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Influence of Grounded Transformers on the Sensitivity of Ground Distance

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ABSTRACT
Distance protection allows you to protect power lines from short circuits to the ground. There are a lot of grounded transformers in the power system, which are a source of recharge current in case of short circuits to earth. This recharge affects the operation of distance protection and may cause non-selective disconnection of damage on the line. A power system model was built in the PSCAD software package, which showed the operation of distance protection in case of a short circuit to earth in a network with grounded transformers. Simulation analysis showed that the sensitivity of distance protection decreases in the presence of grounded transformers. It is possible to increase the sensitivity by increasing the compensation coefficient of the zero-sequence current from the calculated nominal value.

Keywords: *Distancee earth fault protection, sensitivity; Zero sequence current compensation, Grounded transformers.*

1. INTRODUCTION

Distance protection (DP) is used in the Russian power system as protection of power transmission lines (power lines) from phase-to-phase short circuits (short circuits). To protect against ground faults, earth fault protection is mainly used, which uses the current and power of the zero-sequence short circuit. But the earth fault protection has a number of disadvantages that can be eliminated when using the DP from all types of earth faults [1].

Since the middle of the last century, it has been known that the DP can, in principle, protect the line from both phase-to-phase short circuits and ground faults. But at that time, electromechanical relays were used, it was quite a complicated process to mass-produce DP from all types of short circuits due to the high technologically difficult task of assembling the device and the high cost. The massive transition, especially since the beginning of the XX1 century, from electromechanical relays to microprocessor ones provided an opportunity to implement this idea, because physically, everything remains the same as for the DP with the use of electromechanical relays, except for some insignificant details. At the same time, a quick transition was not possible, including due to insufficient regulatory and technical framework and lack of recommendations for calculating the settings and determining the measurements of the DP. It should be especially noted that the presence of an extensive network, which is replete with many parallel lines and the presence of a large number of solders, adds additional complexity to the calculations.

All of the above factors affect the selectivity and sensitivity of protection, so it is necessary to choose the right methods and techniques for determining the measurement in these modes of network operation [2].

2. GROUND DISTANCE

A feature of the distance protection reacting to earth short-circuit currents in the 110-220 kV network is the use of the phase voltage of the damaged phase and the compensated phase current. Compensation occurs by taking into account the zero-sequence current and the compensation coefficient, which depends on the resistivity of the straight line and the zero sequence of the line [3].

The formula looks like this:

$$Z_{p0} = \frac{U_p}{I_p + k_0 \cdot I_0} \quad (1)$$

where Z_{p0} – distance measurement at the place of protection installation; U_p – phase voltage of the damaged phase at the place of protection installation; I_p – phase current of the damaged phase at the place of protection installation; k_0 – zero sequence current compensation coefficient determined by the specific parameters of the protected line $(Z_0\text{-}Z_{1l})/Z_{1l}$.

I_0 – zero sequence current measured at the protection installation location.

The phase voltage will be determined as follows:

$$U_p = Z_{1K} \cdot I_p + I_0 \cdot (Z_{0K} - Z_{1K}) \quad (2)$$

where Z_{1K} и Z_{0K} – resistance of the direct and zero sequence from the installation site protection to the point of short circuit.

3. INFLUENCE OF GROUNDED TRANSFORMERS

A grounded transformer in case of a short circuit to earth is an additional power source of zero-sequence current. The current flowing through the neutral of the transformer will cause an additional voltage drop in the short circuit (Figure 1).

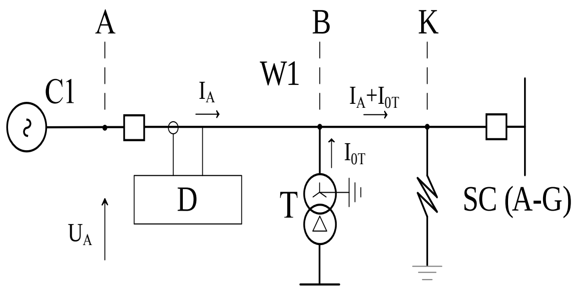

Figure 1 Influence of grounded neutrals on resistance measurement.

