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TRANSMISSION LINES PROTECTION USING SIPROTEC NUMERICAL RELAYS

SUMMARY

This paper analyses the fundamental principles of distance protection relays while highlighting the importance of correct relay parameterising through a set of relay tests. Numerical distance relays can have up to 6 distance zones, and nowadays most of them have a quadrilateral (polygonal) characteristic. The specific objective of this study was to apply those principles on a SIPROTEC distance protection 7SA611 relay with the help of Omicron CMC 56 testing device, as well as to describe the testing process. As a part of the testing, DIGSI and Test Universe Software were used. Experimental results confirm the theoretical principles of distance protection and show the advantages of numerical relays. This paper concludes that optimal choice of reach settings and time delays between the zones, as well as zone directions, can significantly impact the selectivity of the protection system, and therefore the scope and time of the outage.

Keywords: distance protection, numerical relay, polygonal characteristic, SIPROTEC, zone settings

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1. INTRODUCTION

Transmission lines form a fundamental part of the electrical power system, as they present the path between generation and load. Often factors like deregulated market environment, economics, and environmental requirements urge utilities to operate transmission lines close to their limits. In a tightly interconnected system any fault, if not detected and isolated quickly, will cascade into a system-wide disturbance resulting in widespread outages. Consequently, it is crucial to equip transmission line terminals with relayed circuit breakers. Transmission protection systems are designed to identify the location of faults and isolate only the faulted section, that is to say, a minimum number of circuit breakers should trip, and preserve the selectivity of the system. The protection system selected should also provide redundancy to limit the impact of device failure, and backup protection to ensure dependability. For high-speed clearing times for faults occurring at any point on a transmission line, it is essential to produce some form of a communication channel between the transmission line terminals. This way, protective relaying systems can exchange information to determine whether the fault is internal or external to the protected line. The reliability of communications impacts the safety of the protection system. Thus its importance is vital. For transient faults such as lightning strikes, automatic reclosing may be applied, followed by fault clearance, to restore the line service [1].

2. DISTANCE PROTECTION

Bearing in mind that the line impedance is proportional to its length, it is appropriate to measure the impedance of a line up to a predetermined (reach) point. Such a relay described as distance relay, operates only for faults occurring between the point of relay location and the selected reach point, hence giving discrimination for faults that may occur in different line sections.

The fundamental principle of distance protection involves dividing short-circuit voltage (U_{SC}) and current (I_{SC}) at the relay location, as shown in Figure 1. So calculated apparent impedance (Z_{Lm}) is then compared with the impedance of the reach point (Z_1). If the reach point impedance is higher than the measured impedance, it is assumed that a fault had occurred on the transmission line between the relay and the reach point. For this basic protection decision, there is no requirement for further information and the protection, therefore, does not depend on any additional equipment or signal transmission channels.

Distance protection acts typically as primary protection for overhead lines and cables. Most commonly used numerical distance protection uses microprocessor technology with analogue to digital conversion of measured values (current and voltage), computed distance determination and digital processing logic. An extra advantage of numerical distance protection is integrated fault location function [2, 3].

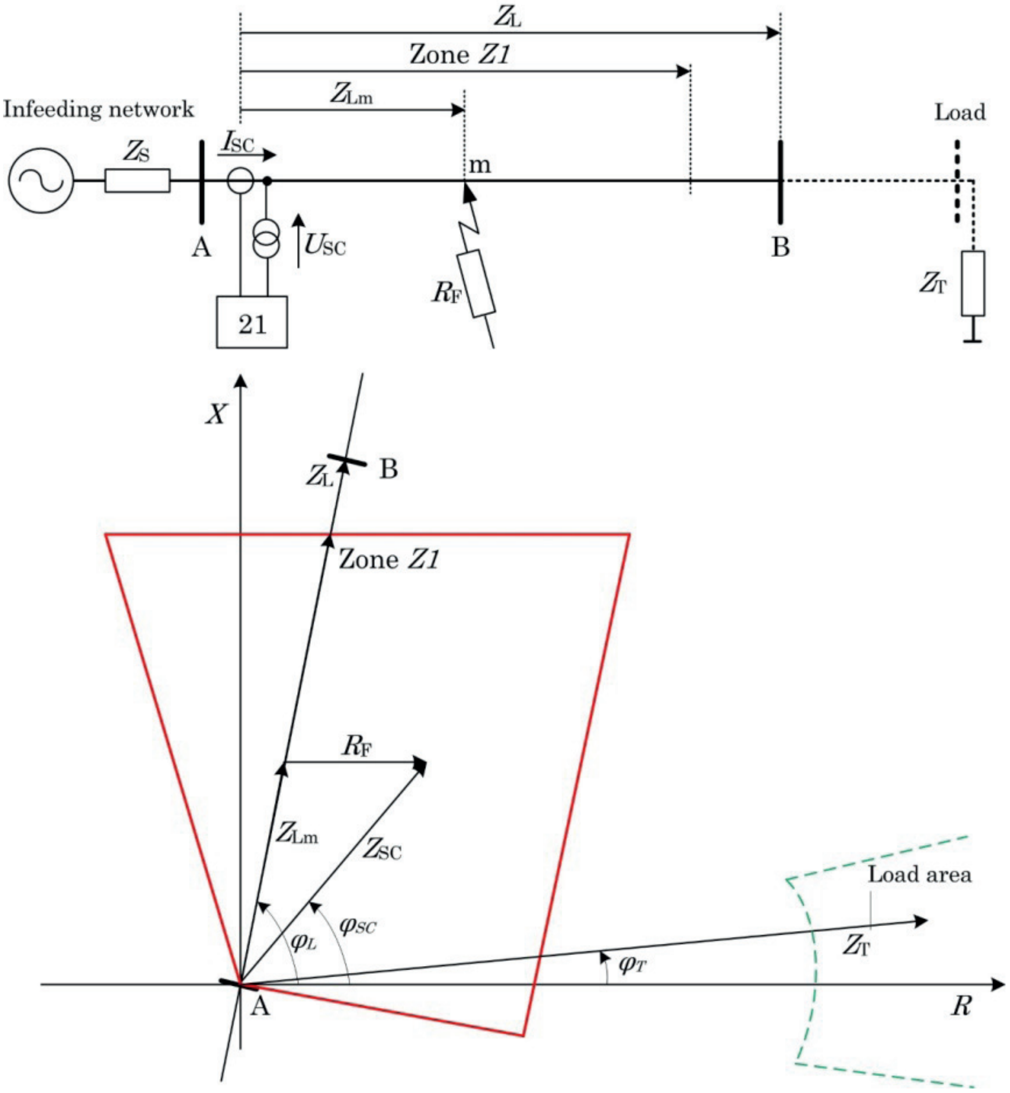


Figure 1 Distance protection fundamentals

2.1 Zones of Protection

Cautious choice of the reach settings and tripping times for different zones allow correct coordination between distance relays on a power system. Basic distance protection will compromise instantaneous directional Zone 1 protection and one or more time-delayed zones. Numerical distance relays may have more than five zones, some of which can be set to measure in the reverse direction. Typical settings for three forward-looking zones of basic distance protection are given in the following sub-sections.

