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INFLUENCE OF FAULT RESISTANCE ON THE OPERATION OF RELAY PROTECTION BEFORE AND AFTER THE CONSTRUCTION OF NEW LINES

Kristijan Frlan, Renata Rubeša
HEP – Transmission System Operator
Department of Relay protection
M. Tita 166 Opatija
Croatia
kristijan.frlan@hep.hr; renata.rubesa@hep.hr

Ante Marušić
Faculty of electrical engineering and computing
Unska 3 Zagreb
Croatia
ante.marusic@fer.hr

ABSTRACT
Construction of new lines and restructuring of power system (PS) network is one of the basic ways to increase the safety and availability of network. During each change of configuration of the PS it is necessary to analyse the influence of the configuration change on the safety, stability and availability of the system, as well as the influence on the existing relay protection system.
The influence of the network reconfiguration on the operation of relay protection in one part of the PS in which new lines are constructed in order to improve the safety of network will be analysed in this paper. The system is modelled by using the CAPE program for the analysis of the relay protection operation in the PS. Voltage and current values as the consequence of fault will be analysed, as well as the change of impedance measured by relays in the old and new configuration systems.

KEY WORDS
relay protection, fault impedance, current distribution

1. Introduction

Availability of the PS is one of the main priorities in the management of the system today due to economical, as well as technical reasons. Liberalization of the electric supply market introduces new relationships between the consumer and the supplier. Interruption of electricity delivery is mainly viewed through financial prism, which makes the investments in PS infrastructure in order to improve its safety necessary.

Despite substantial development of new technologies, there still occur problems in the PS which cannot be influenced. Different faults cause many unforeseeable disturbances. Influences most often under scrutiny as causes of mistake during the determination of fault conditions are fault resistance and intermediate in-feed. Mistakes caused by those influences can lead to incorrect tripping of relays [1].

The Istrian peninsula belongs to the western area managed by Transmission System Operator (TSO) - Rijeka, and is connected in a specific way with the main part of the power system. At the eastern part of the peninsula there are two thermo-electric power plants: Plomin1 (156 MVA) at the voltage level of 110 kV and Plomin2 (263 MVA) at the voltage level of 220 kV. Those thermo-electric power plants are connected with sub-stations Melina 400/220/110 kV and Pehlin 220/110 kV with the two lines at the voltage level of 220 kV and with the sub-station Lovran with one line at the voltage of 110 kV. In the north of the Istrian peninsula there is a connection with the Slovenian power system at the voltage level of 110 kV. The main protection on all the lines is distance protection of electromechanical, static and numerical types (Figure 1).

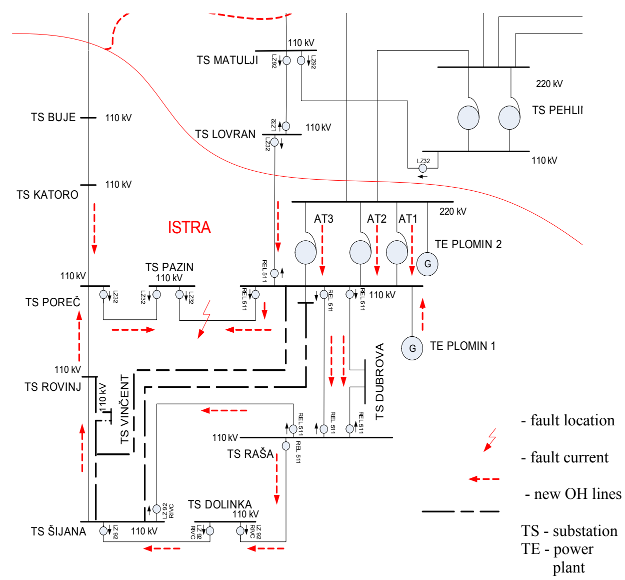

Figure 1 Analyzed Part of TSO Rijeka With Fault Current Distribution

Specific flows of energy during faults in the power system are caused by its configuration in Istria. Regardless of the fault type and fault location, it gets fed directly and indirectly from the power plant Plomin 220/110 kV as the only strong source. Usage of computer programs for fault simulation enable the prediction as to how the system will react to the real fault. The possibility of accurate prediction of voltage and current values in the PS is minimal, because it is almost impossible to determine all the factors which influence them. It is, however, possible to get a clearer picture, that is directions where major problems can be expected.