This phenomenon will cause a change in the measured resistance value, which will affect the operation of the distance protection.

The voltage at the place where the protection is installed will consist of the values of symmetrical components (forward, reverse and zero) and will look like this:

$$U_A = Z_{1K} \cdot (I_{A1} + I_{A2} + I_0) + I_0 \cdot (Z_{0K} - Z_{1K}) + Z_{0BK} \cdot I_{0T} \quad (3)$$

Comparing expressions (3) and (2), it becomes clear that under the influence of grounded transformers, formula (1) cannot be used, otherwise the resistance measurement will be determined incorrectly in the direction of increase, which can lead to a decrease in the response zone and non-selective shutdown [4].

4. MATHEMATICAL MODEL

4.1. Distance protection model

Remote protection will be represented by the model shown in Figure 2, consisting of two large blocks: Signal Processing and Protection Scheme.

- Signal processing – this block is presented for calculating the current and voltage values of symmetrical components. Before that, the phase values of the current pass through the fast Fourier transform algorithm to isolate the values of the amplitude and phase of the first harmonic;
- Protection Scheme – this block shows the scheme of the DP operation. It consists of an element for calculating the measurement, the remote protection device itself with a circular characteristic and output signals about the activation of protection.

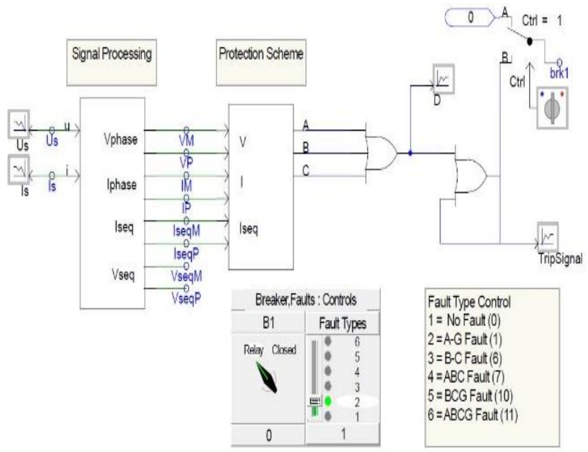

Figure 2 Distance protection model.

4.2. Building a model

To determine the dependence of the increase in the measurement of the resistance of remote protection on the number of grounded transformers, their power and installation location, we will build a mathematical model of the power system (Figure 3).

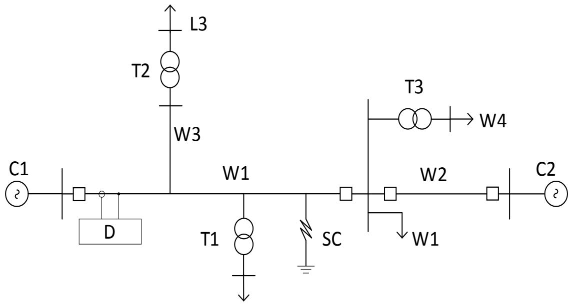

Figure 3 Mathematical model of the power system.

The model will consist of the following elements: C1 and C2 systems, 3 power transmission lines, 3 110/10 kV transformers, 4 loads and a distance protection at the beginning of the L1 line. From the L1 line there are 2 soldering stations, one of them with a power line. The parameters of the elements of the power system are given in Tables 1–4.

