



PS1 – S3-08



Providing Remote Backup Functions of Relay Protection of Transformers in the Direct and Quadrature Axis Dissymmetry

Ivan V. NAGAY
South-Russian State Technical University
(Novocherkassk Polytechnic Institute)
Russia
nagayiv@mail.ru

KEYWORDS

Multiple direct and quadrature axis dissymmetry regimes, open-phase regime, information signs, recognition of faults, backup protection.

1 INTRODUCTION

The urgency of the problem under discussion. Regimes of multiple direct and quadrature axis dissymmetry, followed by an open-phase fault in the transmission lines (TL) and a simultaneous short-circuit (SC) in a network of effectively grounded neutral or a ground fault in a network with isolated or resistance-grounded neutral, in the networks with the compensation of capacitive currents. As a rule, it is not accompanied by an increase in currents to levels comparable to short-circuit currents in electrical distribution networks voltage 6-110 kV.

It should be noted, that most of the remote backup relay protection (RP) of the TL with tapping substation or double-ended substations, and in some cases and local backup protection are not sufficiently sensitive to the regime considered [1-3]. Such damage not only cause energy losses in electrical distribution networks, but also cause damage to power transformers due to the prolonged flow of currents above their rated currents 2-4 times [1-5], motors, surge in the earthed star power transformers, damage voltage transformers, the possible unwanted operation of protection on an adjacent parallel line [1-3]. Open-phase regime with an open-phase fault, in which there is short-circuiting switch and short-circuit fed by the substation (transformer) is one of the toughest in terms of providing a reliable off damage from the feeding stations, as its inclusion under the influence of transformer protection leads to an increase in current is not more than 5-10%. Which is not enough to act the protection of the power supply substation [1-5].

2 MAIN PART

Review of existing solutions. Now there are no special protection against these types of faults [1-3] in distribution networks 6-110 kV. Networks with effectively-grounded neutral are the subject of this review, and main protection against these types of faults is the overcurrent (directional) protection of the zero-sequence (OPZS), that sensitivity is usually insufficient. Several technical solutions [1,6,7], with higher technical perfection in comparison with OPZS enable us to solve the problem of building protection from direct and quadrature axis dissymmetry (DQAD), but, unfortunately, they are not widely used in these power grids.

DQAD field. This approach in building protection from DQAD is shown in the example network with radial line (Fig. 1), that supply tapping substation, with the following parameters: $Z_{G1} = 32e^{j85^\circ}$ Om – system resistance G1; $Z_{11} = 5,5e^{j55^\circ}$, $Z_{12} = 8e^{j55^\circ}$ Om – resistance of the first

and second overhead line sections; $Z_{l1} = 225e^{j88^\circ} \text{ Om}$ and Z_{l2} , that takes a value from $556e^{j88^\circ} \text{ Om}$ to $87e^{j88^\circ} \text{ Om}$ – resistance of transformers of the tapping substation T1 (transformer power is 10 MVA), T2. Transformer power T2 ranged from 2.5 to 16 MVA and the load power of transformers T1 and T2 varied in the range $(10 \div 100)\%$ of their rated capacity, load current angle $\varphi_{\text{load}} = -(20 \div 40)^\circ$, tapping line resistances are on the order of magnitude smaller than the resistance of the main sections of overhead lines, and even more transformers, and therefore not included in the calculations. The transient resistance is the site of damage varied in the range $(0-20)\%$ of the resistance of the transformer.