In order to obtain general guidelines regarding the functioning of the system during fault appearance in the network a simulation using the CAPE software will be performed in one part of TSO Rijeka. The CAPE software (Computer-Aided Protection Engineering) [2] is a specialized software developed primarily for relay protection engineers which calculates current and voltage values during faults in the power system, so that appropriate settings of relay protection devices can be chosen. Program modules contained in this software enable the analysis of power system abnormality, as well as future network planning, with the additional possibility of adding all the elements of the power system important for the functioning of the relay protection system: lines, transformers, generators, measuring transformers, circuit breakers and relay protection devices.

Table 1 Voltage Values Obtained From the Fault Record and Simulation for Single – Phase to Ground Fault (L2-E)

REL 511		CAPE		Error	
	kV		kV	Magnitude [%]	Angle [°]
U_{L1}	66∟356°	U_{L1}	66.2∟0°	0.28	4.00
U_{L2}	40∟236°	U_{L2}	36.2∟227°	9.50	9.00
U_{L3}	67∟123°	U_{L3}	67.6∟111°	0.88	11.87

In this paper the influence of fault resistance on the fault impedance change measured by relays, as well as voltage and current values in the system as causes of fault, will be analysed.

2. Verification of Simulation Model

2.1 Description of the Simulation Model

Development of the transmission power system requires more analysis of the protection system by means of simulation software. Relay protection system consists of different generations and types of relays characterized by various operational features. Construction of new substations and lines, and by implication of new relay protection devices, require checking the operation of relays when different types of faults occur in the new network configuration. In order to obtain general guidelines regarding the reaction of the system during fault occurence in the network a simulation using the CAPE software has been performed.

2.2 Testing the Accuracy of Simulation Model on the Real Faults

The model of the entire power system of the Transmission System Operator – Rijeka has been made. The accuracy of the model has been confirmed by comparison of the obtained results with the fault records of numerical relays REL511 during the occurence of real faults in the network. A single-phase to ground fault (L2-E) occuring at 00.56 pm on 22 February, 2007, on the line Raša-Šijana has been analysed. According to the record the fault occured at 74,01 % of line distance from the substation of Raša to the substation of Šijana. In the numerical relay REL511 distance, overcurrent and earth fault functions are active [3]. Oscillogram of currents and voltage recorded by the relay has been shown in Figure 2.

Tables 1 and 2 show current and voltage values during fault occurence obtained from the relay record, as well as simulation values obtained by using the CAPE software [4]. The error of the model has been calculated.

Table 2 Current Values Obtained from the Fault Record and Simulation for Single – Phase to Ground Fault (L2-E)

REL 511		CAPE		Error:	
	A		A	Magnitude [%]	Angle [°]
I_{L2}	1871∟171°	I_{L2}	1847∟174°	1.28	2.6

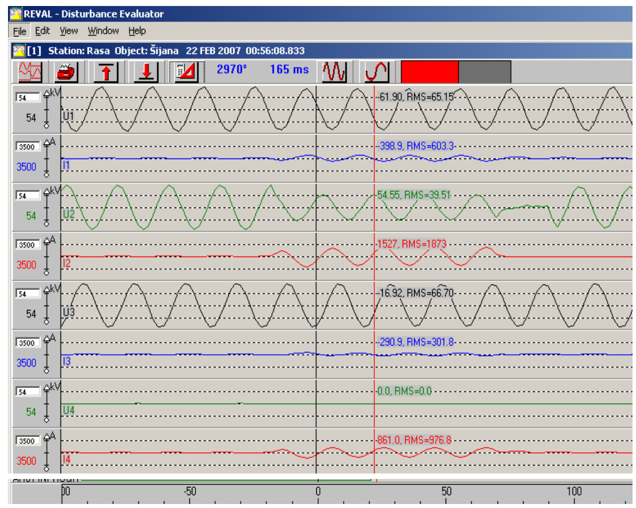

Figure 2 Oscillogram of Currents and Voltage During Single – Phase to Ground Fault on the Line Raša - Šijana

One part of the network model on which testing the accuracy of simulation model has been performed is shown in Figure 3. It is obvious from this figure that the results of simulation correspond with current fault values recorded in the system.