Table 1. Parameters of the source power system

Parameters	Designation	C1	C2
Voltage	U, kV	110	110
Impedance	Z_S, Ohm	10, deg10	7, deg5

Table 2. Parameters of power transmission lines

Parameters	Designation	W1	W2	W3
Length	L, km	60	50	16
R.	r_0, Ohm /km	0.118	0.118	0.118
X	x_0, Ohm /km	0.435	0.435	0.435

Table 3. Parameters of transformers

Parameters	TD-40000/110	TDN-16000/110
S, MVA	40	16
U_{HV}, kV	121	115
U_{LV}, kV	10,5	11
u_{XI}, %	10,5	10,5
ΔP_{CuL}, kV	160	85
ΔP_{NLL}, kV	50	19

To begin with, let's take T1, T3 – TDN-40000/110, T2 – 16000/110.

Table 4. Load Parameters

Load	P, MW	Q, MVAR
L1	25,5	15,8
L2	21,25	13,17
L3	8,5	5,3
L4	29,75	18,44

A short circuit will be made at a distance x from the place where the protection is installed. The distance to the short circuit location will be changed to bring the protection to the edge of operation. The triggering edge will mean such a state of the distance protection: if you remove the point of the short circuit by some small value, then the protection ceases to work and vice versa. This will allow you to determine the failure of protection even with a small increase in resistance measurement.

Manitoba Hydro International's PSCAD software package was used to model the power system and the distance protection model. This program provides a high set of capabilities for building a network, performing short circuit modeling, etc. (Figure 4).

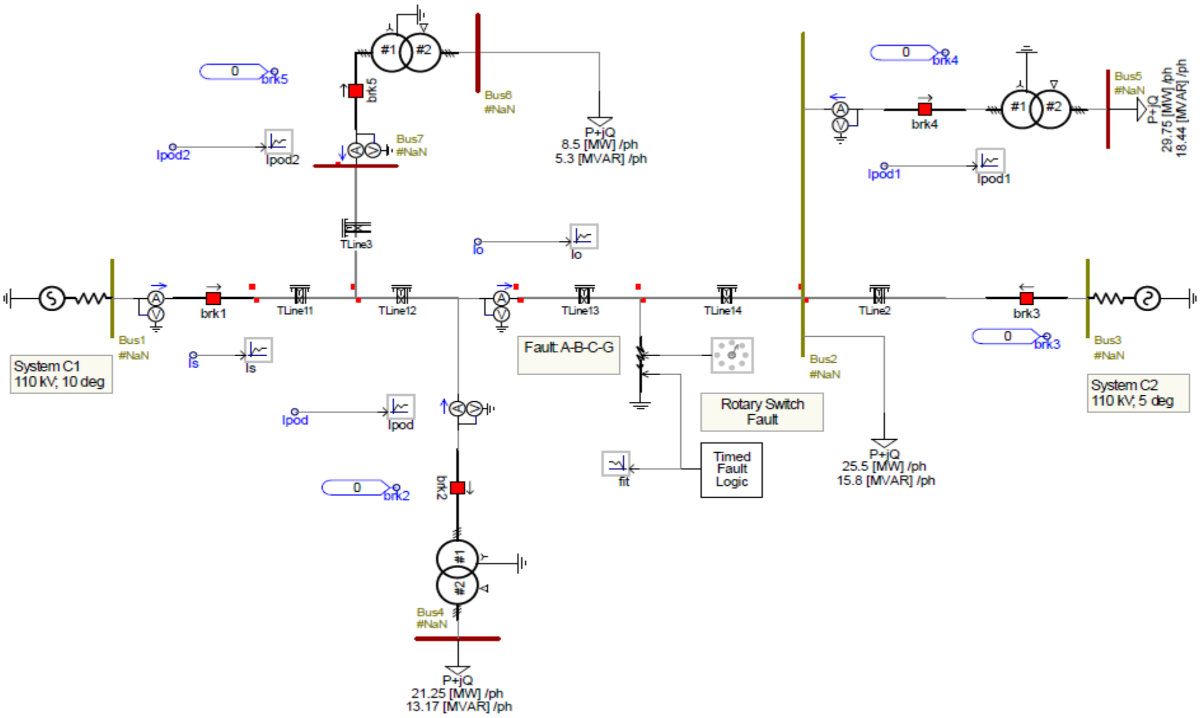

Figure 4 Mathematical model of the power system.