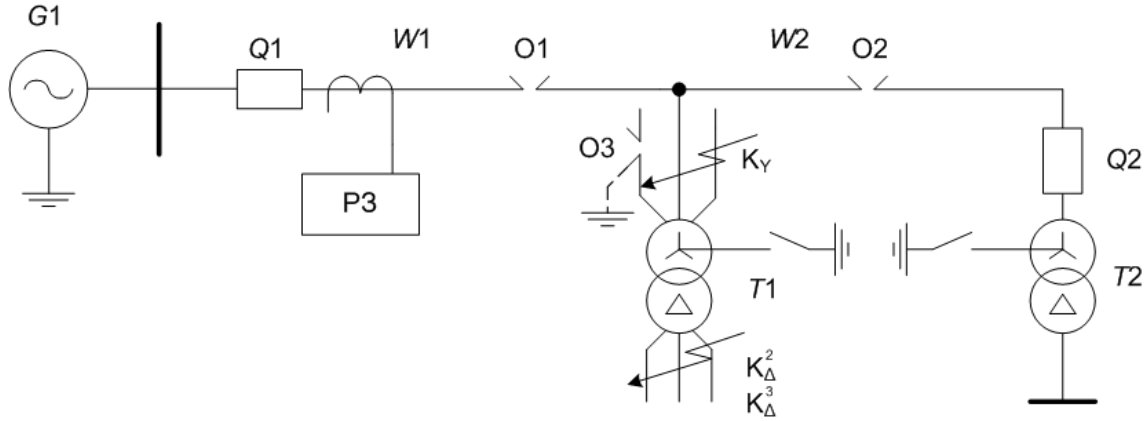


Fig. 1: Explanatory diagram of a network 110 kV with tapping substation

The worst from the standpoint of the sensitivity of back-up protection are the following types of multiple direct and quadrature axis dissymmetry (Table 1): broken wire (O1 – O3) and SC with ground of phase A (K_Y) of the first and second section W1 and W2 with SC on the transformer T1 site (AY regime), phase A broken wire and SC AB (ABY regime), CA (CAY regime), phase A broken wire and SC (two- and three-phase fault) in phases AB (AB Δ regime), BC (BC Δ regime), CA (CA Δ regime), ABC (ABC Δ regime) on the side of low voltage transformer T1 (K_Δ) «star-delta».

Mode of failure						Controlled current
Broken wire in the phase A	O1	O2	O3	K_Y	K_Δ	$I_{AY}, I_{BY}, I_{CY}, I_1, I_2, I_0$
	+	–	–	–	–	$I_{AY}=0, 0,1I_{K3}<I_0<0,3I_{K3}$
	–	+	–	–	–	$I_{AY} < I_{BY}, I_{AY} < I_{CY}, 0,1I_{K3}<I_0<0,3I_{K3}$
	–	–	+	–	–	$I_{AY} < I_{BY}, I_{AY} < I_{CY}$
	–	–	+	K_{AY}	–	$I_{AY} < I_{BY}, I_{CY} > I_{BY}, 0,1I_{K3}<I_0<0,3I_{K3}$
	–	–	+	K_{ABY}	–	$I_{AY} < I_{CY}, I_{BY} > I_{CY}, I_0 > 0,3I_{K3}$
	–	–	+	K_{ACY}	–	$I_{AY} < I_{CY}, I_{BY} < I_{CY}, I_0 > 0,3I_{K3}$
	–	–	+	–	$K_{AB\Delta}$	$I_{AY} < I_{BY}, I_{BY} > I_{CY}, 0,1I_{K3}<I_0<0,3I_{K3}$
	–	–	+	–	$K_{BC\Delta}$	$I_{AY} < I_{CY}, I_{BY} < I_{CY}, 0,1I_{K3}<I_0<0,3I_{K3}$
	–	–	+	–	$K_{CA\Delta}$	$I_{AY} < I_{CY}, I_{BY} < I_{CY}, 0,1I_{K3}<I_0<0,3I_{K3}, I_2 < 0,1I_{K3}$
	–	–	+	–	$K_{ABC\Delta}$	$I_{AY} < I_{CY}, I_{BY} < I_{CY}, 0,1I_{K3}<I_0<0,3I_{K3}, I_2 < 0,1I_{K3}$

Table 1: Direct and quadrature axis dissymmetry regimes and ratio of controlled current

The first three types of complex faults are the development of a simple fault: the fall phase wire to the ground, phase wire to the other phase wire whipping (breakdown of air insulation). The last four regimes can arise when working overhead in open-phase mode, which is practiced in some power systems, incomplete switching on one of the poles switching device supply, tapping or double-ended substations, line phase broken wire, such as loop on the anchor support, etc. Short-circuit the phases B and C, with simultaneous rupture of phase A and phase to phase fault are excluded from this list due to significant levels of current and sensitivity of the supply substation RP.

