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PERFORMANCES ANALYSIS OF NUMERICAL PROTECTIVE RELAY 7SA612

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Abstract: This article presents the performances analysis of numerical relay 7SA612, used for protection of high voltage overhead transmission lines. Although the main function of 7SA612 relay is the distance protection, it offers a multitude of protection functions, such as fault locator, directional earth–fault protection, synchronization check or selection of single/three pole auto–reclosing. The analysis was based on the simulation results, during induced fault testing, using the computer–controlled Omicron CMC 356 set. In the case of distance protection, several tests were accomplished both in the case of double–phase and three–phase faults. Omicron CMC 356 testing set provided great fidelity to real power system. Using the fault report, the user can examine the relay operation every time the system conditions are changed. The simulation results proved the correct operation of numerical protective relay 7SA612 for all induced faults. In all situations, the tested numerical relay operated reliably and selectively, with very small fault clearing times.
Keywords: protective relaying, distance protection, poly–phase faults

1. INTRODUCTION

Any protection system must ensure the performances as regards selectivity, speed of faults clearing, reliability and safety with respect to the people and the goods [1,2].

In High Voltage (HV) and Extra High Voltage (EHV) networks, the speed of faults clearing is essential to maintain the power quality (in term of long, short, very short interruptions, or voltage dips), because in these cases the electromagnetic disturbances affect very much the underlying transmission and distribution systems [3].

Transmission lines are some of the most important, but critical, power system components, because they cover large distances, are exposed to different climate conditions and may present a high failure rate [1]. The basic protection of HV transmission lines is distance protection, because of its simplicity and other advantages, such as reduced dependence of sensitivity on the network operation regime, tripping time shorter as the faults is closer to the protective relay location, etc. [1–11].

Conventional distance protection is based on impedance measurement elements that estimate the line impedance from the relay location to the fault using voltage and current phasors [1].

Compared to electromechanical relays or static relays, numerical distance relays offer a high level of precision, sensitivity and flexibility [2,5–9]. Self–supervision functions of numerical relays increase their continuity in operation and reduce duration and frequency of maintenance operations. In addition to the protection functions, numerical relays allow the recording of disturbances that occur in network (perturbograph function) and the diagnosis of connected devices (e.g. circuit breakers) [5,6]. Moreover, numerical relays allow communication in local dedicated area network and human–machine communication, and can be connected in a control system at local and central level [2].

The performances of numerical distance protection relays are influenced by many factors. In [10,11] are studied the errors that can affect the accuracy of fault impedance measurement due to certain fault variables, such as fault resistance, type and fault location. In addition, reference [12] takes into account other dynamic factors, switching angle and source impedance ratio; in [13] is analyzed the effect of arcing fault on distance protection operation.

Power quality deterioration represents a significant factor impacting numerical protection system behaviour; references [14–16] deal with the effects of harmonics and frequency deviation on numerical distance relays operational performances.

The operating range of numerical protective relays changes if the network conditions change. For instance, the change of network topology or load value lead to false trips [2,3].

In recent years, as an alternative to conventional distance protection, have been developed artificial intelligence, like the neural networks [17–20] and fuzzy logic based algorithms [21–23], since they present very promising results with regards to precision and operating time. The neural relays have higher accuracy than the conventional relays in detecting the fault (location, type and phase of the fault). Moreover, the number of linear relays can be reduced by using neural technologies [19,20].

The main purpose of this study was the analysis of distance protection performances for numerical relay 7SA612, in order to validate this relay, and also prove the effectiveness of schemes and protection settings in the case of 220 kV overhead transmission lines (OTLs) that starting from Mintia electric station.

The organization of this paper is as follows: Section 2 presents the features and main functions of numerical relay 7SA612, Section 3 presents the experimental setup and the induced fault testing of this relay, and finally, in Section 4 are the conclusions.

2. NUMERICAL PROTECTIVE RELAY 7SA612

Numerical relay 7SA612 (SIEMENS SIPROTEC) can be used for protection of OTLs and cable lines whose voltage levels are from 5 kV to 765 kV, and their length varies from 10 km to 300 km [24].