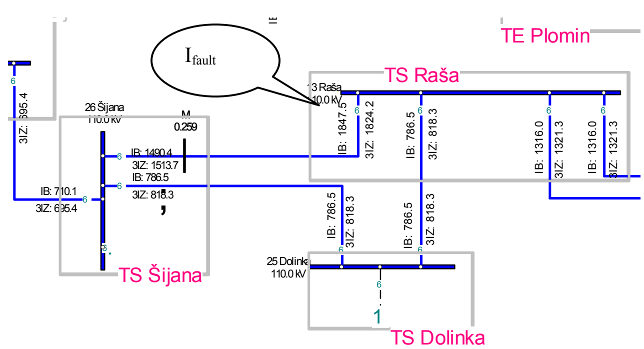

Figure 3 Model of a Part of the PS in which the Model Verification has been Performed

Error in the current value obtained by the CAPE software compared to the current value of the real fault is

1.28%, while the phase fault is 2.6°. Obtained results point to the conclusion that the model is appropriate for further analyses.

3. Analysis of Relay Protection Operation

3.1 Fault Current Calculation

Distance relays operation on the line Plomin1-Pazin (voltage level of 110 kV), including the influence of fault resistance, will be discussed. In Pazin electromechanical relay LZ32 is used, while in Plomin1 numerical relay REL511 is used. Single-phase to ground faults (L1-E) are simulated on 25, 50 and 75% of line distance from Pazin to Plomin1. Fault current values and contributions to the fault current from both sides of the line are shown in Table 3.

It is apparent that the current contribution from Plomin1 prevails in the fault current value, while the contribution from Pazin is a lot smaller, so distribution of fault current contribution is markedly uneven. The influence of fault resistance on the distance relays operation will be analysed in this light.

3.2 Influence of Fault Resistance on Relay operation

Influence of fault resistance on distance relays operation will be considered in terms of tripping characteristics of the relay in R-X diagram. The electromechanical relay LZ32 in Pazin has got MHO characteristic, while the numerical relay REL511 in Plomin1 has got quadrilateral characteristic. Single phase to ground faults (L1-E) are simulated at 25, 50 and 75% of line distance from Pazin to Plomin1 with different fault resistance values (0,1.0, 2.5Ω).

The data of the line on which simulation has been performed are shown in Table 4.

In Figures 4a, b and c the tripping characteristic of relay REL511 in Plomin1 with the first zone of distance protection for different fault locations and with different fault resistance values (0, 1.0 and 2.5Ω) has been shown. In Figures 5a, b and c the tripping characteristic of relay LZ32 in Pazin with the first and second zones of distance protection for different fault locations and with different fault resistance values (0, 1.0 and 2.5Ω) has been shown.

3.3 Analysis of Obtained Results

Simulated faults point to the fact that the numerical relay REL511 in Plomin1 shows relatively small error in the determination of fault impedance due to the fault resistance change regardless of the location of the simulated fault on the line.

Increase of resistance from 0 Ω to 1.0 Ω, and then to 2.5 Ω did not cause any more substantial problems in the determination of tripping fault impedance.

It is obvious from the tripping characteristics of the electromechanical relay LZ32 in Pazin that even with small values of fault resistance there occur large errors in the determination of fault location measured by the relay from the real fault impedance. During the simulated fault at 25% of line distance and at 2.5Ω of fault resistance the relay calculates fault impedance in the second zone, although it is situated in reality in the first zone. The error is somewhat smaller, as expected, when the fault location is closer to the location of relay, but even then the accuracy of operation is questionable.

The design of the electromechanical relay LZ32 itself is not the only cause of incorrect measurements. The configuration of the PS which does not ensure even feed of fault location from both sides is an important factor influencing the accuracy of measurement. To be more precise, that side of the line which is at the same time the location of weaker feed of fault location, in this case Pazin, is more subject to the changes of voltage and current conditions due to the influence of fault resistance, and by implication to the fault impedance measured by distance relays [4].

4. Redistribution of Currents in the New System Configuration

4.1 New System Configuration

Two new lines of 110 kV are being constructed in order to improve the safety of the power system in Istria. New lines and the future system configuration have been drawn in Figure 1. Both lines are connected from Plomin 220/110 kV towards the substation Šijana. One of them is connected in such a way that the secondary winding of the autotransformer AT3 in Plomin connects directly with the substation Šijana, while the other is connected as a three terminal line via the new substation Vinčent. The existing line Raša – Šijana will not be in function any longer.

