrong trip of a distance relay in the Peruvian Power System.

In august 26 of 2004, a single fault to ground occurred in a 138 kV subtransmission line L-1111 as shown in Figure 1. Circuit L-1111 was protected by mho phase and ground distance relays. The fault was detected by the distance relay of at the Paramonga terminal of the 220 kV circuit L-2215 This line is the main interconnection between The North area of Peru and the South-

Center Area of Peru. After the tripping of the line L-2215, the North area had a severe deficit of active power, producing a Blackout in the North area.

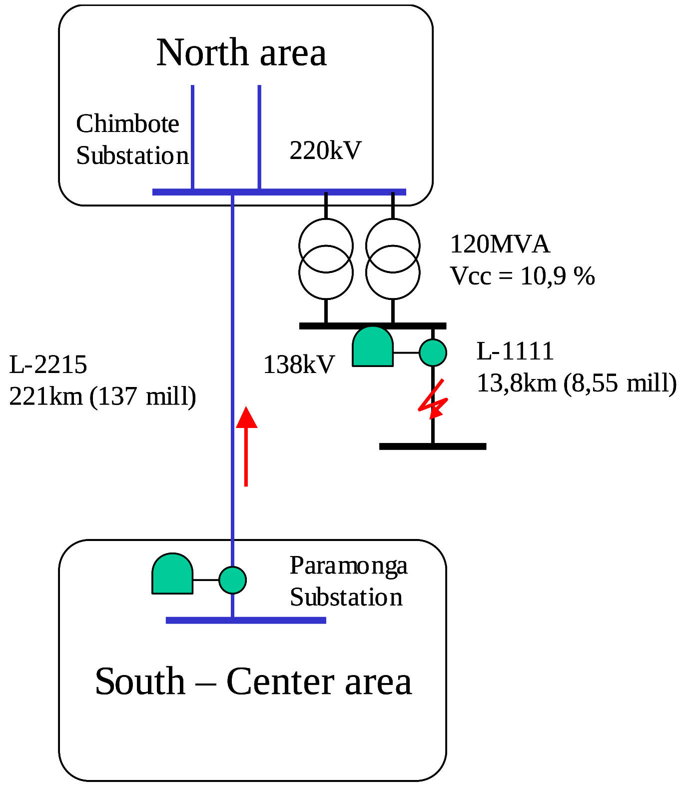


Figure 1. Fault in a 138kV line.

Figure 2 shows the apparent impedance of the fault presented to the L-1111 distance relay. This single phase to ground fault was not cleared by the distance protection of line L-1111, because the short line protected with a distance relay with a mho characteristic for phase to ground that was not sufficiently sensitive as shown in Figure 2. This fault was cleared after a time delay by a directional ground time overcurrent relay.

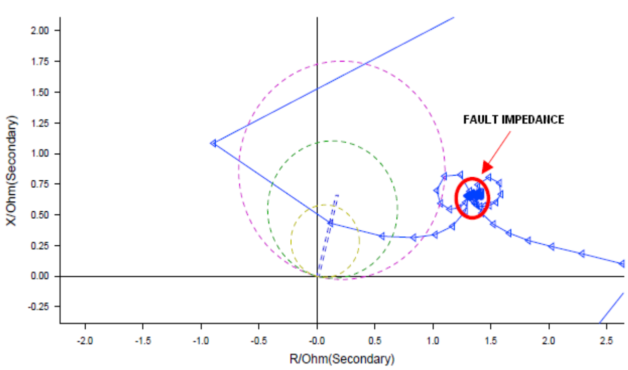


Figure 2 – Apparent Impedance Presented to L-1111 Distance Relay

After the disturbance, circuit L-1111 was re-energized in order to test if the fault was temporary. Figure 3 shows the oscillographic record retrieved from the relay during re-energization. Note the approximately 0.3 per unit voltage on C phase. Such a low voltage would impact transmission power transfer. In this case the switch on to fault protection tripped the line promptly in 100ms. The impedance shown in Figure 2, was plotted with information obtained from this record.

