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Differential protection of three and four parallel lines of idling current control

***Abstract**. Algorithms of operation of three or four parallel lines protections, based on the difference between the control currents in the corresponding phases and current in comparison with their idling current are proposed. The implementing of protections of three parallel lines on logic elements is given. The work is considered in different modes. It is shown that when the three lines of action of cascade zone do not exceed the line length of 0.08, while the four - 0.06.*

Streszczenie.** Opisano algorytm umożliwiający zabezpieczenie linii trzy- lub czteroprzewodowej bazujący na analizie różnic między prądami oraz różnicy pradów jałowych.* ***Różnicowe zabezpieczenie linii trzy- i czteroprzewodowej na podstawie analizy prądów jałowych.

Keywords: current, idling, corresponding phases.
Słowa kluczowe: zabezpieczenie elektroenergetyczne, prądy jałowe, linia trójprzewodowa

Introduction

Three or four parallel lines are used [1, 2] for the transfer of large capacity and ensure the reliability of electricity supply to consumers. In most cases, the distance protection is used for two parallel lines [3, 4] as well as to protect them from short circuits [1]. At the same time on two parallel lines, if the sensitivity is provided, directed transverse differential current protection is also set. The protection has such advantages as high performance and does not respond to swing the network. Its application is also possible for three or four parallel lines. However, three lines need three sets of protection, and four ones - six. The construction of protection with the implementation of microprocessor-based components is not difficult. However, its principal disadvantages are not eliminated. As the distance protection, it uses voltage circuit, the use of which can sometimes even lead to a very large accidents [1]; incorrect operation when circuits at two points in a network with isolated neutral and wire break short circuit in the network with grounded neutral, is also not excluded. Besides, in some cases its sensitivity is not sufficient. In this paper, developing the idea, set out in [5], the protection of three or four parallel lines, devoid of these shortcomings, is offered.

Principle of operation and selection of settings

Current magnitudes are controlled in the corresponding line phases. Maximum current is to be found and compared with each of these currents. If the difference between the maximum current and the current in phase of one line less than current Inb unbalance (defined short circuit (fault) on the tire of opposite substation) for homonymous phase of the other lines: the difference between the maximum current and the current in this phase is larger than I_{ub} and subtracted current exceeds load current, the fixed line is damaged (the first condition is satisfied for a given line) i.e.:

$$I_g^M - I_{gn} < k_1 \cdot I_{ub} \tag{1}$$

$$I_g^M - I_{gj} \geq k_1 \cdot I_{ub} \tag{2}$$

$$I_{gj} \geq k_2 \cdot I_{xxj} \tag{3}$$

where I_{gn} - the absolute value of the current in the g-phase (g - A, B, or C) of n-line (n = 1, 2, 3, 4), and I_{gj} и $I_{xx.j}$ - the absolute value of the current in the g-phase, and idle j-line (j = 1, 2, 3, 4), respectively, I_g^M - the absolute value of the maximum current in the g-phase of all lines (short-circuit for the current lines in the faulty phase) k_1, k_2 - detuning coefficients, and $n \neq j$ (when n = 1, j = 2, 3, 4).

It should be noted that the sign in (1) is not confused, but due to the specific construction of the protection associated with the use of a maksiselektor, and the implementation (1) for the phase of one of the lines corresponds to the non-compliance (2) for it and vice versa.

The current I_{ub} is maximal, if the above-mentioned three-phase short circuit is maximal and the current I_{gj} is minimal. This occurs when the error ε_1 of the current transformers and the error ε_2 of transformer reactors used to obtain information about the current in the lines, convert it into a voltage, are maximal, and the errors ε_3 from the difference in the resistances of lines and the errors ε_4 of the devices are known. We accept ε_1 = 0,1, ε_2 = 0,02, ε_3 = 0,03, ε_4 = 0,02, in accordance with existing assumptions. Then, we take into account the errors of calculation, taking k_1=1,05:

$$\begin{aligned} I_{op} &= 1,05 \cdot I_{нб} = 1,05(I_k^p \cdot (1+\varepsilon_2+\varepsilon_3) - \\ &- I_k^p \cdot (1-\varepsilon_1-\varepsilon_2-\varepsilon_4)) = 0,2 I_k^p \end{aligned} \tag{4}$$

where: I_{op} - conventional operating current of a protective device, I_k^p - the absolute value of the current lines in phases for three-phase short circuit on tires opposite substation excluding errors.