Table 3 Fault Current for the Simulated Single-Phase to Ground Fault (L1-E)

Distance to fault in % from Pazin	Fault Current [A]	I_{fault_Pazin} [A]		I_{fault_Plomin} [A]		Ratio I_{fault_Pazin}/ I_{fault_Plomin}
		[A]	% of fault current	[A]	% of fault current	
25%	4436.54	1150.71	25.9	3286.00	74.0	0.35
50%	5485.68	1004.09	18.3	4800.81	87.5	0.21
75%	7834.76	904.42	11.5	6931.55	88.4	0.13

Table 4 Line Data

Line	Voltage level (kV)	Line lenght (km)	$Z_1(\Omega)_{prim.}$		$Z_0(\Omega)_{prim.}$		Max. line current (A)
			R_1	X_1	R_0	X_0	
Plomin1- Pazin	110	24.93	2.96	9.84	8.95	37.00	650

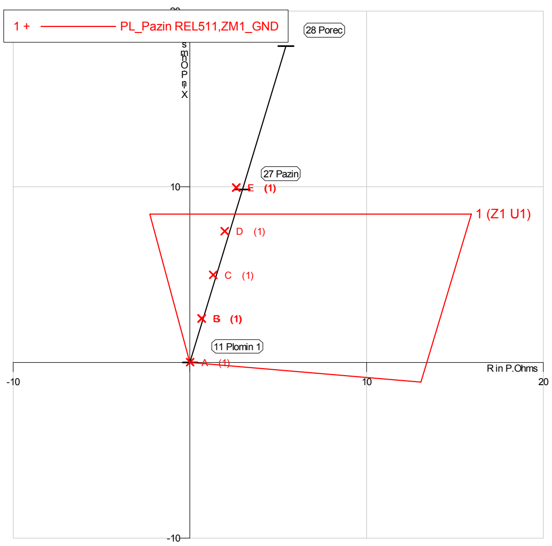

Figure 4.a Tripping Characteristic of the Relay REL511 in Plomin – R=0Ω

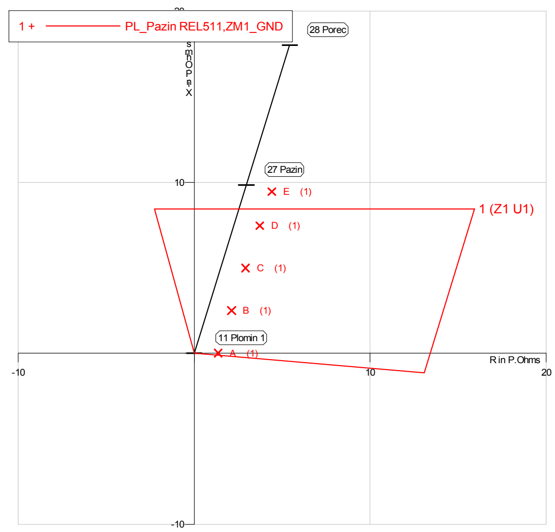

Figure 4.c Tripping Characteristic of the Relay REL511 in Plomin – R=2.5Ω

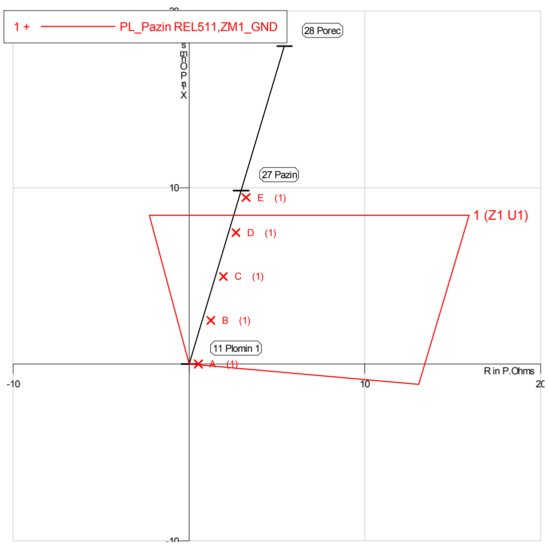

Figure 4.b Tripping Characteristic of the Relay REL511 in Plomin – R=1Ω

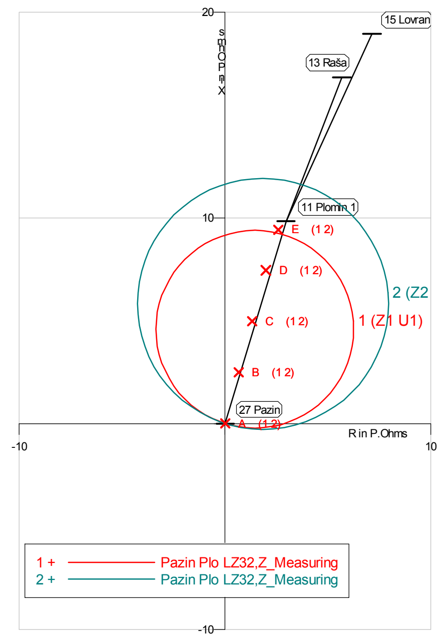

Figure 5.a Tripping Characteristic of the Relay LZ32 in Pazin – R=0Ω

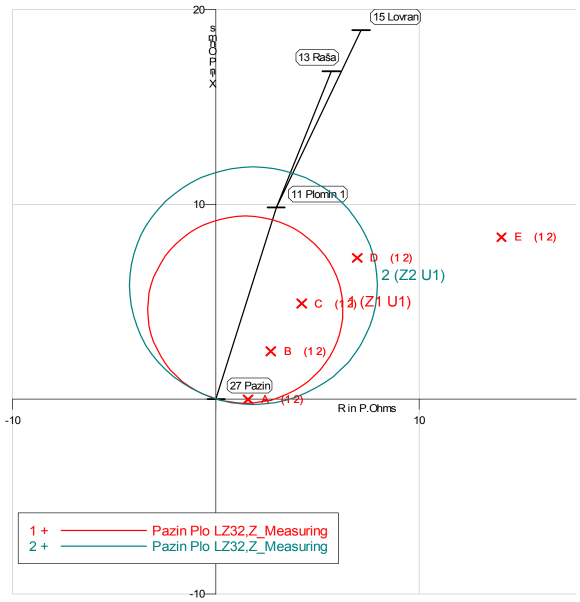