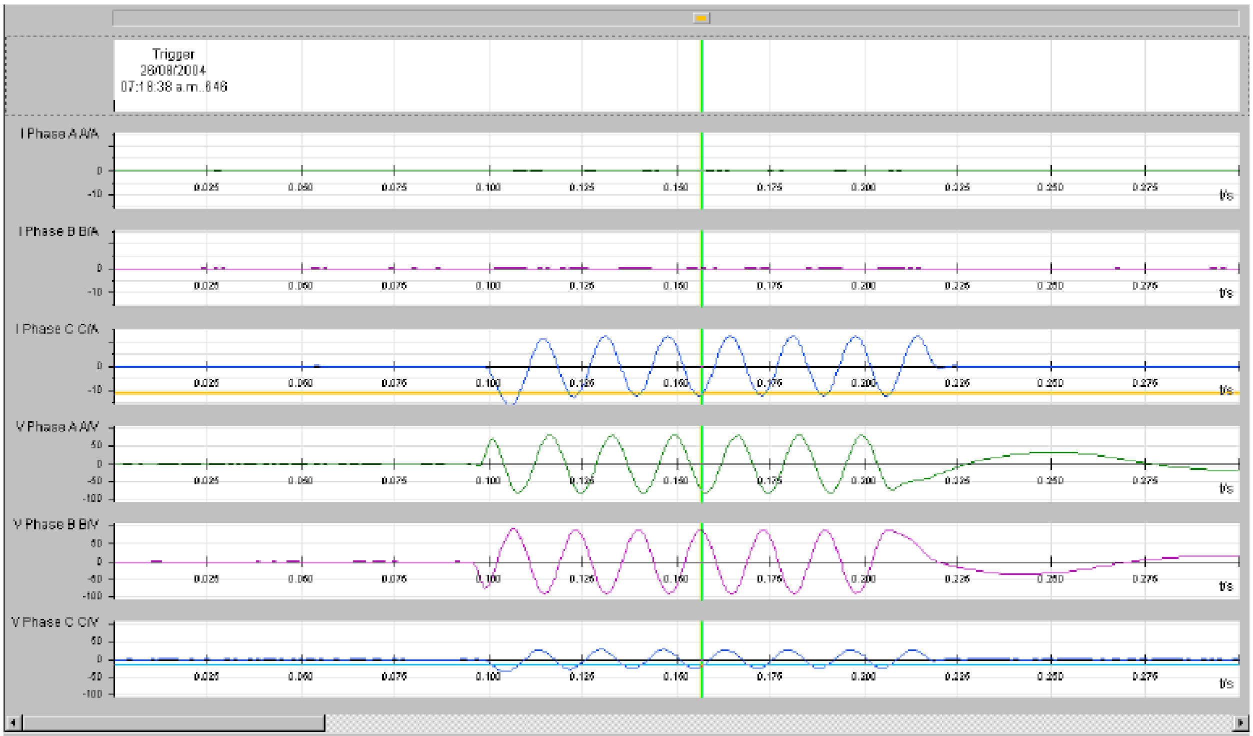


Figure 3 – Recorded data from L-1111 during line re-energization.

The power swing produced by the uncleared fault and the flow conditions through line L-2215 which was near its stability limit caused the zone 1 of the distance protection of the line L-2215 in Paramonga Substation to operate, tripping the line as it is shown in the Figure 4.