Besides the main function, the non–switched distance protection with 6 measuring systems (21/21N), numerical relay 7SA612 also has many complementary protection functions, such as: fault locator (FL), directional earth–fault protection (50N/51N/67N), backup overcurrent protection (50/51/67), STUB–bus overcurrent protection (50 STUB), breaker–failure protection (50BF), power swing detection/tripping (68/68T), overvoltage/undervoltage protection (59/27), over/underfrequency protection (81O/U), synchronization check (25) and selection of single/three pole auto–reclosing (79) [24]. The fault locator function is a very important feature of 7SA612 numerical relay, because in the case of persistent faults on long OTLs it is imperative to identify the problem area and take measures to restore power circulation on the line [1,24].

This numerical relay has implemented logics that permit the application of several protection schemes: Permissive Overreaching Transfer Trip (POTT), Permissive Underreaching Transfer Trip (PUTT), Unblocking/Blocking, Weak Infeed protection, etc. [24].

The operation of distance protection is based on the measurement of fault loop impedance (from the relay location to the point where the fault occurred) [1].

The 7SA612 relay successively compares the impedance of fault loop with some set impedances, which reflect the length of the protected zones. When the measured fault loop impedance is smaller than the impedance setting, the 7SA612 relay will detect an internal fault and send a trip signal (one or three–pole) to the circuit breaker to isolate the faulted OTL [1,2,24].

The operating time of distance protection depends on the distance between the relay location and the fault location (Figure 1). Fundamental distance protection contain an instantaneous directional zone (Zone 1) and more time-delayed zones [1,2]. Basically, distance protection commands tripping of circuit breaker with a longer delay the greater distance to fault location (Figure 1) [1,2]

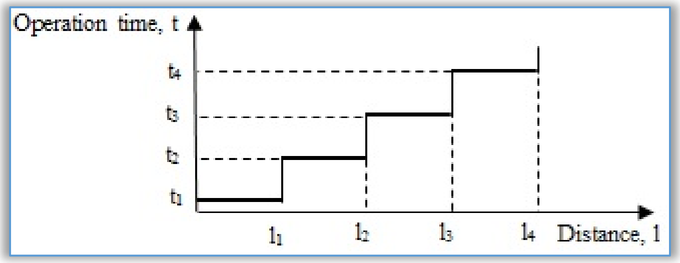

Figure 1. Stepped characteristic of a distance protection [1]

In the case of internal fault, distance protection must to operate as fast as possible [1,2]. Also, distance protection must be able to discriminate between internal and external faults to prevent unnecessary disconnection of the healthy OTLs [1,2].

Distance protection can realize the time–delayed clearing of faults on the adjacent lines, which for various reasons are not disconnected by their own circuit breakers. Thus, the distance protection of a line constitutes at the same time backup protection for the adjacent elements of the neighboring lines [1,2].

For 7SA612 relay are available five independent distance zones (Z1...Z5) and one separate overreach zone (Z1B), that protects 120% of the OTL and is used in tele protection logic and auto–reclosing. In the case of 7SA612 relays that protect the 220 kV OTLs starting from Mintia electric station, Z3 zone was set to sense in the reverse direction (towards the 220 kV bars), Z1, Z2, Z4 zones were set to forward (towards the OTL) and Z5 zone was non–directional [24].

The quadrilateral tripping characteristic (Figure 2) offers special advantages in the case of long and very charged lines [24]. In order to prevent the unwanted tripping in load operation, in the relay tripping

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characteristic (Figure 2) is excluded a load area that corresponds to the maximum load with the highest power factor; the load area represents a trapezoid, characterized by R_{Load} and φ_{Load} [24].

To discern the type of fault, the 7SA612 numerical relay measures the neutral voltage displacement and the zero-sequence component of current and compares it to the negative-sequence component of current [24].

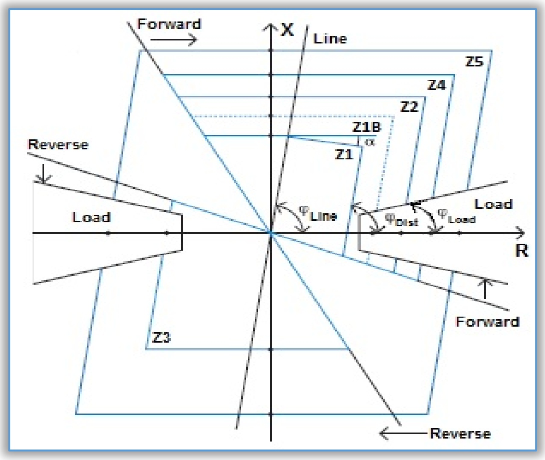

Figure 2. Quadrilateral characteristic of numerical relay 7SA612 [24]