4.3. Selecting protecting settings

For the first stage of the distance protection, which will protect the line from all types of short circuits, we will choose a setpoint of 85 % of the line length. We get Z = 0.85*L1*Z1 = 0,85*60*0,451 =23 ohms.

The response characteristic will be a circle passing through the origin, with an angle of maximum sensitivity of 80 degrees.

Define the centre of the circle:

X0 = Z0/2 * cos(m.s.)= 11.5* cos (80°)= 2 ohms.

Y0 = Z0/2*sin(m.s.)= 11.5*sin (80°)= 11.3 ohms.

Zero sequence current compensation:

k0 = (Z0 – Z1)/Z1 = (1,2 – 0,451)/0,451 = 1,66.

5. MEASUREMENT DEFINITION

First, we will check the correctness of the operation of the distance protection with a short circuit to the ground using a compensated zero-sequence current. To do this, we will disconnect transformers T1, T2, T3 to exclude the influence of zero-sequence current supply from grounded neutrals.

The setpoint and the algorithm for determining the measurement are selected. Let's put a point SC: 85 % of the length of the line. Protection in this mode should be displayed on the edge of operation.

According to Figure 5, it can be seen that the measurement resistance crosses the response characteristic and is on the verge, i.e., with further removal of the short circuit point, the distance protection will not work due to an increase in resistance.

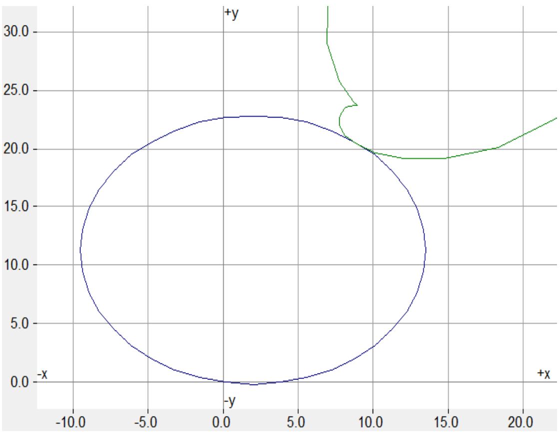

Figure 5 Distance protection on the verge of triggering without transformers.

This means that the zero-sequence current compensation correctly determines the resistance to the point of damage, the protection will work selectively.

Next, we will determine the influence of grounded transformers on the accuracy of the measurement. We will turn on transformers T1, T2, T3 separately and together.

5.1. Switching on the transformer T1

Transformer T1 is a soldered substation on the protected line. For transformer T1, a power of 40 MVA was initially selected. The results of the network operation with the T1 transformer turned on during the short circuit showed that the resistance measurement increased and the distance protection did not work. It can be concluded that the length of the response zone has decreased, the measurement resistance was approximately 26 ohms. The current of the damaged phase at the fault site was 2,366 kA, and at the protection installation site 2,166 kA. The recharge from the neutral of the transformer T1 turned out to be equal to 0.25 kA. Reducing the transformer power to 16 MVA will lead to less impact on the operation of the DP, while the measurement was 23.6 ohms.

5.2. Switching on the transformer T3

Let's determine the effect of T3 with a power of 40 MVA on the measurement resistance of the DP by turning off all other transformers (Figure 6).

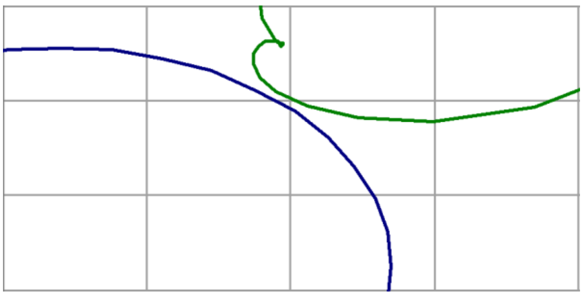

Figure 6 Switching on the transformer T3

Calculations have shown that the distance protection will not work, the measurement resistance vector will not cross the response characteristic. I had to enlarge the diagram to see a slight shift in the resistance of the short circuit in the direction of increase, but sufficient for the protection to fail.