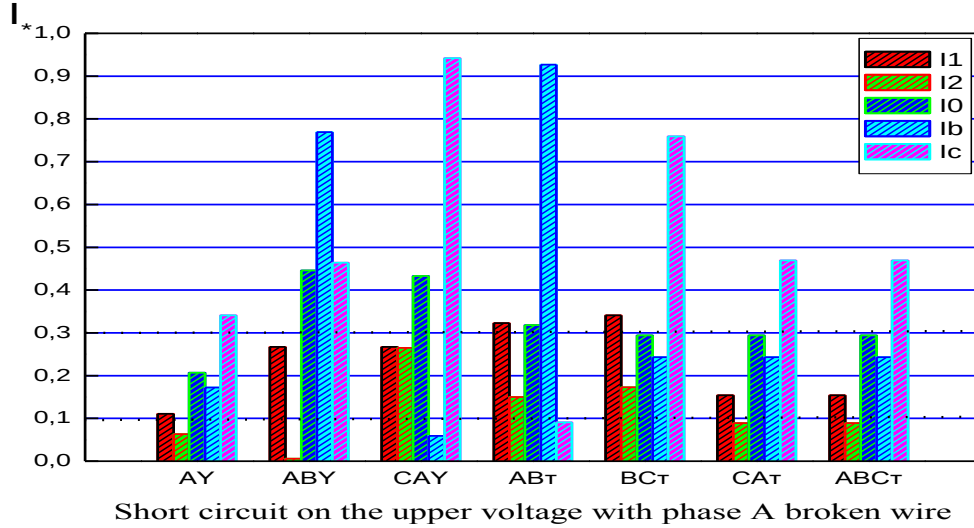


Fig. 2: Value of the phase currents and the currents of symmetrical sequences in different modes of multiple DQAD

Calculated modes to assess the sensitivity of backup protection of the transformer tapping substation is breakage of one phase and it is a short to ground from the feeding transformer. The calculated expression for this mode [5] with their simplisitic for $\underline{Z}_{1L} = \underline{Z}_{2L}$ are given below. Currents corresponding sequences on the left of the broken wire, at the SC and the right of it respectively $I_{\alpha y}$, $I_{\alpha k}$, $I_{\alpha L}$, may be defined ($\alpha = 1, 2, 0$ – number of symmetrical sequences, positive, negative and zero sequences):

$$\begin{aligned} \dot{I}_{A1k} &= \dot{E}_c \left(\frac{\underline{Z}_{1L} - \beta_j \underline{Z}_{2L}}{\underline{Z}_2 \underline{W}_j} + \frac{\underline{Z}_{1L} - \rho_j \underline{Z}_{0L}}{\underline{Z}_0 \underline{W}_j} \right); \\ \dot{I}_{A1y} &= \dot{E}_c \left[\left(\frac{1}{\underline{Z}_2} + \frac{1}{\underline{Z}_0} \right) \frac{\underline{Z}_A}{\underline{W}_j} - \frac{\underline{P}_j}{\underline{Z}_2 \underline{Z}_0 \underline{W}_j} \right]; \\ \dot{I}_{A2y} &= \frac{(\rho_j \underline{Z}_{2L} - \beta_j \underline{Z}_{0L}) \dot{I}_{A1k} - \underline{Z}_0 \dot{I}_{A1y}}{\underline{Z}_2 + \underline{Z}_0}, \quad \dot{I}_{A1k} = \dot{I}_{A2k}; \quad \dot{I}_{A2k} = \dot{I}_{A0k}, \end{aligned}$$