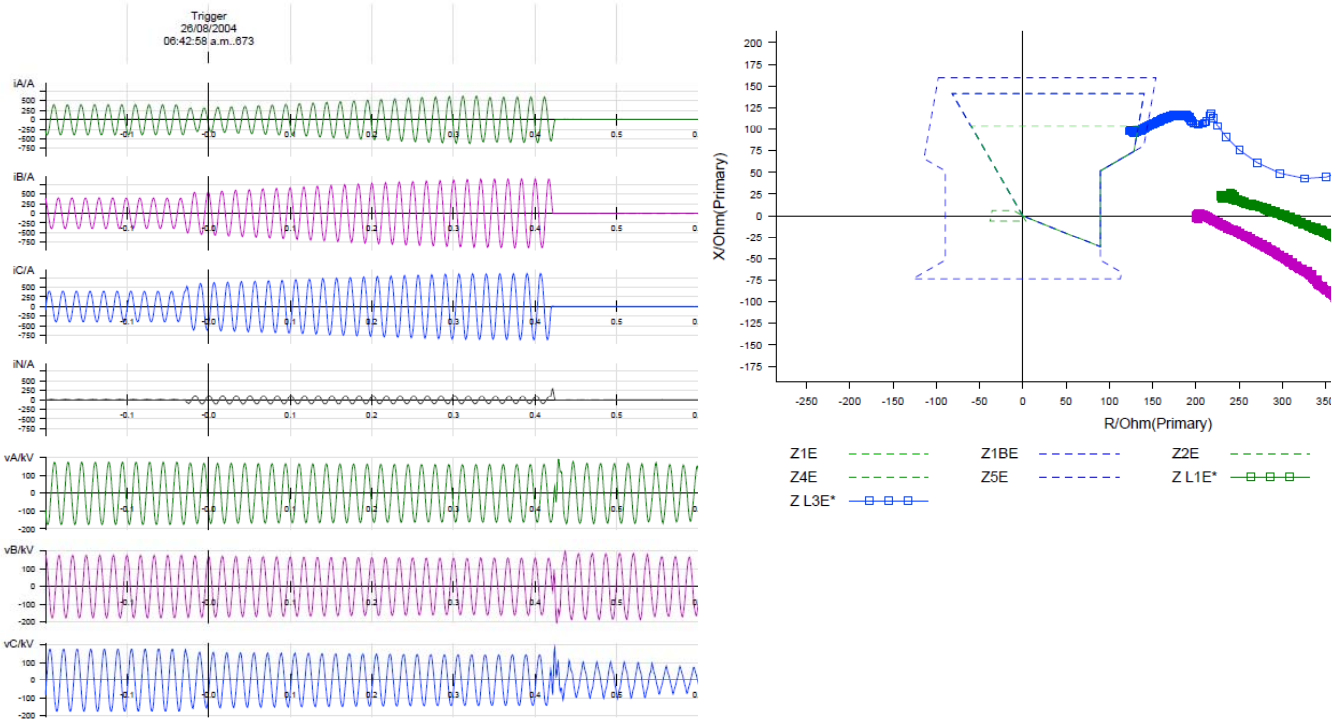


Figure 4. Fault in _L-1111 line plus a power swing seen by a Distance protection in 220kV.

The undesirable trip of Circuit L-2215 had three causes.

i) Slow clearing of the L-1111 fault started a power swing. It is not known whether or not the swing would have recovered to a stable condition

ii) The power flow was not considered during the settings of the protection relay at Paramonga L-2215

iii) During the setting of the protection relay at Paramonga L-2215, there were no simulations of resistive faults in Chimbote 138kV. The relay was set only considering percentages of the impedance of the line.

After the fault, as a corrective action the settings of the distance relay in the L-2215 were changed. Also the mho distance relays in line L-1111 were replaced with quadrilateral distance relays for phase to ground faults. Figure 5 shows the settings of the new relay with quadrilateral characteristic and the old relay with mho characteristic.

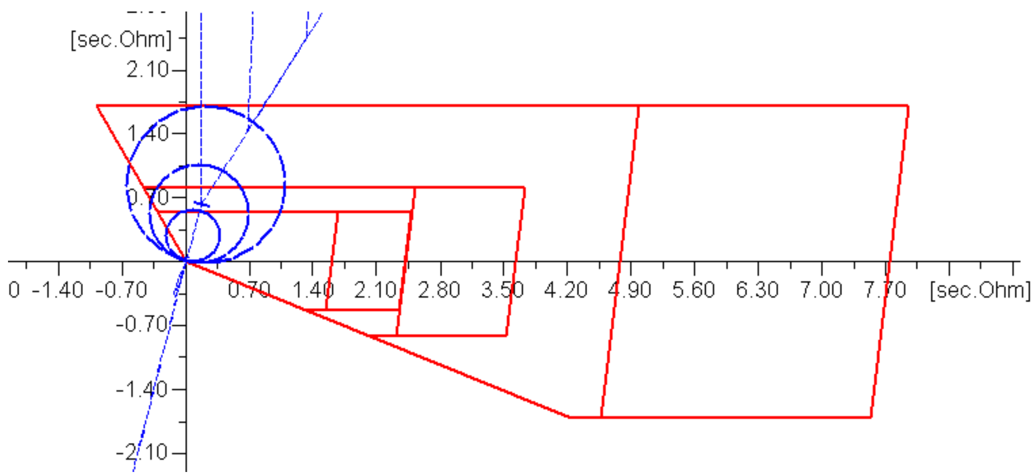


Figure 5. Old and New Characteristics for the protection of line L-1111.