Figure 5.b Tripping Characteristic of the Relay LZ32 in Pazin – R=1Ω

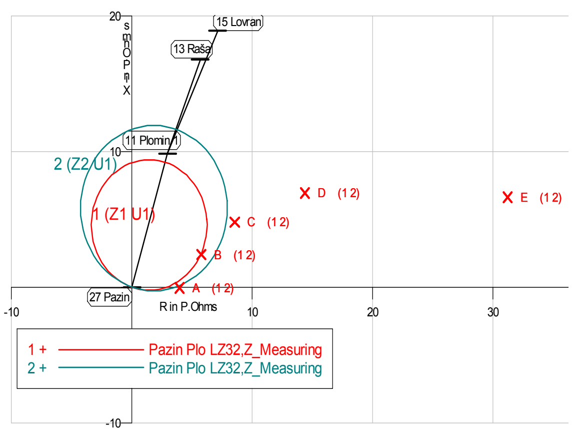

Figure 5.c Tripping Characteristic of the Relay LZ32 in Pazin – R=2.5Ω

4.2 Analysis of Relay Protection Operation in the New System Configuration

By simulating faults in different locations of the system it was analysed how the new lines influence the distribution of fault currents. Tables 5 and 6 illustrate the currents values of the simulated single-phase to ground fault (L1-E) on the lines Raša-Dolinka and Plomin1-Pazin for the old and new system configurations respectively.

The fault is simulated in the middle of the line with different fault resistance values [6].

It is evident from the obtained results that the new system configuration has resulted in better distribution of fault currents on the line Raša-Dolinka, i.e. in that part of the system in which the new lines have got bigger influence. In the remaining part of the system in which the influence of new lines is smaller (the analysed line Plomin1-Pazin) the contribution ratio has remained almost identical.