где $\underline{Z}_1 = \underline{Z}_{1F} + \underline{Z}_{1L}$; $\underline{Z}_2 = \underline{Z}_{2F} + \underline{Z}_{2L}$; $\underline{Z}_0 = \underline{Z}_{0F} + \underline{Z}_{0L}$; j – number of the phase A, B, C and $\beta_1 = \rho_1 = 1$, $\beta_2 = a^2 = e^{j240^\circ}$, $\rho_2 = a = e^{j120^\circ}$, $\beta_3 = \rho_2$, $\rho_3 = \beta_2$;
 $\underline{Z}_{\alpha F} = \underline{Z}_{\alpha c} + \underline{Z}_{\alpha DM} + \underline{Z}_{\alpha Nk}$, $\underline{Z}_{\alpha L} = \underline{Z}_{\alpha KR} + \underline{Z}_{\alpha T1} + \underline{Z}_{\alpha H}$, $\underline{Z}_{\alpha c}$ – system resistance; $\underline{Z}_{\alpha DM}$, $\underline{Z}_{\alpha Nk}$ – resistance of the line sections on the left and on the right (between SC) to broken wire spot; $\underline{Z}_{\alpha KR}$ – resistance of the line section from the SC to tapping substation; $\underline{Z}_{\alpha T1}$, $\underline{Z}_{\alpha H}$ – $T1$ and it load resistances.

$$\underline{W}_1 = \underline{Q} \underline{Z}_A - \left[\frac{(\underline{Z}_{1L} - \underline{Z}_{0L})^2}{\underline{Z}_0} + \frac{(\underline{Z}_{2L} - \underline{Z}_{0L})^2 \underline{Z}_1}{\underline{Z}_2 \underline{Z}_0} \right]; \quad \underline{Q} = 2 + \frac{\underline{Z}_1}{\underline{Z}_0}; \quad \underline{P}_1 = (\underline{Z}_{2L} - \underline{Z}_{0L})^2;$$

$$\underline{W}_2 = \underline{W}_3 = \underline{Q} \underline{Z}_A - \left[\frac{3\underline{Z}_{1L}^2 + \underline{Z}_{1L}^2 + \underline{Z}_{1L} \underline{Z}_{0L} + \underline{Z}_{0L}^2}{\underline{Z}_0} + \frac{(\underline{Z}_{2L}^2 + \underline{Z}_{2L} \underline{Z}_{0L} + \underline{Z}_{0L}^2) \underline{Z}_1}{\underline{Z}_2 \underline{Z}_0} \right];$$

$$\underline{P}_2 = \underline{P}_3 = \underline{Z}_{2L}^2 + \underline{Z}_{2L} \underline{Z}_{0L} + \underline{Z}_{0L}^2; \quad \underline{Z}_A^{(1)} = \underline{Z}_{1L} + \underline{Z}_{2L} + \underline{Z}_{0L} + 3R_n, \quad R_n – \text{transient resistance.}$$

The emergence of asymmetric damage in the network causes of symmetrical sequences and the change of phase currents, and their angles, as reflected in Figure 2 (transformer power T2 is equal to the transformer power T1, neutral transformer T2 ungrounded). In this case, the base current is passed

the current three-phase short circuit at low voltage side of transformer T1. In this three-phase fault current for this transformer is about 10 times the rated current (voltage of the transformer short-circuit is $U_{*K} = 0,105$). Phase currents in all cases exceed the rated current of the protected transformer, which once again underlines the unacceptability of his long regime DQAD not only in the presence of damage on the side of low voltage, but also in the DQAD in a network of higher voltage.