3. Setting a distance relay for a new configuration of the line.

In 2008, another line was built parallel to the line L-2215 in order to increase the capability of power delivery to the north area as shown in Figure 6. The methodology followed to set this relay is described in this section.

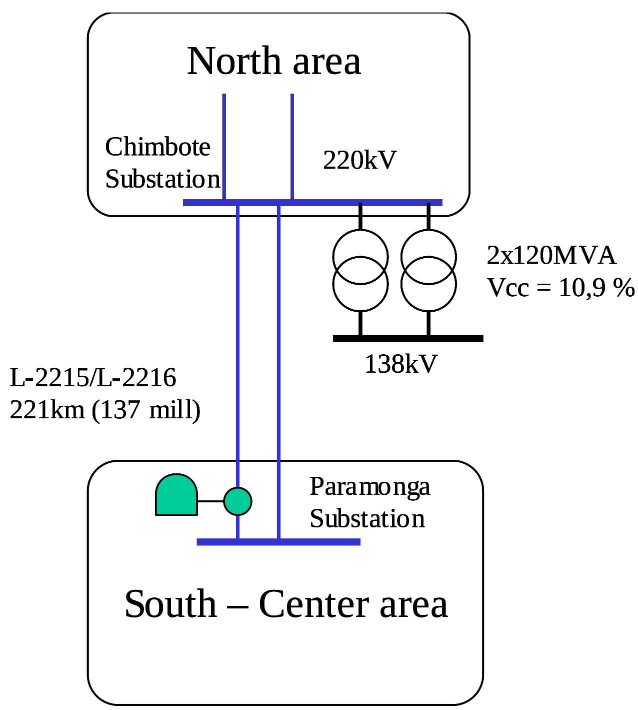


Figure 6. New configuration for the Interconnection between the North and the Center area.

i) Various scenarios of power flow and contingencies were analyzed in order to determine the maximum power flow through the lines L-2215 and L-2216. Based on this maximum power flow condition the minimum load impedance was calculated using the formula.

$$Z_{\min} = \frac{(0{,}85 x V_{nom})^2}{S_{\max}}$$

The maximum allowable resistive reach is calculated as a percentage of the minimum load impedance.

$$R_{\max} = a \; x \; Z_{\min}$$

In this case the maximum allowable resistive reach calculated for this line is 94 Ω.

ii) This maximum allowable resistive reach must be checked with the resistive reach considering arc resistance (lengthening with time) based on the Warrington formulation.

$$R_{arc} = \frac{28700 * (S + 2.v.t)}{I^{1,4}}$$

Where

S = distance between phase to phase or phase to ground (meters)
I = Short Circuit Current [Amperes]
v = wind speed transverse to the arc [meters/second]
t = Short circuit duration (seconds)

In this case the values used for this calculation are show in the following table.

Arc Resistance using Warrington Formulation				
Voltage	kV	220	220	220
Phase to Ground distance	Meters	4,00	4,00	4,00
Phase to phase distance	Meters	7,00	7,00	7,00
Wind Speed	meters/second	10,00	10,00	10,00
Short Circuit time	Seconds	0,50	0,50	0,50
Short Circuit Current	Amps	5 000	4 000	2 000
Rarc Phase to phase	Ohms	2,66	3,64	9,61
Rarc phase to ground	Ohms	3,23	4,42	11,67

iii) Initially the reactive reach of Zone 1 was considered as 85% of the reactance of the line, and the resistive reach for phase-to-phase and phase-to-ground fault as the maximum resistive reach. With these settings phase-to-phase faults were simulated at (1%, 20%, 50%, 80% and 99% of the line) considering the fault resistance calculated with Warrington Formulation. In this case the assumed resistance was 10 Ω (approximately 9,61 Ω), with the parallel line in service and out of service, and the scenario of maximum generation in the North area. According to this simulation, the resistive reach for phase-to-phase faults set to 35 Ω will be sensitive enough (see Figure 7). Note the impact of infeed from the parallel line to the fault resistance (through the remote terminal) makes the resistive component increase as the fault approaches the remote terminal.