2.1.1 Zone 1 Setting

Zone 1 is a high-speed, instantaneous zone with no deliberate delay and is typically set to provide 80-85 % coverage of a two-ended line. The resulting (15-20 %) safety margins ensure that there is no risk of Zone 1 protection over-reaching the protected line due to errors in the current and voltage transformers, inaccuracies in line impedance data provided for setting purposes (usually based on a calculation and not on a measurement) and errors of relay setting and measurement [3]. Otherwise, there would be a loss of discrimination with fast operating protection on the following line section. A time-delayed Zone 2 must cover the remaining 15-20 % of the line. Zone 1 should never overreach beyond the remote bus. Its tripping time approximately consists of one to two cycles (20 to 40 ms at 50 Hz) [2].

2.1.2 Zone 2 Setting

Distance protection additionally provides the option of backup protection for the adjacent line(s) (and for a failed Zone 1). The second stage (over-reaching zone) is used for this purpose. It reaches through the adjacent busbar and into the adjacent line(s). Additionally, it ensures full coverage of the line with allowance for the sources of error already listed (its primary purpose is to clear faults in the protected line beyond the reach of Zone 1).The reach setting of the Zone 2 is set to cover the protected line +50% of the shortest adjacent line at the remote bus or 120% of the protected line, whichever is greater. In many applications, it is common practice to set the Zone 2 reach to be equal to the impedance of the protected line section +50% of the shortest adjacent line. It ensures that the resulting maximum effective Zone 2 reach does not extend beyond the minimum effective Zone 1 reach of the adjacent line protection [1].

Zone 2 tripping time must be time-delayed to secure grading with the primary relay on the adjacent line(s) that fall within the Zone 2 reach. Thus complete coverage of a line section is obtained, with a fast clearance in the first80-85% of the line and somewhat slower clearance of faults in the remaining part of the line[3].The tripping time is approximately 250 to 300 ms [2].

2.1.3 Zone 3 Setting

Remote backup protection for all faults on adjacent lines can be provided by a third zone of protection which needs to be time delayed to discriminate with Zone 2 protection increased with trip time of circuit breaker for the adjacent line.

Zone 3 reach should cover at least 120% of the impedance given to the relay for a fault located at the remote end of the second line [1]. Zones 1 and 2 should never overreach the end of the remote line, and Zone 3 should never underreach it. Equally, Zones 1 and 2 are set using the actual impedance of the protected line, ignoring current infeed at the remote busbar, while Zone 3 must be set for a fault at the end of the remote line with maximum infeed conditions at the remote bus.

The Zone 3 distance element rarely needs to operate; however, it must not work during extreme loading conditions, stressed power system conditions, or slow power swings [3, 4]. All three zones are presented in Figure 2.

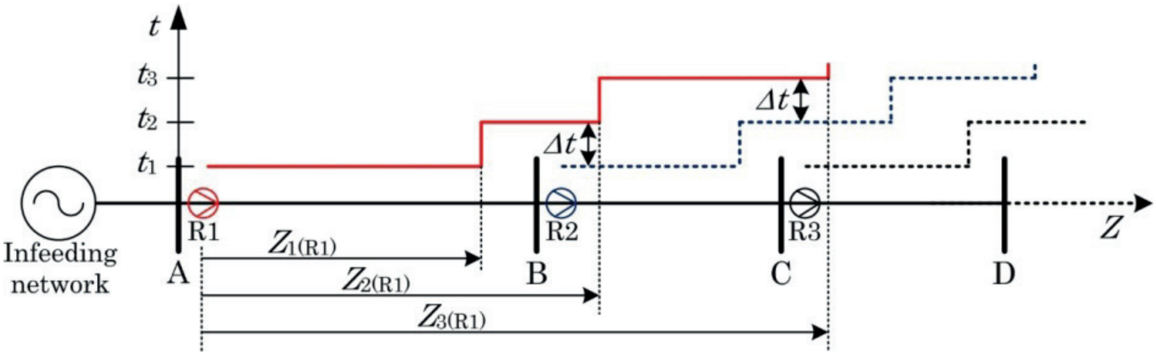


Figure 2 Zone reach and tripping time setting

2.2 Distance Relays Characteristics

Relay measurements are based on the comparison of either amplitude or phase quantities. In the case of a numerical relay, algorithms compare measured voltage and current. When plotted on a set of rectangular coordinates (resistance R as the abscissa and reactance X as the ordinate), the relay characteristics form geometric figures. Some of the most used characteristics are plain impedance characteristic, mho impedance characteristic, offset mho and lenticular characteristic, fully cross-polarised mho characteristic, partially cross-polarised mho characteristic and finally, a quadrilateral characteristic which is used by the SIPROTEC relay series.

2.2.1 Quadrilateral Characteristic

This form of polygonal impedance characteristic is shown in Figure 3. The characteristic consists of forward and resistive reach settings that are impartially changeable. As a result, it offers better resistive coverage than any mho-type characteristic for short lines. This is principally the case for earth fault impedance measurement, where the arc resistances and fault resistance to earth contribute to the highest values of fault resistance.

Regarding avoiding unnecessary mistakes in the zone reach accuracy, it is common to dictate a maximum resistive reach in regards to the zone impedance reach.

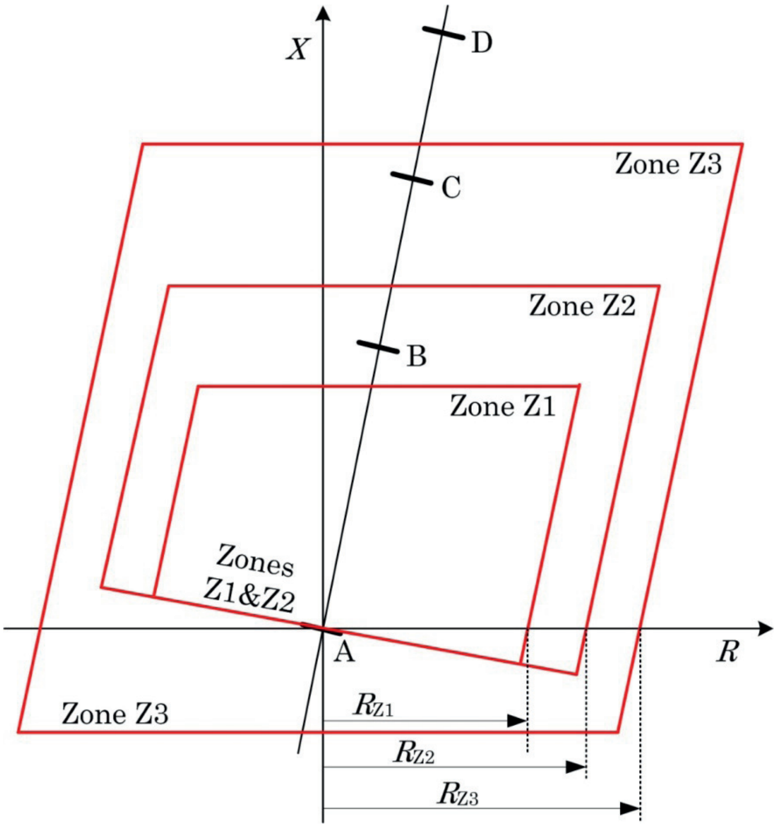


Figure 3 Quadrilateral characteristic

Quadrilateral elements with plain reactance reach lines can introduce reach error problems for resistive earth faults where the angle of total fault current differs from the angle of the measured current. This occurs when the local and remote source voltage vectors are phase shifted due to pre-fault power flow. However, it can be overcome by selecting an alternative use of a phase current for polarisation of the reactance reach line. Polygonal impedance characteristics are exceedingly flexible regarding fault impedance coverage for both phase and earth faults. Due to this, most digital and numerical distance relays now offer this form of characteristic [1].