3. DISTANCE PROTECTION PERFORMANCES ANALYSIS

The tests were carried out with the assistance of Omicron CMC 356 set [25] and Test Universe (this test software was developed by Omicron), at the mounting location of 7SA612 relay [9]. We connected the CMC 356 set to the secondary circuit of the cell where the tested relay 7SA612 was mounted [9]. The test setup aimed to inject transient signals into 7SA612 numerical relay and to measure the operating time of the relay [9].

The hardware connection between Omicron CMC 356 and the tested relay consisted of two three–phase analog signals (voltages and currents) and two binary signals (trip and pick–up). Thus, the Omicron CMC 356 set was used to generate transient signals (voltages, currents) and inject them into the tested relay. To ensure that the relay will measure voltages and currents similar to the one in the real OTLs, the injected signals must have a good accuracy and resolution [9].

Also, the Omicron CMC 356 set was used to monitor the reaction (analog and binary) of tested relay [9].

Relay settings can be done automatically or manually in both primary and secondary sides. To be able to program and communicate with numerical relay 7SA612 were used DIGSI software, the graphic tool to manage components of the SIEMENS systems protections. Thus, we used DIGSI software to configure the tested relay and set the protection functions [9].

DIGSI software can automatically draw the quadrilateral characteristic of 7SA612 relay. A special advantage is the fact that reactance X and resistance R can be set separately in the protection characteristic of tested relay, which provides fault impedance coverage for both phase to phase and phase to earth faults; this characteristic allow an optimal performance in the case of faults with fault resistance [24].

The testing of protection zones was done in Test Universe software. Test Universe controls the test signals, generates data entries, processes the measurement data and generates the reports [9].

The choice of the faults to be simulated was made with the purpose to cover the worst events that occur in HV OTLs. Some of the most important results will be presented further.

Simulation of Double–Phase Fault on Zone 1 of Distance Protection, in the Case of 220 kV Mintia–Timişoara OTL

First were simulated double–faults (R–S, S–T, T–R) on zone 1 of distance protection, with tele protection and auto–reclosing functions cancelled. The protected OTL Mintia–Timişoara had the following parameters: line length 130.02 km; line angle 80°; rated current I_n=1600 A.

Positive–sequence impedance and zero–sequence impedance of analyzed OTL were:

$$\underline{Z}_d = 8.779 + j \cdot 52.785 \ \Omega/\text{phase} \quad (1)$$

$$\underline{Z}_h = 41.75 + j \cdot 156.269 \ \Omega/\text{phase} \quad (2)$$

Zero–sequence compensation factors were:

$$R_E/R_L=1.25, \ X_E/X_L=0.65 \quad (3)$$

In (3) R_L, X_L represents the resistance and the reactance of power line, and R_E, X_E represent the resistance and the reactance of return conductor.

The line circuit breaker had the following settings: trip time 50 ms; close time 100 ms. The transformation ratios of measuring transformers were: 220 kV/100 V (max. 120 V, for voltage transformers); 1.2 kA/1 A (max. 10 A, for current transformers).

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Table 1 – Settings of distance protection

Distance protection zones	R (Ω/phase) poly–phase faults	X (Ω/phase) poly–phase faults	R_E (Ω/phase) earth faults
Z1	35	45	35
Z1B	35	65	55
Z3	10	4	10
Z2	35	65	55
Z4	35	80	55
Z5	35	140	55