The coefficient k_2 is assumed to be 1.05, assuming that the current transformers reduce the load current, and the device and transreaktor increase.

The algorithm of protection

To compile the algorithm we use a technique consisting of the verbal formulation of operating conditions of the protection, recording it in characters of the algebra of logic and the implementation of algorithm on the logical elements of any nature or programmatically. The operating conditions for a network with isolated neutral are formulated as follows. Protection should work: 1) to disconnect the first power transmission lines, if there are signs of inequality (1) for the current in its phase A AND a signal of the embodiment (2) and (3) for the currents in phases A of the second or the third line, OR there are ... signals. (Hereinafter, the formulation is exactly the same, but in the phases B and C, respectively); 2) to disconnect the second transmission line, if not fulfilled the above condition of operation of the first transmission line, AND a signal on the implementation of (1) for the current in phase A of the second transmission line AND a signal of the embodiment (2) and (3) for the currents in phases A the first and third lines, OR there are ... signals (Hereinafter referred to phases B and C, respectively); 3) to turn off the third transmission line, if the conditions of operation for the first and second power lines are not met

AND there is a signal ... (the same way). In the symbols of algebra of logic the conditions of operation are written as follows: (5)

$$O_1 = S_{A1}(D_{A2}\cdot\overline{S}_{A2} + D_{A3}\cdot\overline{S}_{A3}) + S_{B1}(D_{B2}\cdot\overline{S}_{B2} + \\ + D_{B3}\cdot\overline{S}_{B3}) + S_{C1}(D_{C2}\cdot\overline{S}_{C2} + D_{C3}\cdot\overline{S}_{C3})$$

$$O_2 = (S_{A2}(D_{A1}\cdot\overline{S}_{A1} + D_{A3}\cdot\overline{S}_{A3}) + S_{B2}(D_{B1}\cdot\overline{S}_{B1} + \\ + D_{B3}\cdot\overline{S}_{B3}) + S_{C2}(D_{C1}\cdot\overline{S}_{C1} + D_{C3}\cdot\overline{S}_{C3}))\cdot\overline{O}_1 \quad (6)$$

$$O_3 = (S_{A3}(D_{A1}\cdot\overline{S}_{A1} + D_{A2}\cdot\overline{S}_{A2}) + S_{B3}(D_{B1}\cdot\overline{S}_{B1} + \\ + D_{B2}\cdot\overline{S}_{B2}) + S_{C3}(D_{C1}\cdot\overline{S}_{C1} + D_{C2}\cdot\overline{S}_{C2}))\cdot\overline{O}_1\cdot\overline{O}_2 \quad (7)$$

where: O_1, O_2, O_3 - disabling signals to the first, second, third transmission lines; S_{A1}, S_{B1}, S_{C1}, S_{A2}, S_{B2}, S_{C2} and S_{A3}, S_{B3}, S_{C3} - signals about the inequality (1) for the currents in phases A, B, C of the first, second and third lines; D_{A1}, D_{B1}, D_{C1}, D_{A2}, D_{B2}, D_{C2} and D_{A3}, D_{B3}, D_{C3} - signals about the inequality (3) for the same current.