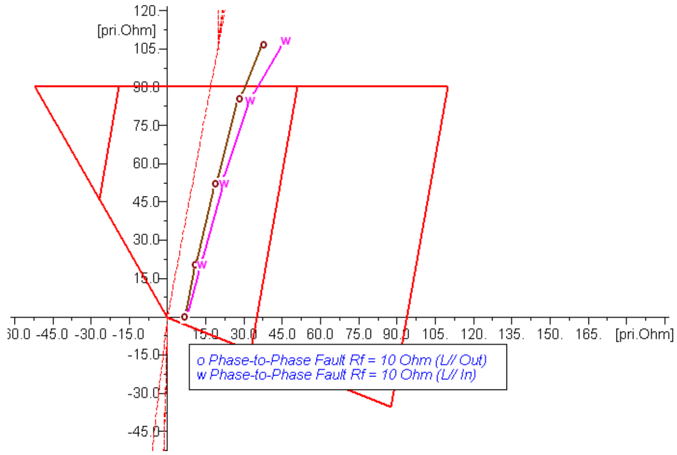
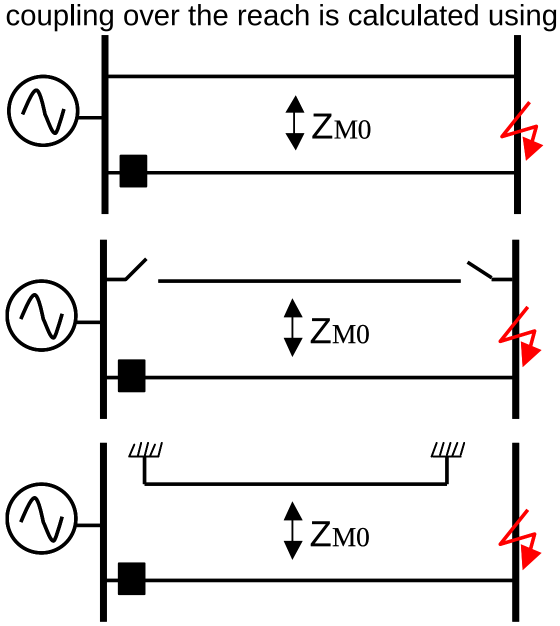


Figure 7. Phase-to-Phase faults in the line L-2215.

iv) Because the line in study has a parallel line, the settings of the phase to ground elements are influenced by the mutual coupling. Theoretically the effect of the mutual coupling over the reach is calculated using the formulas shown in Figure 8.



$$Z = Z_L \frac{[1 + k_0 + k_{M0}]}{(1 + k_0)}$$

$$Z = Z_L \frac{[1 + k_0]}{(1 + k_0)}$$

$$Z = Z_L \frac{\left[1 + k_0 - k_{M0}\left(\frac{Z_{M0}}{Z_{L0}}\right)\right]}{(1 + k_0)}$$

Figure 8 – Formula for impact of mutual coupling on measured impedance.

Where k0 = (Z0-Z1)/3Z1 and kM0 = (ZM0)/3Z1

To check the reactive reach of the Zone 1 ground distance element, it was necessary to simulate a fault in Chimbote Substation considering :

A) Phase to ground fault in Chimbote 220kV with the parallel line in service
B) Phase to ground fault in Chimbote 220kV with the parallel line out of service
C) Phase to ground fault in Chimbote 220kV with the parallel line out of service and grounded.

With these simulations it was determined that it was necessary to reduce the reach of zone 1 to 84 Ω (around 80% of the line impedance). Case C was the case that resulted in overreach of Zone 1 (see Figure 9).