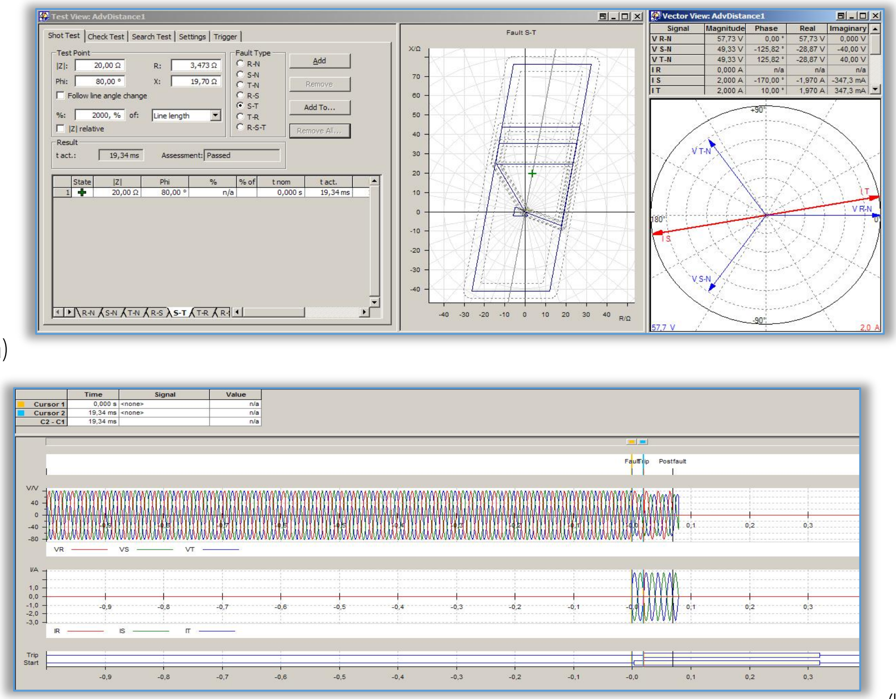
Table 2 – Settings of distance protection zones and allowed tolerances for OTL Mintia–Timişoara

Distance protection zones	Fault loop	Trip time (operating time of zones)	Relative tolerance for time steps	Absolute tolerance for time steps	Relative tolerance for measured impedance, Z_{rel}	Absolute tolerance for measured impedance, Z_{abs}
Z1 (zone 1)	L–L	0 s	1%	±100 ms	5%	100 mΩ
Z1 (zone 1)	L–N	0 s	1%	±100 ms	5%	100 mΩ
Z1B (overreach zone 1)	L–L	0 s	1%	±100 ms	5%	100 mΩ
Z1B (overreach zone 1)	L–N	0 s	1%	±100 ms	5%	100 mΩ
Z3 (zone 3)	L–L	600 ms	1%	±100 ms	5%	100 mΩ
Z3 (zone 3)	L–N	600 ms	1%	±100 ms	5%	100 mΩ
Z2 (zone 2)	L–L	800 ms	1%	±100 ms	5%	100 mΩ
Z2 (zone 2)	L–N	800 ms	1%	±100 ms	5%	100 mΩ
Z4 (zone 4)	L–L	1.2 s	1%	±100 ms	5%	100 mΩ
Z4 (zone 4)	L–N	1.2 s	1%	±100 ms	5%	100 mΩ
Z5 (zone 5)	L–L	2.4 s	1%	±100 ms	5%	100 mΩ
Z5 (zone 5)	L–N	2.4 s	1%	±100 ms	5%	100 mΩ

Table 1 and Table 2 present the settings of distance protection zones and allowed tolerances for OTL Mintia–Timişoara.

7SA612 relay is set to perform oscillographic fault records at the start of any protection function. Test reports gave complete information about the operation of analyzed protection. All analog quantities (voltages, currents) of OTL in the pre–fault (1 s), fault (maximum 6 s) and post–fault (500 ms) periods can be analyzed as waveforms, phasor diagrams and positive, negative and zero–sequences.

Figure 3 presents the results simulation of double–phase fault S–T on the 220 kV OTL Mintia–Timişoara.



(a)

(b)

Figure 3. Simulation of double–phase fault (S–T) on the 220 kV OTL Mintia–Timişoara:
a – setting of test point and phasors diagram during the fault testing; b – analog and digital values during the fault testing

In the case of double–phase fault S–T on the 220 kV OTL Mintia–Timişoara (Figure 3), test report reveals the following information:

- voltages of faulty phases decreases: VL2=49.33 V (∠–125.82°), VL3 = 49.33 V (∠125.82°), but voltage of phase 1 (R) is normal: VL1 = 57.73 V (∠0°);
- currents of faulty phases (I_S, I_T) are very high (in a real fault), have the same rms value, but are in phase opposition;
- there are no zero–sequence components of voltages and currents, but appear the negative–sequence component of voltage and current (V2 = 5.774 V; I2 = 1.155 A);
- double–phase short–circuit is an unsymmetrical fault.