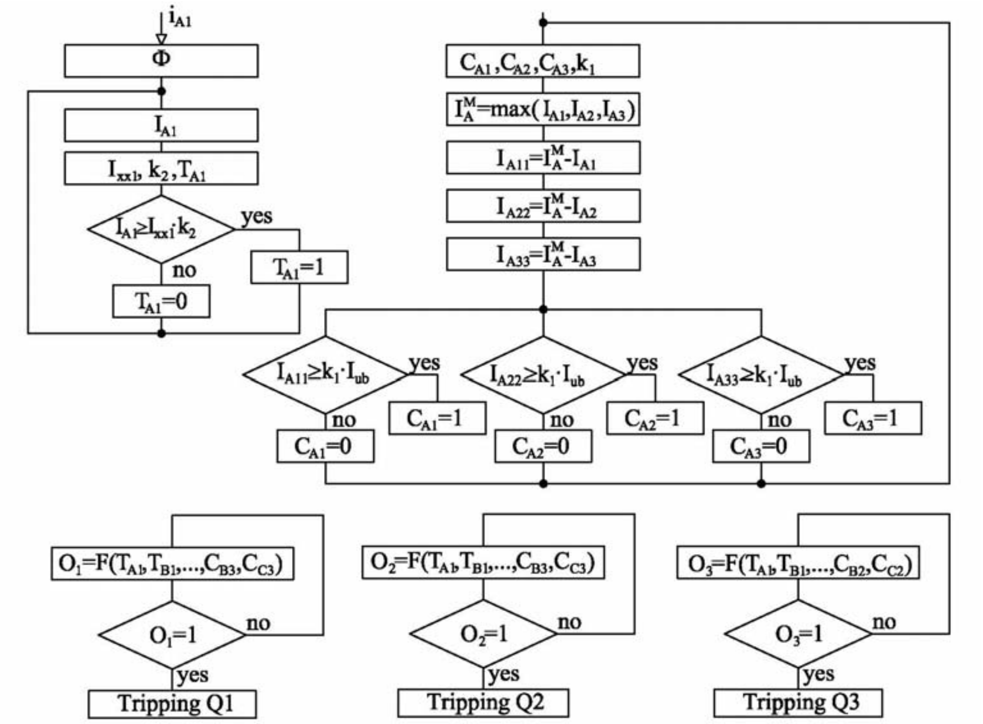

Fig 1 Block diagram of the algorithm of protection of three parallel lines for phase A

All variables are set to logical 1 if there is a corresponding signal and a logical 0 if it is not. For networks with earthed neutral operation conditions are written by (5, 6, 7), but without multipliers $\overline{O}_1$, $\overline{O}_2$.

Verbal recording algorithm and the symbols of algebra of logic for four parallel lines are similar to the above, but additionally used signals S_{A4}, S_{B4}, S_{C4} and D_{A4}, D_{B4}, D_{C4} on the implementation of, respectively, the inequalities (1) and (3) for the currents in phases A, B, C of the fourth line.

Program implementation

Figure 1 shows the structure of the algorithm to protect functioning of the three parallel lines for phase A for its implementation on microprocessor. Introduced open-circuit current I_{xx1}, I_{xx2}, и I_{xx3} of the first, second and third power lines, and the offset coefficients k_1 и k_2, logical variables $D_{A1}\ldots D_{C3}$ and $S_{A1}\ldots S_{C3}$, unbalance current I_{ub}. The instantaneous values of the two phase currents $i_{A1}\ldots i_{C3}$ are processed in parallel, then after digital filtering the corresponding absolute values $I_{A1}\ldots I_{C3}$ are compared with the open-circuit currents (3). After that, each of the variables $D_{A1}\ldots D_{C3}$ takes a value of 1 or 0, for example, D_{A1} =1, if $I_{A1} \geq k_2 \cdot I_{xx1}$. Next we need to find the largest of the currents I_A^M, I_B^M, I_C^M in each of three similar phases A, B and C. The values of the difference between the peak current and the currents of similar phases I_{A11}, I_{A22}, I_{A33} (I_{B11}, I_{B22}, I_{B33} и I_{C11}, I_{C22}, I_{C33}), are calculated, for example, $I_{A11} = I_A^M - I_{A1}$, $I_{A33} = I_A^M - I_{A3}$, $I_{B22} = I_B^M - I_{B2}$. These differences are compared with unbalance current according to (1). If the inequalities holds S_{A1}, S_{A2}, S_{A3} (S_{B1}, S_{B2}, S_{B3} or S_{C1}, S_{C2}, S_{C3}) are set to logic 1, otherwise - 0. Protection circuit breaker operates on the first, second or third power lines, if in accordance with the operation conditions with respect to (5), (6) or (7) O_1=1, O_2=1 or O_3=1.