2.3 Experimental Work

As one of the world's leaders in manufacturing protection equipment for power systems, Siemens has designed SIPROTEC relay series which was chosen for testing. It implements integrated protection, control, measurement and automation functions in the same device. Another benefit is the possibility of both local (via integrated keypad and display) and remote (via PC) control [7].

2.3.1 Distance Protection 7SA611 Relay

The following parameterisation and testing were performed on SIPROTEC 4 7SA611 relay which is used for protection of overhead lines and cables at all voltage levels from 5 to 400 kV. The unit also enables single-pole, three-pole and multiple auto-reclosures. Therefore, it can detect power swings and prevent non-selective tripping. 7SA6 contains a powerful 32-bit microprocessor which allows utterly numerical processing of all functions in one device, starting from the acquisition of the measured values to the output of commands to the circuit breakers. For the quick location of the damage to the line after a short circuit, there is an integrated fault locator which may also compensate for the influence of a parallel line and load [5]. The tripping characteristic is polygonal with separate setting along the X-axis (reach) and R-axis (arc resistance reserve) and separate R-setting for earth faults. Furthermore, it offers six distance zones, selectable as forward, reverse or non-directional reaching, and nine time stages [8].

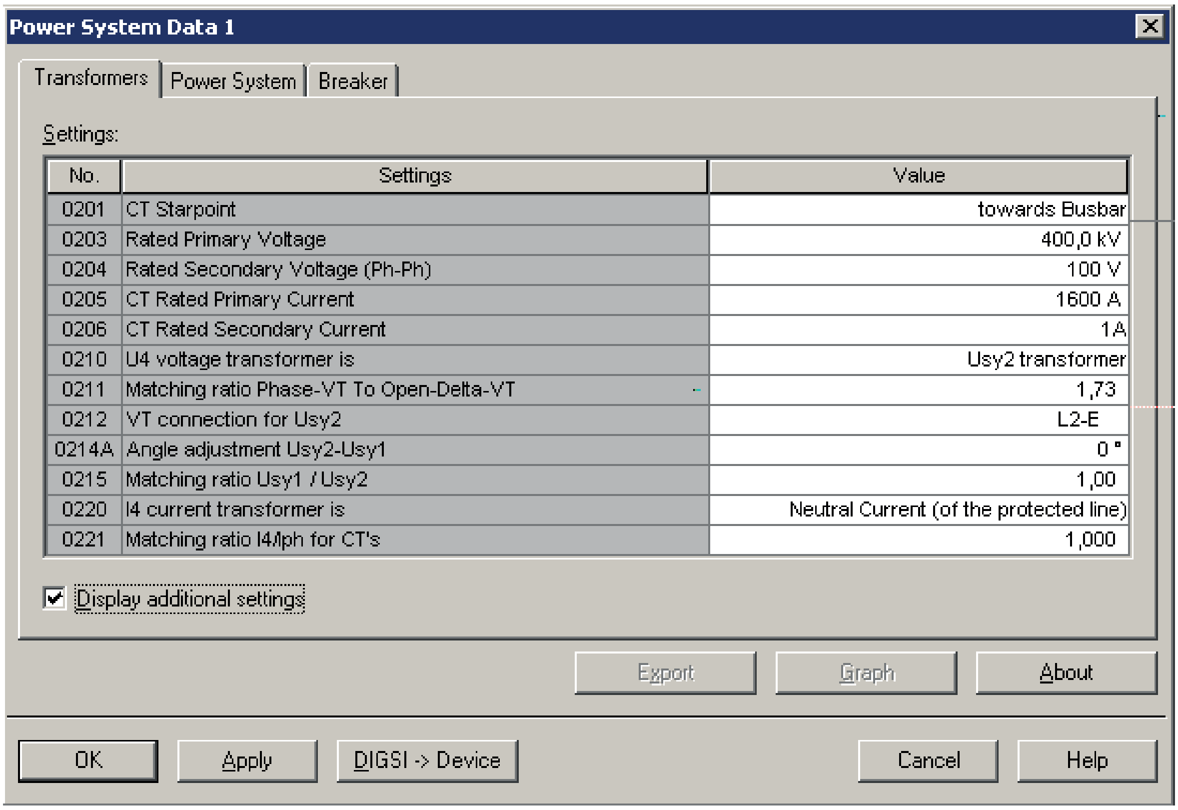
2.3.2 DIGSI software

The PC operating program DIGSI is the user interface to the SIPROTEC devices, regardless of their version. The word DIGSI is an abbreviation of a German expression "Digitalizer Simulator", which means a digital simulation of a relay [6]. Its design has a modern and intuitive user interface. It is often referred to as a powerful all-in-one tool for configuring, setting, testing and communicating with the device. Moreover, it offers the possibility to display signals from various fault records in one diagram and synchronise these signals to a common time base. In addition to finding out the details of the line fault, the localisation of the fault is of particular interest in order to save time used for on-site inspection of the fault.

2.3.3 Parameterising Distance 7SA611 Relay

There are two different approaches to parameterisation. The first one is to proceed in offline mode and later switch to online mode and transfer all the settings into the relay. The second one (used here) is to parameterise the relay directly, that is to say, as soon as settings are changed, they are immediately transferred to the relay. For this experiment, the relay parameterisation contains data of a real 400 kV line of the length of 79, 9 km (Figure 4).

Some of the critical parameterising settings necessary to set up correctly are considering transformers, power system, and circuit breakers as shown in the following figure.