In the case of double–phase fault simulation it is found that time operation of protection (19.34 ms, Figure 3.b) is lower than the absolute tolerance allowed (100 ms), so the test is passed.

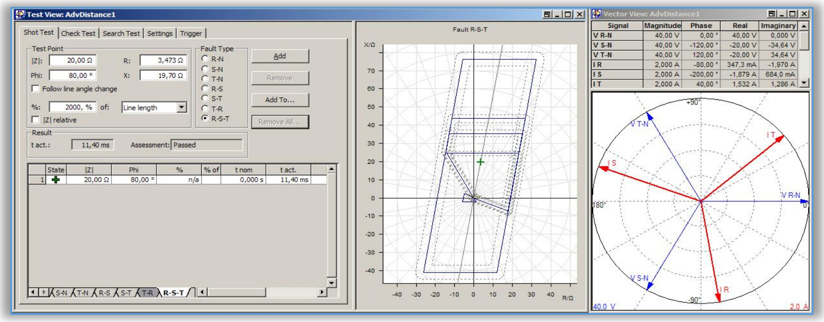
Simulation of Three–Phase Fault on Zone 1 of Distance Protection, in the Case of 220 kV Mintia–Timişoara OTL

Figure 4 presents the results simulation of three–phase fault R–S–T on the 220 kV OTL Mintia–Timişoara, with tele protection and auto–reclosing functions cancelled.

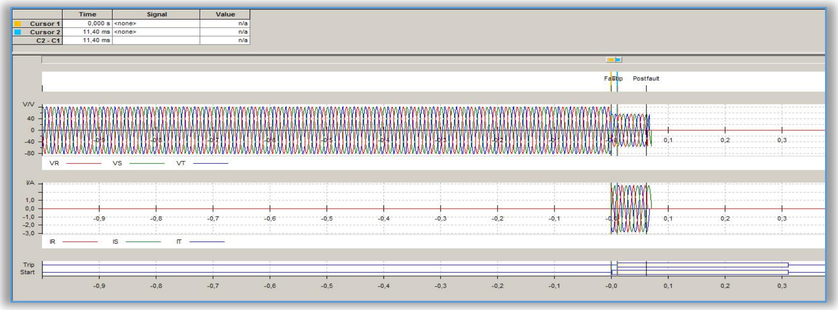
Test report in the case of three–phase fault simulation reveals the following information:

- voltages and currents are symmetrical systems, but their rms values and initial phases change from normal operation, prior to the fault;
- rms values of phase voltages decrease during the fault;
- phase shift between short–circuit currents and phase voltages is 80°;
- in a real regime, the rms values of currents for three–phase short–circuit are higher than rms values for double–phase short–circuit;
- it does not exist zero–sequence and negative–sequence components of voltages and currents, three–phase short–circuit being a symmetrical fault.

Because the time operation of protection (11.4 ms, Figure 4.b) is lower than the absolute tolerance allowed (100 ms), the test is passed.



(a)



(b)

Figure 4. Simulation of three–phase fault (R–S–T) on the 220 kV OTL Mintia–Timişoara:
a – setting of test point and phasors diagram during the fault testing; b – analog and digital values during the fault testing

4. CONCLUSIONS

In this article are applied testing tools to assess the operation of distance protection function of 7SA612 relay during fault induced conditions. The Omicron CMC 356 set demonstrates to be a very powerful tool. It is possible to simulate multitude situations that can occur on HV OTLs and to obtain the best performance of the numerical relay for effective protection. The Omicron CMC 356 set provided possibilities for an accurate dynamic testing of 7SA612 relay because of its very good dynamic performances.

Parallel calculation and monitoring of all six impedance loops, during the process of detecting disturbances, alowed the achievement of a high degree of sensitivity and selectivity of tested relay for all types of fault.

Using the fault report, the user can examine the relay operation every time the system conditions are changed.

Time operation of distance protection was lower than the absolute tolerance allowed for all tested points, in the case of tested OTL Mintia–Timişoara. This proves that 7SA612 numerical relay operated properly both in the case of double–phase and three–phase faults.

We can conclude that simulation results were very satisfactory. Distance protection operated properly under all induced fault conditions. In all situations, the tested numerical relay operated reliably and selectively, with very small fault clearing times.

Finally, the simulations proved the effectiveness of schemes and protection settings in the case of tested OTL that starting from Mintia electric station.

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