The structure of the protection of four parallel lines algorithm is similar to above, but additionally I_{xx4} open-circuit current of the fourth line is introduced and the instantaneous values of the currents in its phases i_{A4}, i_{B4}, i_{C4} are processed.

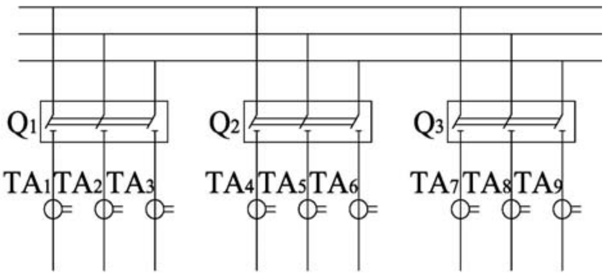

Fig.2. Three parallel lines

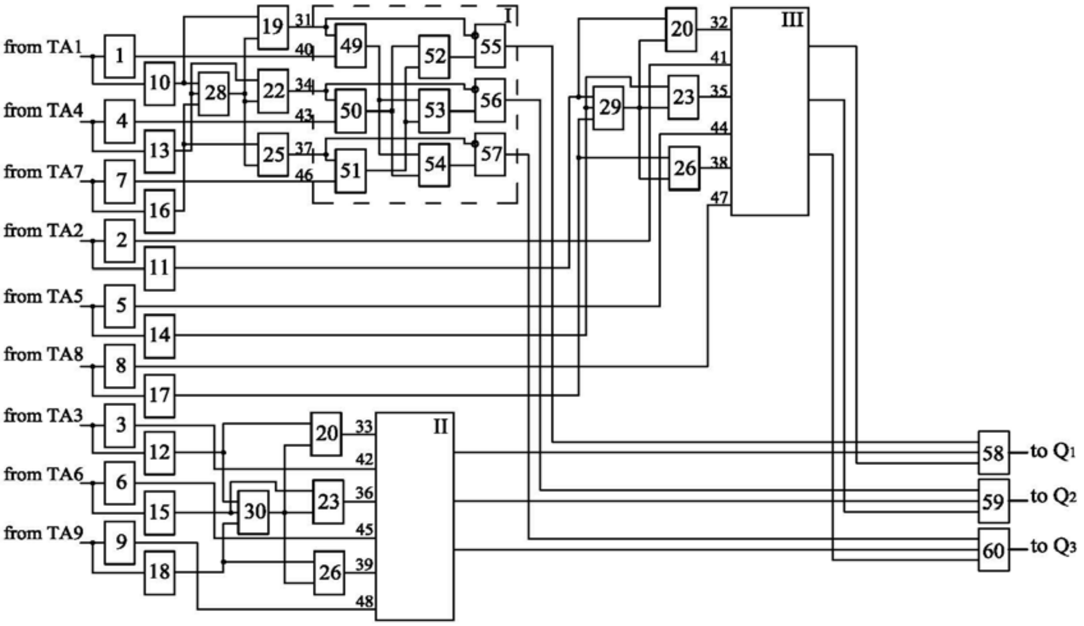

Fig.3. Structural scheme of protection of three parallel lines

Implementation for logic elements.