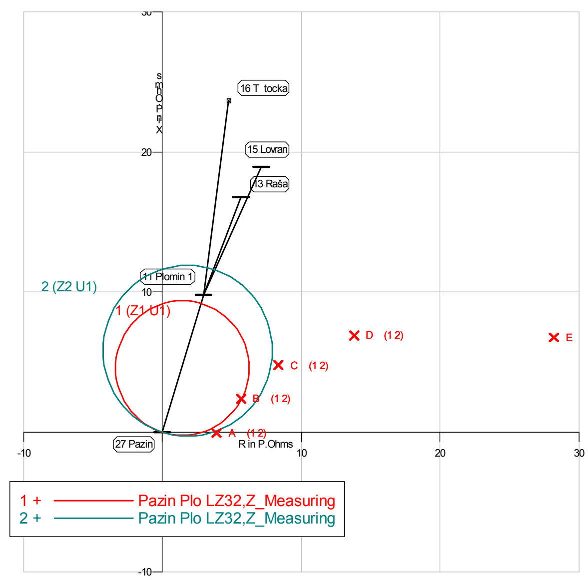

Figure 6 Tripping Characteristic of the Relay LZ32 in Pazin – R=2.5Ω, New System Configuration

Table 5 Fault Currents and Voltage Values in the Phase Struck by the Fault (L1-E) for the Line Raša-Dolinka:

System configuration	**Distance to fault in %**	**R [Ω]**	Fault current [A]	$I_{fault\_Raša}$ [A]		$I_{fault\_Dolinka}$ [A]		Ratio $I_{fault\_Dolinka}/I_{fault\_Raša}$
				[A]	% of fault current	[A]	% of fault current	
old	**50**	**2.5**	3484.5	2415.9	69.3	1072.0	30.7	0.44
new	**50**	**2.5**	3959.7	2448.4	61.8	1516.9	38.3	0.62

Table 6 Fault Currents and Voltage Values in the Phase Struck by the Fault (L1-E) for the Line Plomin1- Pazin:

System configuration	**Distance to fault in %**	**R [Ω]**	Fault current [A]	I_{fault_Pazin} [A]		I_{fault_Plomin} [A]		Ratio $I_{fault\_Pazin}/I_{fault\_Plomin}$
				[A]	% of fault current	[A]	% of fault current	
old	**50**	**2.5**	5145.1	964.09	18.7	4458.17	81.3	0.23
new	**50**	**2.5**	5055.5	980.63	19.4	4075.25	80.6	0.24

After checking the influence of the new lines on the distribution of fault currents a new analysis of the influence of fault resistance on the operation of relay on the line Plomin1-Pazin took place (Figure 6). The analysis was made for faults with 2.5Ω resistance. It was shown that the new system configuration did not ensure more even distribution of fault currents contribution. The electromechanical relay LZ32 continues to be subject to errors in the determination of the correct fault impedance due to the influence of fault resistance.

The error of the numerical relay REL511 in Plomin1 does not influence the accuracy of fault impedance determination in any significant way.

5. Conclusion

External factors, in-feed, fault resistance, as well as the current contribution from the other side of the protected line, cause errors in measurements and fault impedance determination, which can lead to the erroneous tripping of distance relay [7].

The analysis of distance protection operation in one part of the TSO Rijeka has shown that the relays operate in a satisfying way in conditions when there are no external influences on the fault itself. The situation, however, changes when real external factors, which influence the change in the voltage and current conditions in the system, are included in the simulations of faults. It has been shown that the measuring systems of distance relays are sensitive to external influences which influence the nature of any given fault. The change of voltage and current conditions in one part of the system struck by a fault depends considerably on the conditions in which the fault was actually induced. Regardless of the generation to which a relay belongs, electromechanical or numerical, the changes occuring due to the external influences lead to errors during fault impedance determination. The configuration of the PS which does not ensure even feed of fault location from both sides of the line is an important factor which influences the accuracy of measurement. In the considered case it was shown that by constructing new lines only one part of the system was configured better (Raša-Dolinka), making it also safer for the system, while in the remaining part the problems of uneven feed of fault location, and the consequences issuing fortwith are still present (Plomin1-Pazin).

In this paper only the influence of external factors on distance protection operation was considered. It is obvious from fault simulations that the influence of external factors can be so substantial to put into question the correct operation of distance protection, but backup protections can recognize the fault and trip in order to switch off the protected object.

Line differential protection and directional earth-fault protection are some types of protection which can be used as backup or main protective functions in order to decrease the external influences on the accuracy of relay operation, but bearing in mind that these protective functions require relay protection system, as well as telecommunication system resources.

Numerical relays contain more protective functions which can be activated depending on the requirement of the protected system, which enables certain redundancy. By exchanging the existing electromechanical relays with the numerical ones the safety and flexibility of relay protection system would improve substantially.

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