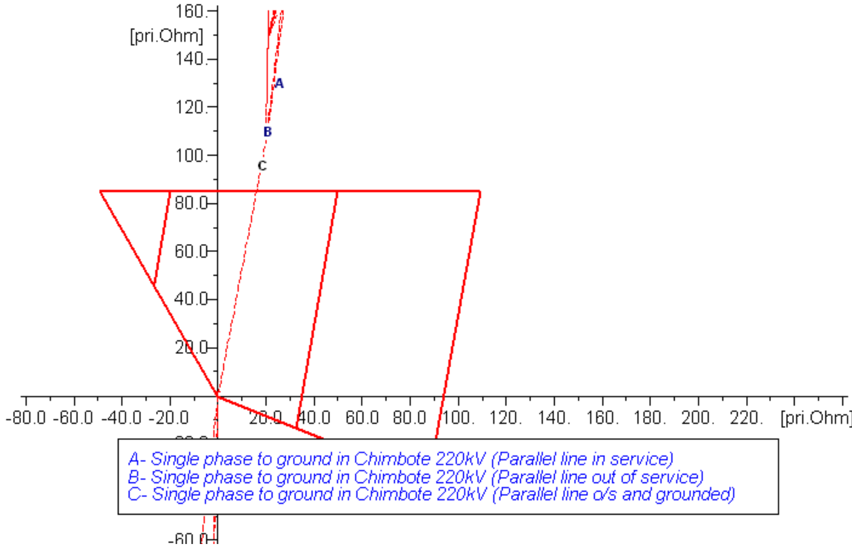


Figure 9. Phase to ground faults in Chimbote 220kV with different conditions of the parallel line.

v) When calculating the resistive and the reactive reach for zone 1, phase to ground faults were simulated at the remote terminal (Chimbote 220kV) for all the load scenarios. The Paramonga terminal always exports power. Figure 10 shows the apparent impedances of phase to ground faults at Chimbote 220kV for the worst operative condition.

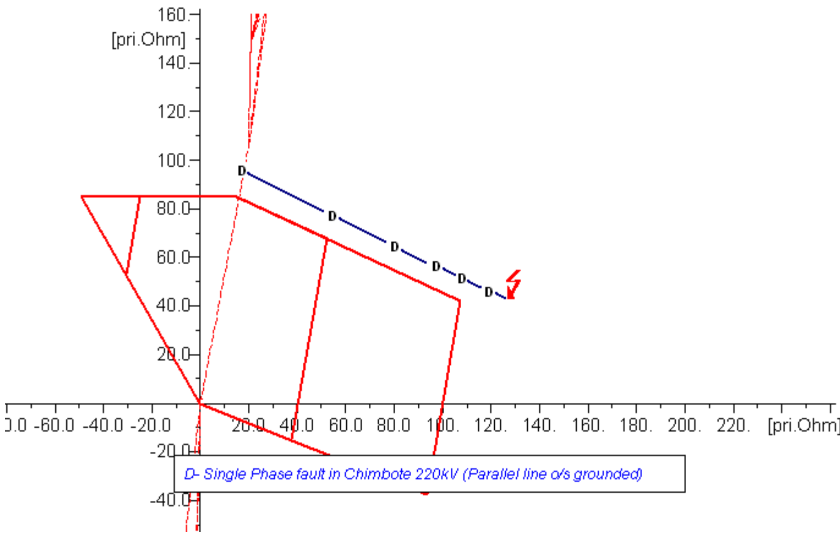


Figure 10. Phase to ground faults in Chimbote 220kV under the worst flow condition.

vi) After the reach for zone 1 was calculated, the reach for zone 2 was calculated. Initially the reactive reach was set at 120% of the line reactance, and the resistive reach the same as the resistive reach for zone 1. Because there are two power autotransformers rated 220/138kV 120MVA at the Chimbote terminal, it is necessary to simulate faults at the Chimbote 138kV busbar (see Figure 11).

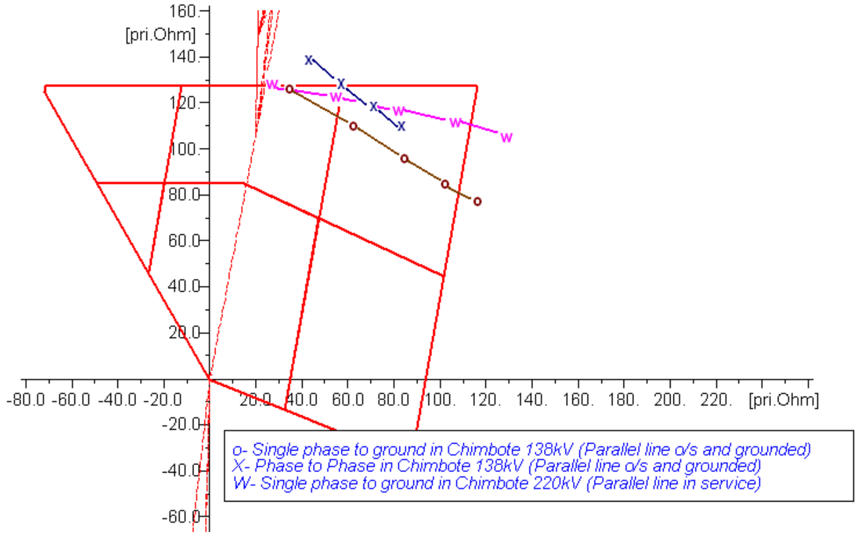


Figure 11. A typical setting of zone 2 with simulation in Chimbote 220kV and Chimbote 138kV.