Problem solving. As a start-up functions for the proposed protection can be used by functions current symmetrical sequences: negative and zero sequence current with matching current $I_{*m} \geq k_r k_i I_{*m}$, but if it values $I_{*m} \leq (0,05 \div 0,1) I_{*\Sigma}$, $I_{*\Sigma}$ – maximum load current supply line, it is possible to use measurement of the increment of the current symmetrical sequences and phase currents. Effective way is to use the measurement of relative measurement (Fig. 3a) currents symmetrical sequences ($I1/I0$ and $I2/I0$) and sum and difference phase current moduluses ($(I_B + I_C)/(I_B - I_C)$), I_B, I_C – currents of two phases with the highest values (phase A broken wire it phases are the phase B and C, base current in this case adopted the rated current of the transformer. This version of the relative measurement is similar to that used in [9], but has its differences to identify areas of emergency regimes. At the same time the mean-square distance between the current areas in the symmetrical sequences and phase current exceeds the rated current of the protected transformer, which allows for recognition of multiple regimes of DQAD and simple SC. The task of constructing starting measurement of the relative measurement is the maximum distance of regions 1 and 2, while reducing their areas. This can be achieved by correcting the input signals, as shown in Figure 3b.

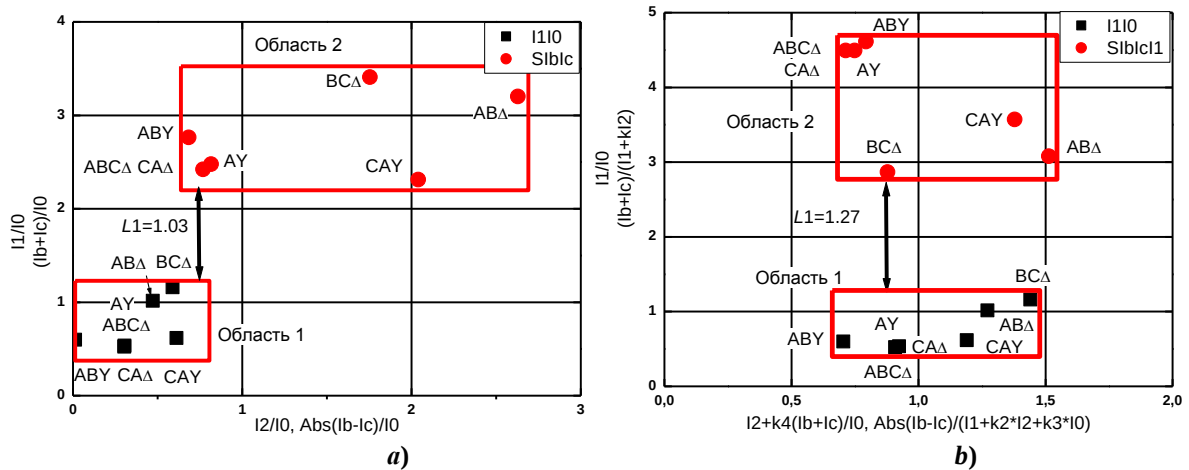


Fig. 3: Multiple DQAD regimes areas for start-up functions of the relative measurement of the current symmetrical sequences and sum and phase current modulus: a – without input signal correction and b – with input signal correction.

To evaluate the effectiveness of protection far backup important is the ability to recognize its modes of DQAD with selection of type of fault. This requires the use of a minimum set of information signs, which will provide non-overlapping areas of regimes of multiple DQAD. It may form a vector dimensional space of information attributes (in this case, the currents of symmetrical sequences, phase currents and their angles) $\mathbf{I} = (I_1, I_2, \dots, I_{N1}, \varphi_1, \varphi_2, \dots, \varphi_{N2})$, which coordinates characterize the properties of the protected object [8]. To estimate the measure of the closeness or similarity between the modes in the N - dimensional space of information signs will be legitimate to use the Euclidean

$$\text{metric } D^2(v_{pk}, v_{ql}) = \sum_{j=1}^N (I_{pk}^j - I_{ql}^j)^2, \quad p, q = 1, 2, \dots, n; \quad k = 1, 2, \dots, k_p; \quad l = 1, 2, \dots, k_q, \quad I_{pk}^j - \text{values}$$

of j - sign of k - subregime in p -ro class, i.e. regime v_{pk} ; I_{ql}^j – mean of j sign of l subregime in q class, i.e. regime v_{ql} . Required for the recognition result can be obtained if the value measure of the closeness between the regimes of a class Ψ_p tends to the minimum value