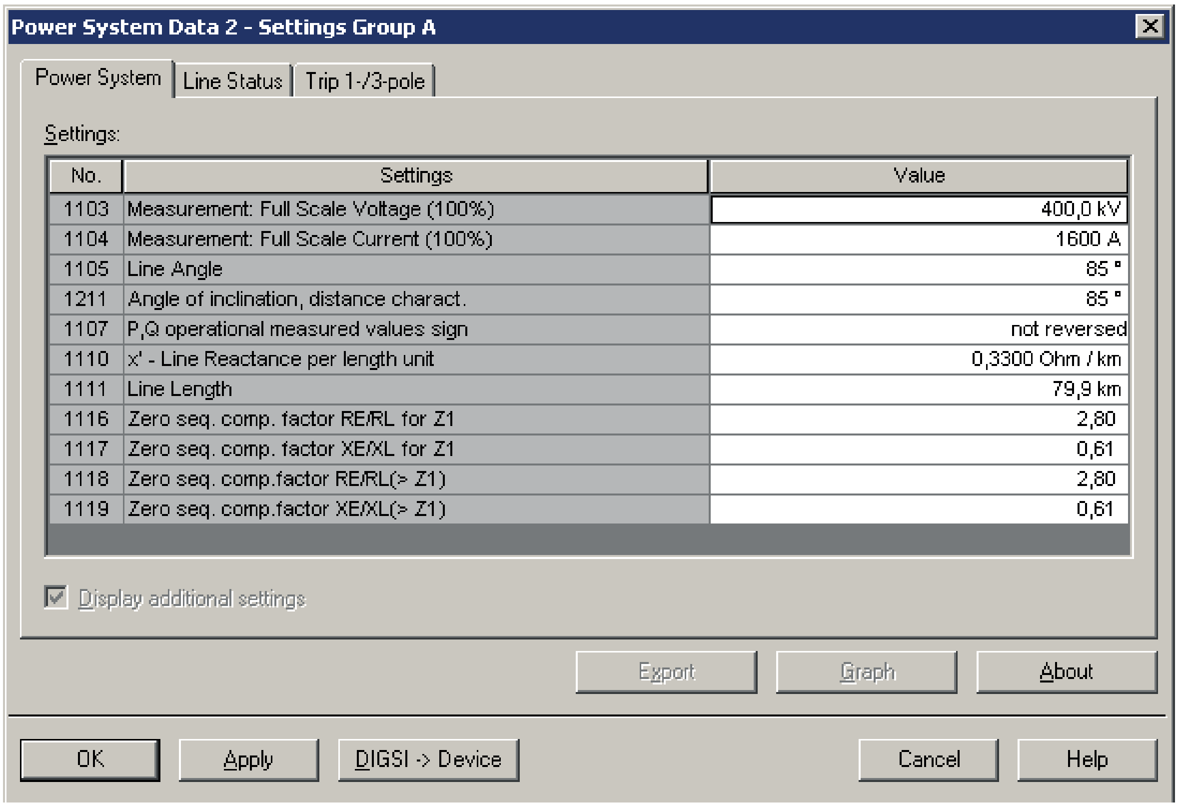
Settings:

No.	Settings	Value
0201	CT Starpoint	towards Busbar
0203	Rated Primary Voltage	400,0 kV
0204	Rated Secondary Voltage (Ph-Ph)	100 V
0205	CT Rated Primary Current	1600 A
0206	CT Rated Secondary Current	1A
0210	U4 voltage transformer is	Usy2 transformer
0211	Matching ratio Phase-VT To Open-Delta-VT	1,73
0212	VT connection for Usy2	L2-E
0214A	Angle adjustment Usy2-Usy1	0 °
0215	Matching ratio Usy1 / Usy2	1,00
0220	I4 current transformer is	Neutral Current (of the protected line)
0221	Matching ratio I4/Iph for CT's	1,000

☑ Display additional settings

Figure 4 Relay parameterising

Several further physical quantities are adjustable in different Settings Groups as shown in Figure 5.



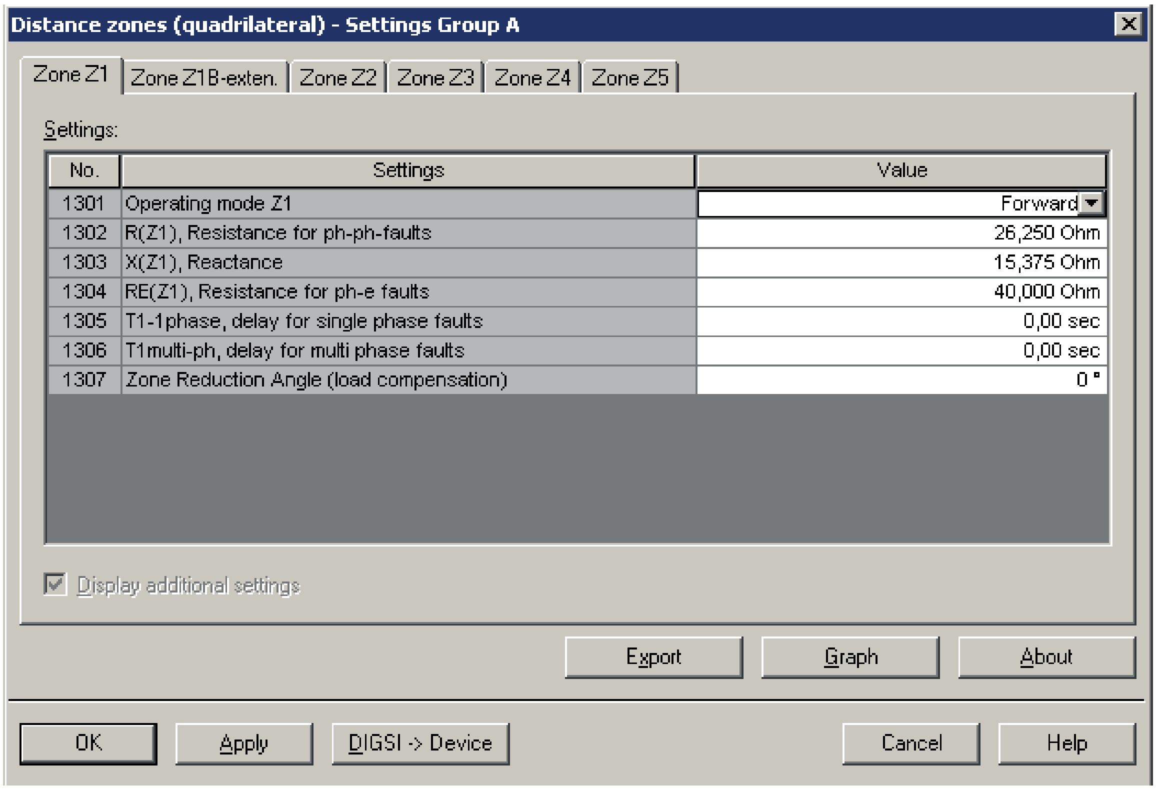
Settings:

No.	Settings	Value
1103	Measurement: Full Scale Voltage (100%)	400,0 kV
1104	Measurement: Full Scale Current (100%)	1600 A
1105	Line Angle	85 °
1211	Angle of inclination, distance charact.	85 °
1107	P,Q operational measured values sign	not reversed
1110	x' - Line Reactance per length unit	0,3300 Ohm / km
1111	Line Length	79,9 km
1116	Zero seq. comp. factor RE/RL for Z1	2,80
1117	Zero seq. comp. factor XE/XL for Z1	0,61
1118	Zero seq. comp.factor RE/RL(> Z1)	2,80
1119	Zero seq. comp.factor XE/XL(> Z1)	0,61

☑ Display additional settings

Figure 5 Relay settings group

As the calculation of the line impedance on a phase to ground loop is not possible only with measured values, additional information regarding the ratio, Z_L/Z_E needs to be provided to the relay. Here, it is assumed that the ratio is constant along the line. After individually setting the distance zones (Figure 6), a graph of the characteristic can be plotted (Figure 7) in which the dotted lines represent the tolerances of each zone. The type of the characteristic is quadrilateral, and although the reach of every single zone can be edited, the form of the characteristic cannot be changed once it is integrated into the relay. Additionally, it is possible to export the relay characteristic in an RIO File which then enables easy import into Omicron (test device used).