Figure 11 shows that with a setting of 120% of the line reactance, faults in Chimbote 220kV are (marginally) detected in zone 2 with the parallel line in service. However, this zone detects also phase to ground faults and phase-to-phase faults in Chimbote 138kV with the parallel line out of service. So it is necessary to choose between increasing the zone 2 time, or reducing the zone 2 reach in order to avoid operating for a fault in Chimbote 138kV when the parallel line is out of service. The second option was selected since this zone is only expected to detect faults in the line; it has to be coordinated with the breaker failure protection of Chimbote 220kV. The time of this zone 2 was set to 300 ms (see Figure 12).

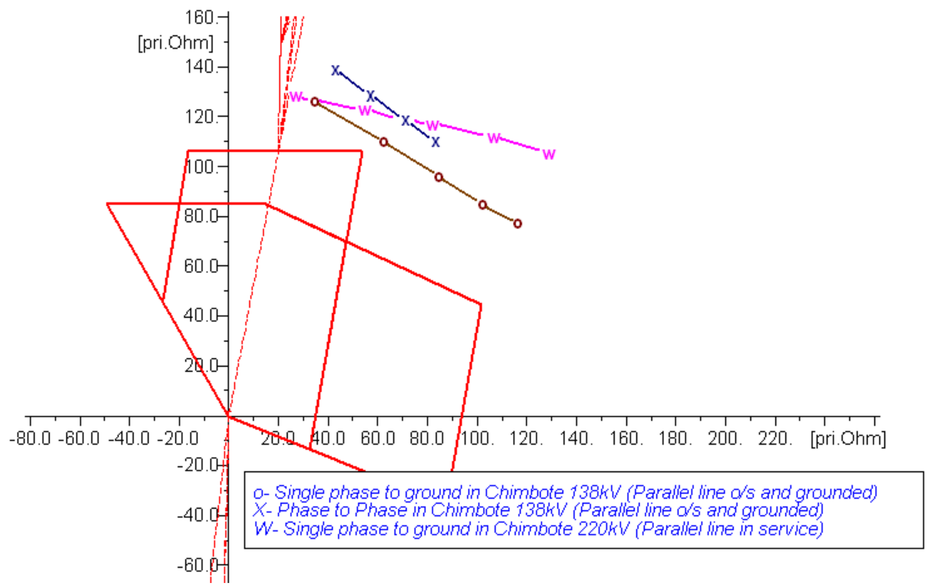


Figure 12. A new setting of zone 2 with simulation in Chimbote 220kV and Chimbote 138kV.

vii) Because this reduced Zone 2 reach could not dependably detect all the faults in the line, a zone 3 was also applied, with settings of 120% of the impedance of the line and a time of 1 second, in order to coordinate with the backup protection of the power autotransformers. Note that the Power Autotransformers have time overcurrent relays that clear 138 kV faults with delays between 500ms to 800ms.. Figure 13 shows the final selection of settings.