$S(\Psi_p) = \sqrt{\frac{2}{k_p} \frac{1}{k_p - 1} \sum_{k=1}^{k_p} \sum_{l=1}^{k_p} D^2(\nu_{pk}, \nu_{pl})} \rightarrow \min$, and measure of the closeness between the regimes

of different classes Ψ_p and Ψ_q tends to the maximum value

$R(\Psi_p, \Psi_q) = \sqrt{\frac{1}{k_p k_q} \sum_{k=1}^{k_p} \sum_{l=1}^{k_q} D^2(\nu_{pk}, \nu_{pl})} \rightarrow \max$, and it's above a critical value, i.e. setting value in

relation to the relay protection. Measure of the closeness between regime under recognition ν and class $\Psi_g, g=1,2,...,n$, which given their regimes $\{\nu_g\}$: $L(\nu, \{\nu_g\}) = \sqrt{\frac{1}{k_g} \sum_{g=1}^{k_g} D^2(\nu, \nu_g)}$ determines

mean-square distance between regime ν and regime in the class Ψ_g . Improving the efficiency of the recognition system in the relay protection will be determined by obtaining the extremum $L(\nu, \{\nu_g\})$.

The problem of recognition of emergency regimes in a multidimensional space can be divided into several sub-tasks with decreasing dimension and in the limiting case recognized the area can be represented by a number of areas in the two-dimensional space, as shown in Figure 4. Field regimes DQAD in the two-dimensional area with current negative and zero sequence shown in Figure 4, and from which it follows that the selection of damage is practically impossible, because distance between modes $BC\Delta$, $AB\Delta$ and CAY , ABY , respectively, less than 15% of the rated current of the transformer to be protected. The mean-square distance between the regime of three-phase fault at phase failure on the side of higher voltages and modes of two-phase short circuit on the side of low voltage does not exceed 33%, which also makes it difficult to recognize the regime. This is especially manifested in the reduction of the protected power transformer.

Using two-dimensional space of the phase currents (in terms of two major currents of the three phase currents) allows for selection of modes of multiple DQAD. In this case, the mean-square distance between any recognizable modes exceed a value of 100% of rated current of the protected transformer. The choice of a special phase in the regime of the DQAD can be achieved with the help of a voter faulted phase, controlling the phase currents and voltages, such as breakage of the considered phase A, there is a reduction of the current phase and voltage increase with respect to other phases.