No.	Settings	Value
1301	Operating mode Z1	Forward
1302	R(Z1), Resistance for ph-ph-faults	26,250 Ohm
1303	X(Z1), Reactance	15,375 Ohm
1304	RE(Z1), Resistance for ph-e faults	40,000 Ohm
1305	T1-1phase, delay for single phase faults	0,00 sec
1306	T1multi-ph, delay for multi phase faults	0,00 sec
1307	Zone Reduction Angle (load compensation)	0 °

Figure 6 Distance zones settings

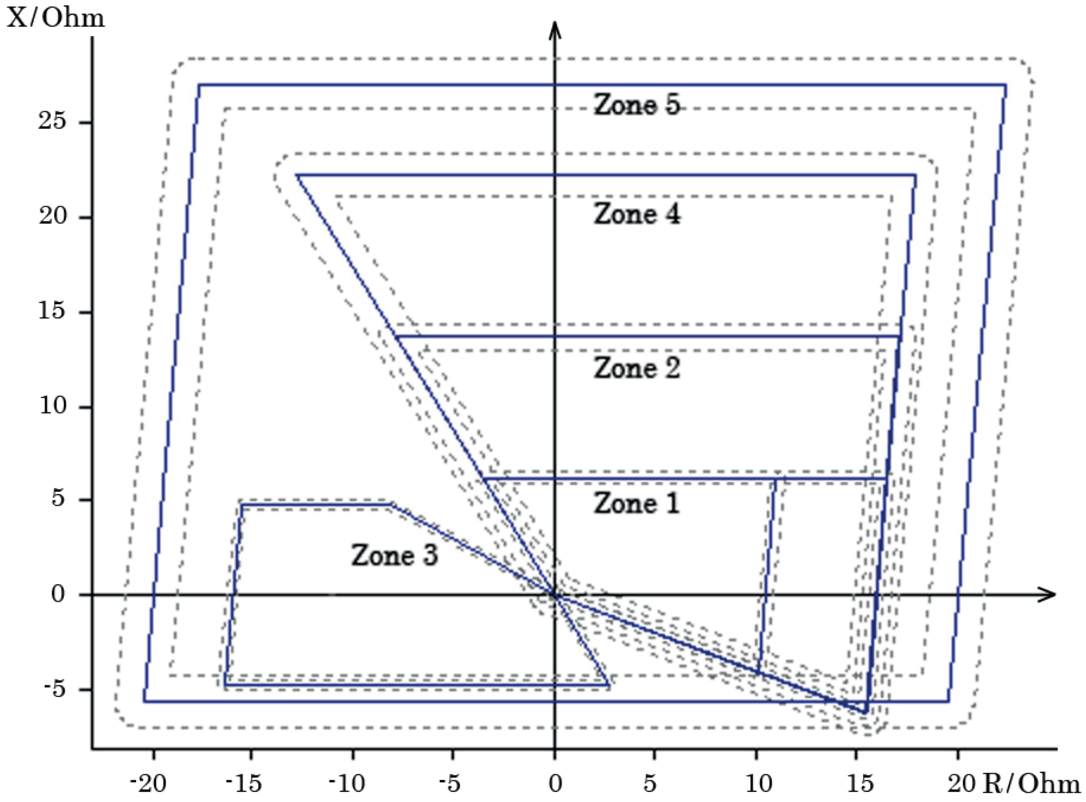


Figure 7 Relay characteristic

2.3.4 Testing Distance 7SA611 Relay

The relay was tested with Omicron CMC 56, a device created for testing all generations and types of protection relays. Its software, Test Universe, is a helpful tool for advanced secondary testing of protection and measuring devices. It enables a range of approaches, from manual to entirely automated and standardised tests, running on a PC or a laptop. For this testing process, the adequate test module was Distance.

It is possible to test each adjusted distance zone separately, or more zones at the same time. Different types of faults (one-pole, two-pole or three-pole short circuit) need to be tested independently. According to the previously set up parameters in DIGSI, the nominal values for tripping time for each zone are as following:

- for Zone 1: 0 ms (instantaneous),
- for Zone 2: 350 ms,
- for Zone 3: 800 ms,
- for Zone 4: 700 ms,
- for Zone 5: 1,5 s.

Table 1 Zone settings (Test Universe)

Label	Type	Fault loop	Trip time	Tol.Trel	Tol.T abs+	Tol.T abs-	Tol.Z rel.	Tol.Z abs
Z1	Tripping	L-L	0,000 s	1,000 %	100,0 ms	100,0 ms	5,000 %	100,0 mΩ
Z1	Tripping	L-E	0,000 s	1,000 %	100,0 ms	100,0 ms	5,000 %	100,0 mΩ
Z2	Tripping	L-L	350,0 ms	1,000 %	100,0 ms	100,0 ms	5,000 %	100,0 mΩ
Z2	Tripping	L-E	350,0 ms	1,000 %	100,0 ms	100,0 ms	5,000 %	100,0 mΩ
Z4	Tripping	L-L	700,0 ms	1,000 %	100,0 ms	100,0 ms	5,000 %	100,0 mΩ
Z4	Tripping	L-E	700,0 ms	1,000 %	100,0 ms	100,0 ms	5,000 %	100,0 mΩ
Z3	Tripping	L-L	800,0 ms	1,000 %	100,0 ms	100,0 ms	5,000 %	100,0 mΩ
Z3	Tripping	L-E	800,0 ms	1,000 %	100,0 ms	100,0 ms	5,000 %	100,0 mΩ
Z5	Tripping	L-L	1,500 s	1,000 %	100,0 ms	100,0 ms	5,000 %	100,0 mΩ
Z5	Tripping	L-E	1,500 s	1,000 %	100,0 ms	100,0 ms	5,000 %	100,0 mΩ

3. TEST RESULTS AND DISCUSSION

3.1 Testing Zone 1 for Single-Pole Short Circuits

Ten different impedances were tested and successfully passed the test as shown in the results from the Test Universe report.

As expected, the relay tripped for all impedances less than the Zone 1 impedance within the Zone 1 tripping time, whereas for the impedances bigger than the Zone 1 impedance, it tripped within the Zone 2 tripping time. Nominal tripping time for Zone 1 is instantaneous, and for Zone 2 equals 350 ms. In both cases, for every selected impedance, there was an inevitable time delay within the permitted tolerances which illustrates the real-life situations in power systems.

Test results consist of the value and the angle of the impedance, nominal and activating time of the relay, time deviation and the decision of the testing as presented in the following figure.