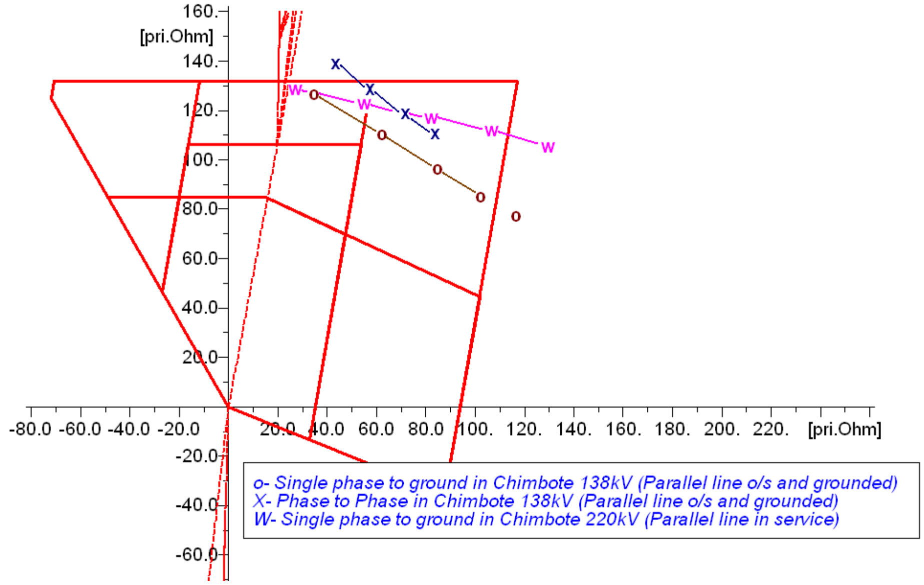


Figure 13. Final settings for the distance protection of L-2215 in Chimbote Substation.

viii) Additionally the teleprotection function zone was set the same as zone 3 for dependable communications assisted protection.

ix) A similar analysis was made for the relay Chimbote 220 kV terminal, resulting in the settings shown in Figure 14.

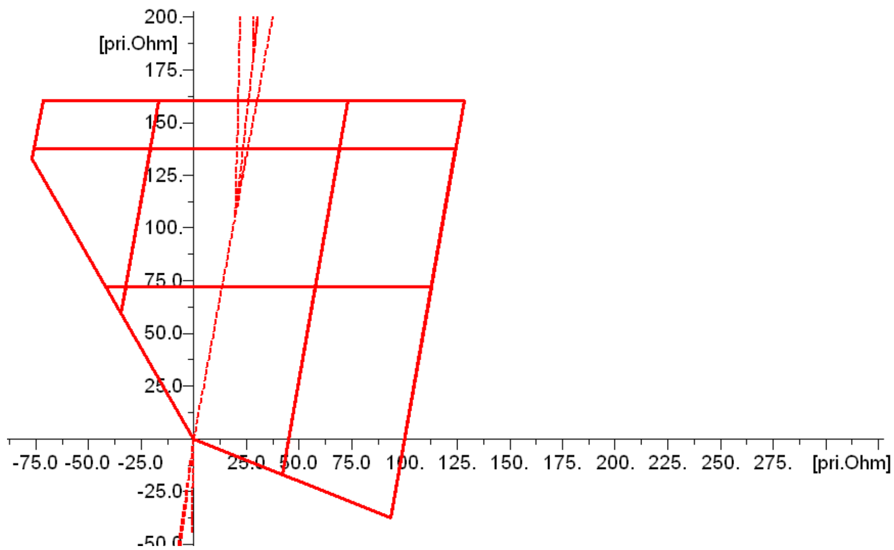


Figure 14. Final settings for the distance protection of L-2215 in Chimbote Substation.

4. Conclusions

i) The use of software tools to calculate the settings of a distance relay is important to analyze all the possible scenarios [1,2,3].

ii) Today there are many power system softwares that include relay models including the manufacturers algorithms (e.g. [4]).

iii) When a protection engineer sets a relay, it is important to consider the specific relay algorithm, with all the options that it has, and consider all credible contingencies [5].

iv) The settings based in percentages of the line are often satisfactory. However, this setting must be checked simulating faults with and without resistance and power flow in many parts of the power system.

v) Power system protection is an art and a science, there are many ways to set a protection relay. The example provided shows one solution. Other solutions are equally viable and depend on the preferences of the utility.

vi) After the change of setting in the protection relays in Peru, these have not operated incorrectly. These settings are going to be checked again in 2010.

5. Acknowledgement

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6. References

[1] COES-SINAC, “Estudio de Coordinación de Protecciones del Sistema Interconectado Nacional”, 2004.

[2] COES-SINAC, “Actualización del Estudio de Coordinación de Protecciones del Sistema Interconectado Nacional”, 2006.

[3] G. Ziegler, “Numerical Distance Protection Principles and Applications”, Second Edition SIEMENS, 2006.

[4] DIgSILENT Power Factory, “User Manual”, www.digsilent.de.

[5] SIEMENS SIPROTEC, “Distance Protection 7SA522 Manual”, www.siprotec.com.