The current at the short circuit location will increase by 0.06 kA compared to the current value at the protection installation location. And the measurement resistance will be 22.5 ohms. This value is less than the actuation setpoint, but the protection will still not work, because the short circuit resistance angle is less than the maximum sensitivity angle at which the maximum actuation value is determined, as can be seen in Figure 6.

It can be said that a grounded transformer on the tires of the opposite substations affects the operation of the DP of the protected line. But the effect will be negligible even with a large transformer power.

5.3. Switching on the transformer T2

The influence of transformer T2 will be similar to T1, but have a different degree due to the place of soldering, additional line W3 and the power of transformer T2. The current in the lines at the installation site of the protection, the short circuit point and the supply from the transformer T3 are shown in Figure 7.

Is – current at the place of protection installation; Io – current at the short circuit location; Ipod2 – current in the neutral of the transformer T2.

It can be seen that the zero-sequence current from the neutral of the transformer T3 feeds the current at the short circuit point to the ground. The effect is small (0.07 kA) due to the low power of the transformer (16 MVA). The same transformer T1 with a power of 40 MVA, has a charging current of 0.25 kA.

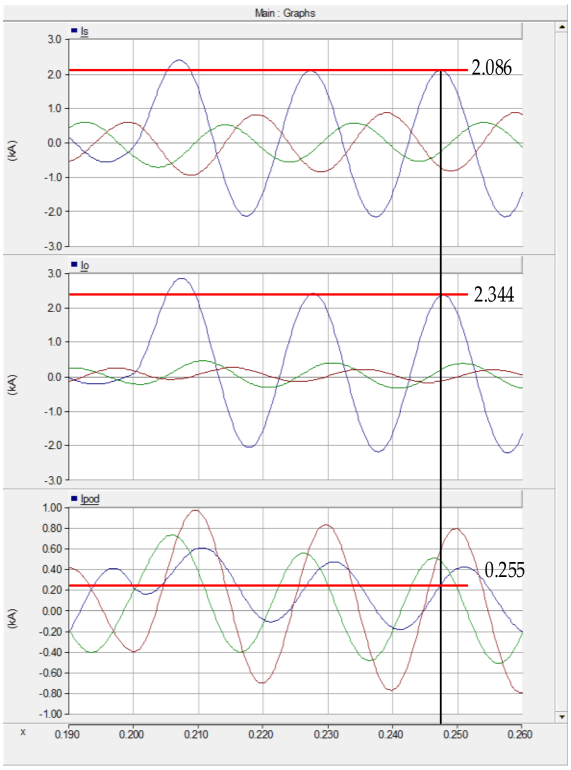

Figure 7 Switching on the transformer T2.

The resistance measurement will be 23.3 ohms, which is more than the trigger setpoint, which means the DP will not work, the length of the trigger zone is reduced.

Transformer T2 is connected to line W1 through the soldering line W3, which also affects the value of the zero-sequence current from the transformer neutral. Let's determine this effect by removing the W3 line and connecting the transformer T2 directly to the W1 line.

The simulation results showed that the influence of the line is insignificant, the zero-sequence current from the transformer T2 increased by 0.1 kA and amounted to 0.9 kA. The measurement resistance increased by tenths.

5.4. Switching on all transformers

Switching on all three transformers will cause the protection to fail at a short circuit at a distance of 85 % of the line length. When transformers T1, T2, T3 are operating simultaneously, the protection will not work, as shown in Figure 8.

The power of transformer T2 has been increased from 16 MVA to 40 MVA to show how two solder transformers on a 40 MVA line will affect. The measurement resistance was 26.4 ohms, which is 15 % more than the setpoint response, even without taking into account the fact that the short circuit angle will be less than the maximum sensitivity angle.