Table 2 Zone 1 test results for one-pole short circuit

| Z |	Phi	t nom	t act.	Dev.	ITest	Result
5,869 Ω	85,00 °	0,000 s	33,60 ms	33,60 ms	2,000 A	Passed
6,062 Ω	74,86 °	0,000 s	34,20 ms	34,20 ms	2,000 A	Passed
6,602 Ω	63,76 °	0,000 s	34,00 ms	34,00 ms	2,000 A	Passed
7,459 Ω	50,00 °	0,000 s	34,00 ms	34,00 ms	2,000 A	Passed
8,494 Ω	42,89 °	0,000 s	34,30 ms	34,30 ms	2,000 A	Passed
6,575 Ω	94,58 °	350,0 ms	384,1 ms	9,743 %	2,000 A	Passed
6,596 Ω	85,00 °	350,0 ms	383,7 ms	9,629 %	2,000 A	Passed
6,834 Ω	73,55 °	350,0 ms	384,3 ms	9,8 %	2,000 A	Passed
7,263 Ω	64,47 °	350,0 ms	383,5 ms	9,571 %	2,000 A	Passed
8,890 Ω	46,83 °	350,0 ms	383,8 ms	9,657 %	2,000 A	Passed

Furthermore, if the test impedances successfully pass the test, they become visually green in the graph (Figure 8).

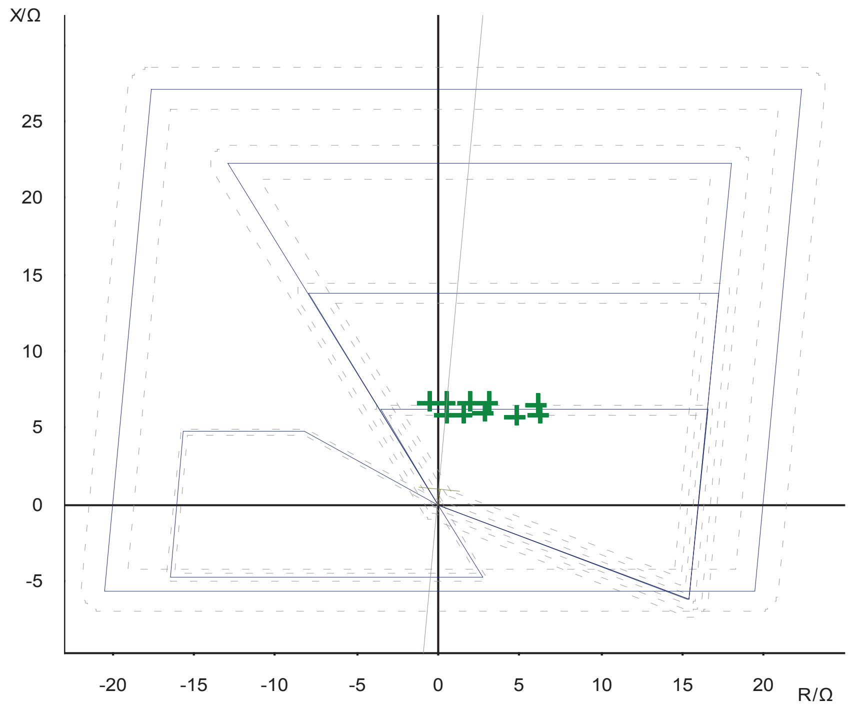


Figure 8 One-pole short circuit (Zone 1 test)

Further fault analysis results become available as well, such as fault physical quantities. These test results point out the voltage and the current of the fault, and consequently, show that the fault had occurred in Phase One.

Table 3 Physical quantities for one-pole short circuit

VL1:	50,7V	0,00 °
VL2	57,7V	-120,00 °
VL3:	57,7V	120,00 °
IL1:	2,00A	-24,31 °
IL2:	0,00A	n/a
IL3:	0,00A	n/a
VFault:	50,7V	0,00 °
IFault:	2,00A	-24,31 °

Additional graphs of fault voltage and current, as well as tripping time of the relay, are available for analysis.