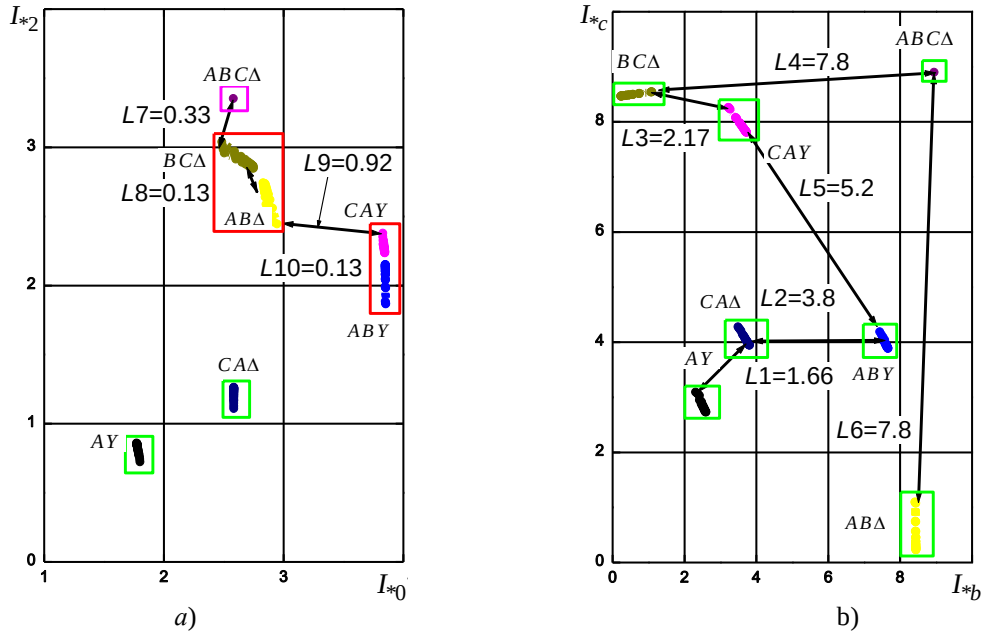


Fig. 4: Direct and quadrature axis dissymmetry regimes areas in plane «modulus-modulus» for the symmetrical sequences (a) and phase currents (b)

The results obtained can also be used in constructing the local backup protection (LBP) of the transformer. At the same time offered to play the maximum current protection with control of phase currents rather than their difference, which allows to realize LBP with the required sensitivity.

3 CONCLUSION

1. To minimize damage to electrical equipment and non-selective shutdown modes of multiple direct and quadrature axis dissymmetry in the overhead lines with tapping substations, you must install a special substation relay protection with increased recognition.
2. Overcurrent protection of transformers on the tapping and double-ended substations must be supplemented by the OPZS or run it in three-phase inclusion in the phase currents, which will provide the required sensitivity to the modes of multiple direct and quadrature axis dissymmetry.
3. Performing selection of multiple direct and quadrature axis dissymmetry in the radial lines with tapping substation on the basis of the control modules and angles of the phase currents and the currents of symmetrical sequences (components of emergency), and their relations with the formation of domains of possible emergency conditions, taking into account previous load-allows to implement an adaptive relay protection, parameters of the operation of which (current pickup and time delay) depends on the parameters of the current and previous regimes of the line.

REFERENCES

- [1] V.I. Nagay, I.F. Maruda, V.V. Nagay. Backup of Relay Protection and Switchgear in Electric Grids. – Rostov-on-Don, IoHE Publisher “IoHE news. Northern Caucasia” 2009. – 316 p.
- [2] I.F. Maruda. Line Short Circuit Relay Protection of Step-Down Transformers at Open-Phase Fault // Electric Power Stations. – 2003. – №2. – P. 44-46.
- [3] I.F. Maruda. Relay Protection for 110-220kV Lines at Phase Breakage // Electric Power Stations. – 2002. – №1. – P. 40-42.
- [4] A.B. Chernin. Electric Values Calculation and Relay Protection Behaviour at Single-Phase Operation Modes in Electric Networks. – M.: Gosenergoizdat, 1963. – 416 p.
- [5] A.M. Averbuch. Examples of Single-Phase Operation Modes and Short Circuits Calculation. – L.: Energy, Leningrad branch, 1979. – 184 p.
- [6] I.V. Nagay. Remote backup in the electrical grid 6-110 kV // News of the electrical engineering, 2010. №6(66). P. 28-30.
- [7] V.I. Nagay, V.V. Nagay, I.V. Nagay. Adaptive Measuring Devices For Emergency Components Of Backup Protection In Electric Distribution Networks // Actual trends in development of power system protection and automation: conf. proceeding of international Scientific & technical conference . – 2009. – Scien.-eng. agency. – P.134-140.
- [8] A.L. Gorelik, V.A. Skripkin. Recognition Methods. –M. Higher Sch. 1984. –P.208
- [9] K.I. Nikitin, M.Ya. Klecel, A.S. Stiski, N.M. Zaiceva. Device of Backup Current Protection of Transfortmer “star/star” // Industrial patent №2353039 RU. 09.01.2008.