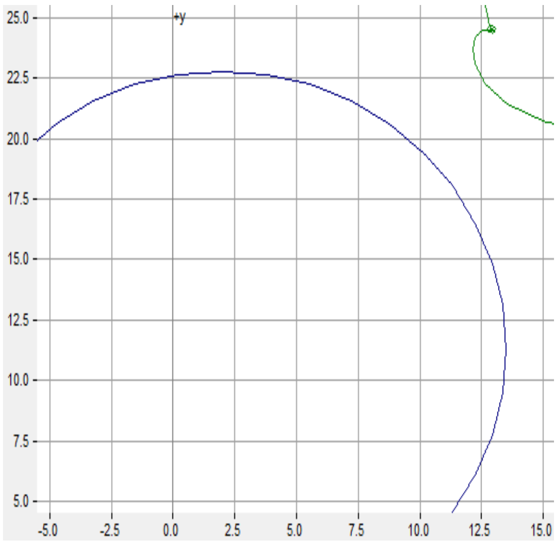

Figure 8 Switching on transformers T1, T2, T3.

The value of the zero-sequence current supply from the neutral of grounded transformers is shown in Figure 9.

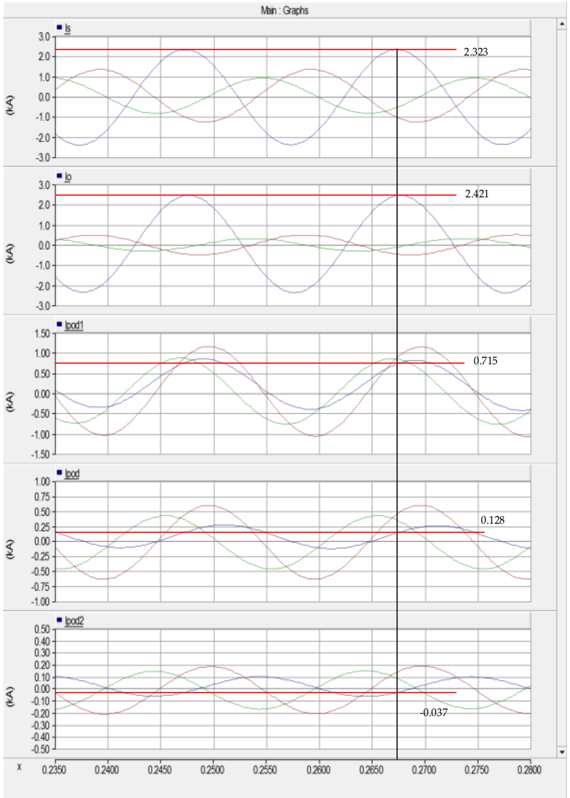

Figure 9 Diagram of currents when all transformers are switched on.

Ipod1 – is the current in the neutral of transformer T3, *Ipod* – is the current in the neutral of transformer T1.

The value of the zero-sequence current recharge will be: from T1 – 0.142 kA, T2 – 0.009 kA, T3 – 0.06 kA. The inclusion of transformers caused a large error, even if the transformer currents T1 and T2 were taken not at the peak value, but with some lag, because the time of current measurement was determined by the peak value at the short circuit location.

5.5. Simulation results

For clarity, we will summarize in Table 5 all the results obtained. Transformer parameters and network topology will remain the same as in Figure 4 and Tables 1–4.

Table 5. Results

Transformer included	Recharge 3I0, kA	Measurement of resistance, Ohms
T1	0,25	23,6
T2	0,06	23,3
T3	0,07	22,5
T1, T2, T3*	0,378	25,4
T1, T2, T3*	0,191	26,4

** - The power of T2 has been changed to 40 MVA.*

When connecting soldered substations with grounded transformers to the protected line, the distance protection may not work selectively due to an increase in the measurement resistance due to the supply of zero-sequence currents from the neutral of transformers. The impact will be more significant the more soldering substations will be connected to the line.