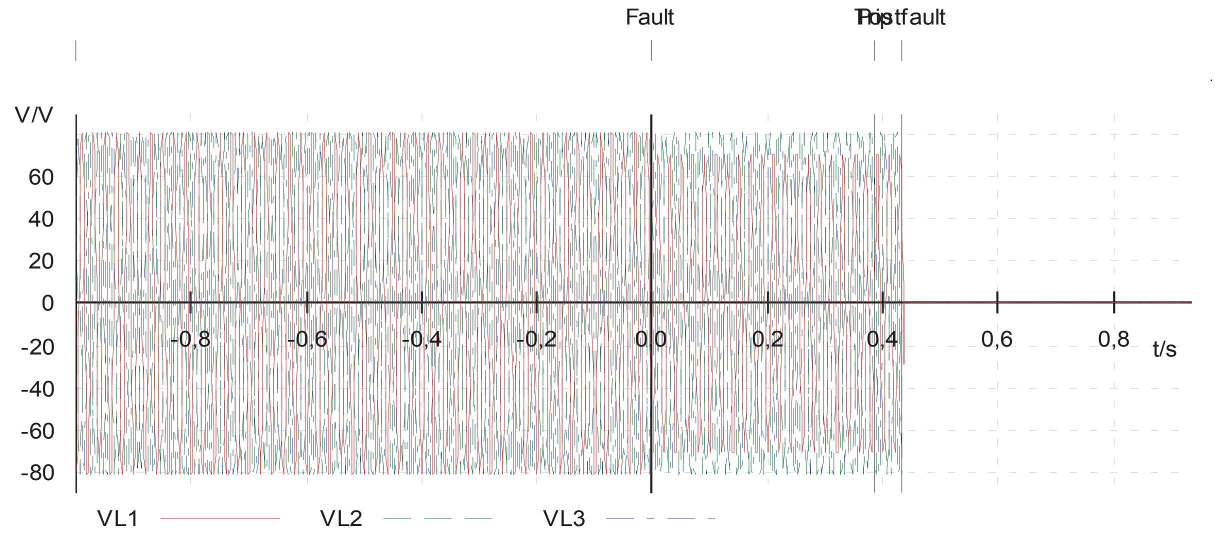


Figure 9 Short circuit voltage

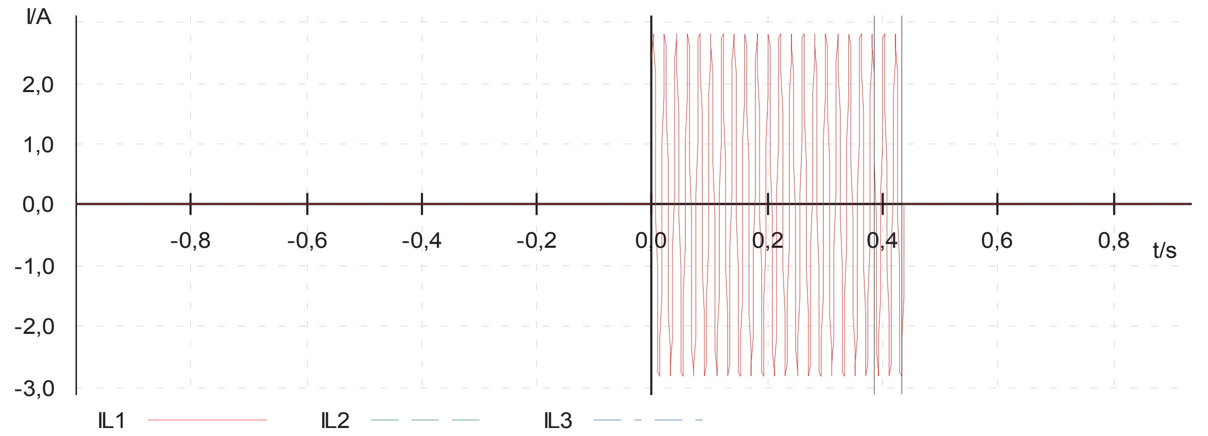


Figure 10 Short circuit current

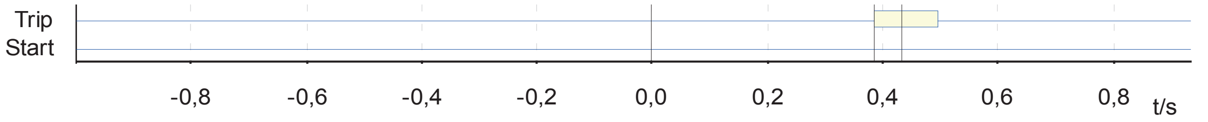


Figure 11 Relay tripping time

3.2 Testing Zone 3 for Single-Pole Short Circuits

As shown in the graph below, Zone 3 was set to have a reversed direction. As a result, it provides distance protection against faults behind the relay (busbar) of the protected transmission line. It is also the reason that the Zone 4 tripping time can be less than the Zone 3 tripping time; otherwise, the zones would not discriminate.

Eight impedances selected are located within the Zone 3 setting, and one within Zone 5 and its relay tripping time, thus, equals the Zone 5 nominal time increased with time deviation.

Table 4 Zone 3 test results for three-pole short circuit

| Z |	Phi	t nom	t act.	Dev.	ITest	Result
8,402 Ω	150,00 °	800,0 ms	855,4 ms	6,925 %	2,000 A	Passed
7,174 Ω	150,00 °	800,0 ms	859,7 ms	7,462 %	2,000 A	Passed
5,855 Ω	150,00 °	800,0 ms	853,8 ms	6,725 %	2,000 A	Passed
4,000 Ω	150,00 °	800,0 ms	860,0 ms	7,5 %	2,000 A	Passed
2,649 Ω	160,00 °	800,0 ms	834,2 ms	4,275 %	2,000 A	Passed
2,455 Ω	140,00 °	1,500 s	1,553 s	3,56 %	2,000 A	Passed
4,776 Ω	150,00 °	800,0 ms	853,9 ms	6,738 %	2,000 A	Passed
6,334 Ω	150,00 °	800,0 ms	854,2 ms	6,775 %	2,000 A	Passed
8,000 Ω	150,00 °	800,0 ms	853,9 ms	6,738 %	2,000 A	Passed

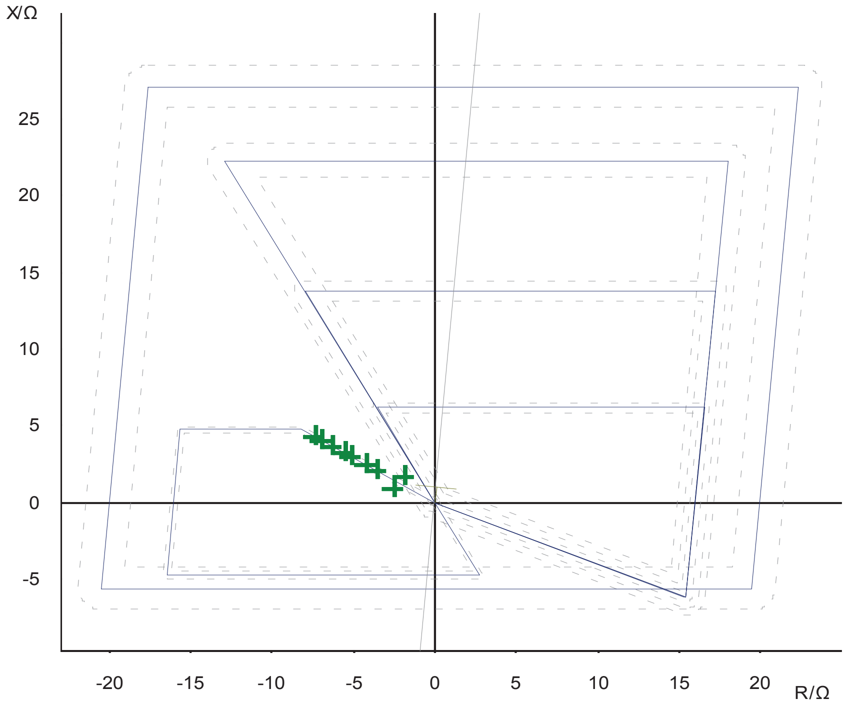


Figure 12 Three-pole short circuits (Zone 3 test)

3.3 Testing Zone 4 for Three-Pole Short Circuits

Due to Omicron's restraints, tests for Zones 4 and 5 were only possible for three-pole short circuits; otherwise, impedances selected would appear to be out of range. In this experiment, six impedances were less than the Zone 4 impedance. Hence the tripping times corresponded to the tripping time of the Zone 4 (nominal time 700 ms + time deviation). On the other hand, the remaining four impedances selected were higher than the Zone 4 impedance and their tripping times consequently corresponded to the tripping time of the Zone 5 (nominal time 1, 5 s + time deviation) as expected. For all the impedances selected, the relay tripped within the correct times, depending on the zone.

Table 5 Zone 4 test results for three-pole short circuit

| Z |	Phi	t nom	t act.	Dev.	ITest	Result
21,20 Ω	82,85 °	700,0 ms	733,5 ms	4,786 %	2,000 A	Passed
21,25 Ω	85,00 °	700,0 ms	734,2 ms	4,886 %	2,000 A	Passed
21,12 Ω	92,00 °	700,0 ms	734,1 ms	4,871 %	2,000 A	Passed
21,55 Ω	79,30 °	700,0 ms	733,6 ms	4,8 %	2,000 A	Passed
21,96 Ω	74,68 °	700,0 ms	733,5 ms	4,786 %	2,000 A	Passed
24,55 Ω	60,00 °	700,0 ms	733,6 ms	4,8 %	2,000 A	Passed
26,26 Ω	62,80 °	1,500 s	1,534 s	2,28 %	2,000 A	Passed
25,23 Ω	70,00 °	1,500 s	1,534 s	2,26 %	2,000 A	Passed
23,52 Ω	85,00 °	1,500 s	1,540 s	2,667 %	2,000 A	Passed
24,00 Ω	100,00 °	1,500 s	1,554 s	3,567 %	2,000 A	Passed