6. SOLVING THE PROBLEM

This problem can be solved by increasing the current compensation coefficient of the zero sequence.

We will determine for each mode of operation of the transformer the value of the current compensation coefficient of the zero sequence, at which the distance protection will correctly determine the measuring resistance of the short circuit.

- When the transformer T1 is turned on, the coefficient k0 must be increased to 3. At this value, the protection will work on the verge of triggering, which is correct at a setpoint of 23 ohms and a short circuit point 51 km from the installation site of the DP (Figure 10);
- When turned on, T2 – k0 will be 2;
- When turned on, T3 – k0 will be 1.78;
- When turned on, T1, T2, T3 – k0 will be 3.74.

Transformer parameters and network topology will remain the same as in Figure 4 and Tables 1–4.

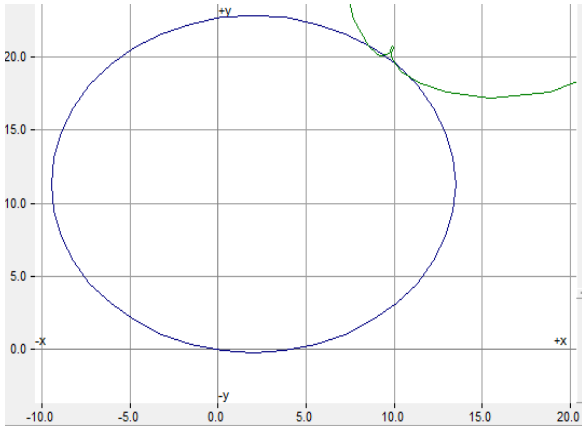

Figure 10 Distance protection operation with recalculated k0 with T1 enabled.

It can be seen that the more grounded transformers there are, the greater the value of the zero-sequence current compensation coefficient should be increased. The magnification has a wide spectrum, by several tens with a small influence and by 2–3 times when several transformers are turned on.

The execution of these calculations can be entrusted to the specialists of the relay protection service of the System Operator or network organizations, in the presence of which there are power lines with soldering of grounded transformers.

7. CONCLUSION

The work of remote protection against all types of short-circuit, in particular from short-circuit to the ground, can be complicated by a number of factors. One of these is the influence of grounded transformers that are installed at the soldered substations of the protected line.

When a short circuit is applied to the ground, the zero sequence current flows to the short circuit location not only through power sources (systems), but also through the neutral of grounded transformers, which causes an additional voltage drop on the line and consequently affects the operation of remote protection.

The more grounded transformers there are and the greater their rated power, the higher the impact will be. In this study, the increase in resistance measurement reached up to 15 %, which reduces the protection response zone. If no measures are taken to solve this problem, the protection may not work selectively with a large number of soldered substations.

This problem is solved by increasing the zero-sequence current compensation coefficient. The meaning of the solution lies in the fact that with an increase in the coefficient, we compensate for the induced voltage with a supply current from the transformers.

Further prospects of the study are the conclusion of an empirical formula for automatic recalculation of the zero-sequence current compensation coefficient by the parameters of the protected line, the number of sealed transformers, their power, the place of soldering.

The very topic of remote protection against all types of short-circuit protection has recently become increasingly popular. This is due to the introduction of microprocessor relay protection devices, the advantages of remote protection over current protection, the need for redundant protection.

At the moment, remote protection against all types of short circuit is used only in the first stage, but with the complexity of the topology of 110–220 kV urban networks, great entanglement, the use of this protection, in the second and third stages may be promising.

The topic of grounded transformers in the work of remote protection, as already mentioned, is only one of the problems. Others include: the effect of mutual induction on parallel and double-chain lines, transient resistance at the point of short circuit, line asymmetry, sequential (longitudinal compensation).

Therefore, we can say that the topic of remote protection is promising for further research.

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