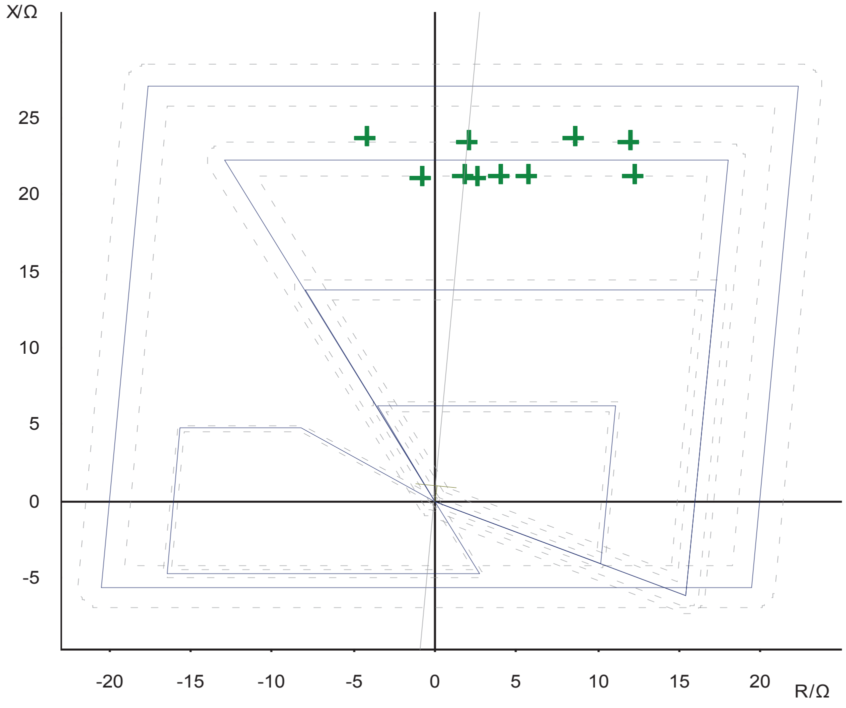


Figure 13 Three-pole short circuits (Zone 4 test)

3.4 Testing the Complete Characteristic for Three-Pole Short Circuits

In this test, impedances were selected within various zones of the polygonal relay characteristic and understandably, the tripping times were different as well.

Bearing in mind that the largest zone determines the fault detection characteristic of the relay, for two tested impedances which are bigger than the Zone 5 impedance, as predicted, there was no trip. This means that these impedances are not part of the protected area and that the protection of this relay will not interfere with the protection of another relay protecting that area.

For other cases there was always a trip within the nominal tripping time of the corresponding zone, increased with time deviation within permissible tolerances. The quickest way to establish which fault impedance belongs to which zone is by its nominal tripping time. From the results summary, it is evident that the first fault is located within Zone 1 reach (instantaneous trip), following three faults are part of Zone 2, further two fit within the Zone 4 reach, and the next two within Zone 5. Additionally, there is a no trip case for an impedance outside of the protected area, and there are two simulated faults within the Zone 3 (reversed direction zone), another one within the Zone 5, and finally, the last case simulated a fault located outside of the characteristic.

Table 6 Complete characteristic test results for three-pole short circuit

| Z |	Phi	t nom	t act.	Dev.	ITest	Result
5,808 Ω	85,00 °	0,000 s	34,30 ms	34,30 ms	2,000 A	Passed
6,329 Ω	80,00 °	350,0 ms	389,8 ms	11,37 %	2,000 A	Passed
6,758 Ω	85,00 °	350,0 ms	389,8 ms	11,37 %	2,000 A	Passed
13,53 Ω	85,00 °	350,0 ms	383,6 ms	9,6 %	2,000 A	Passed
14,24 Ω	85,00 °	700,0 ms	734,2 ms	4,886 %	2,000 A	Passed
21,93 Ω	85,00 °	700,0 ms	734,5 ms	4,929 %	2,000 A	Passed
22,89 Ω	85,00 °	1,500 s	1,534 s	2,24 %	2,000 A	Passed
22,33 Ω	26,43 °	1,500 s	1,534 s	2,253 %	2,000 A	Passed
24,00 Ω	24,74 °	no trip	no trip		2,000 A	Passed
659,1 mΩ	-95,00 °	800,0 ms	819,0 ms	2,375 %	2,000 A	Passed
3,591 Ω	-95,00 °	800,0 ms	813,6 ms	1,7 %	2,000 A	Passed
5,204 Ω	-95,00 °	1,500 s	1,534 s	2,287 %	2,000 A	Passed
6,387 Ω	-95,00 °	no trip	no trip		2,000 A	Passed

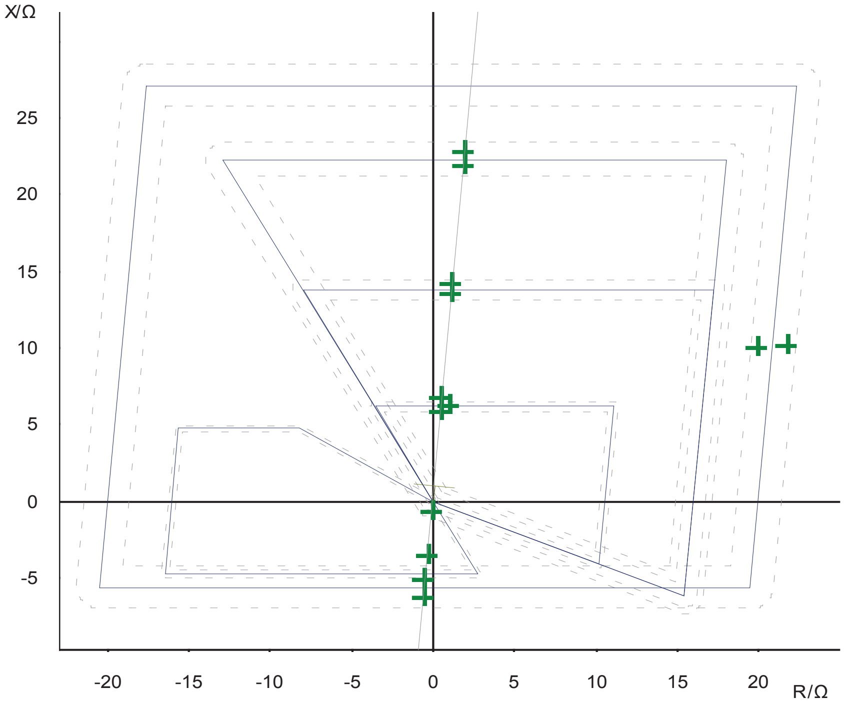


Figure 14 Three-pole short circuits (complete characteristic test)

4. CONCLUSION

This study set out to describe the principles of transmission lines distance protection and to emphasize the importance of correct relay parameterizing as it is crucial for the security and stability of any power system. The challenge today is to implement cost-efficient solutions in modern, intelligent and smart grids where communication and monitoring of the system would enable optimal functioning of power systems across the globe. Hence, setting the adequate protection systems, to provide selective tripping, will minimize the extent and time of the outage. Their communication protocols and precise determination of the fault location, therefore, contribute to the reduction of the on-site inspection time.

In this investigation, the aim was to evaluate adequate zone reach settings and corresponding tripping times of a numerical distance relay and to illustrate the selectivity between different zones of the characteristic.

The results of this study indicate that correct reach settings and tripping times of different zones result in the selective acting of a relay on the protected transmission line and further adjacent line(s), whether in forward or reversed direction. The analysis undertaken here has also confirmed our knowledge on the basic protection principles and applied it to a specific relay type.

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