Figure 2 shows three parallel lines with switches Q1, Q2, Q3 and current transformers TA1–TA9, and Fig. 3, a functional diagram of the security device for network lines with earthed neutral (in the units II and III are the same elements as in I). Current relay 1 - 9, which are connected as current transformers 10 - 18, to the secondary windings TA1-TA9 of current transformers monitor load currents in the line phases (checking (3)) Relay 1, 2, 3 rebuilt from $I_{xx.1}$, relay 4, 5, 6 - from $I_{xx.2}$, relays 7, 8, 9 - by $I_{xx.3}$ and normally provide signals indicating that the embodiment (3). Inequality (1) for the current in each phase of the first, second and third lines is tested in comparison blocks 19 - 27 that when executed provide signals. Comparison blocks are connected to maksiselektors 28, 29, 30 and above mentioned current transducers. The signals from the comparison circuits and current relay arrive to the inputs, 31 - 39 and 40 - 48 logic blocks respectively (Fig. 3.), containing units I, II, III, made on the elements 49, 50, 51 and 52, 53, OR 54, 55, 56, 57 AND-NO, and elements 58, 59, or 60, whose outputs are connected to circuit breaker tripping Q1, Q2, Q3 (Fig. 2). For a network with isolated neutral additional elements are introduced and 61 with one inverted input NO- OR 62, and 63, which connect the circuit to the outputs of elements 58, 59, 60 shown in Fig. 4. and the protection of logic part of three parallel lines shown in Fig. 3.

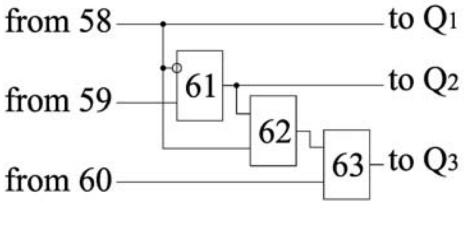

Fig. 4. Connection of additional logic elements

The protection of four parallel lines is similar to the protection of three parallel lines, but in each of the blocks I, II, III three current relays, three inverter currents and the comparison circuit, as well as AND gates, OR, and with one inverted input entered optional for the network isolated neutral protection scheme is complemented by another element of the NO- OR and one element AND.

Analysis

The protection operates as follows. The current in phase C $I_{C2}< k_{omc2}\cdot I_{xx2}$ is absent in the two-phase short circuit in the zone of the cascade action, for example between phases A and B on the second line after the circuit breaker from the substation fed by. In this case the currents in the phases of the remaining lines flow. Therefore, the variables $D_{A1}\div D_{B2}$ and D_{A3}, D_{B3}, D_{C3} are equal to 1 and D_{C2}=0. Inequality (2) holds for the currents in phases A and B are the first and third lines and in the second phase C, and for the rest are not performed. Therefore, I_{A11}, I_{A33}, I_{B11}, I_{B33}, I_{C22} are more than $k_{omc1}\cdot I_{ub}$, and the rest - less and, as a result, signals S_{A1}, S_{B1}, S_{A3}, S_{B3}, S_{C2} are set to logic 1 and S_{C1}, S_{A2}, S_{B2}, S_{C3} – 0. Consequently, O_2=1, and the switch Q2 is turned off.

In the open position, such as first line and short-circuit between the phases A and B on the third line, and the presence of current in the healthy phases, variables D_{A1}, D_{B1}, D_{C1}, D_{C3}, S_{A3}, S_{B3}, S_{C2}, S_{C3} take the value - 0, and all others - 1. Therefore, O_1=O_2=0, O_3=1,and the command is on Q3 off.

The functioning of the protection of three parallel lines in the other modes, as well as The functioning of the protection of four parallel lines, are analyzed similarly.

Sensitivity

The value of cascade action zone l_{cz} estimates the sensitivity for the protection of parallel lines

$$l_{cz} = l \cdot x$$

where: l - line length, x - the line of the tire opposite to the boundary substation cascade coverage, expressed as a percentage, and the coefficient of the sensitivity launchers bodies k_s

$$k_S = I_{k\,min} / I_{op}$$

where: $I_{\kappa.min}$ - the minimum short-circuit current at the point of damage, on the border of the cascade of coverage, after disconnecting the line from the power substation, I_{op} - current protection operation.

Using (2) and (4) define $l_{c.z}$, considering that the fault has occurred in the specified location. Then

$$I_{k1}^{p} - I_{k2}^{p} = 0,2 I_{k}^{p}$$

where: I_{k1}^{p}, I_{k2}^{p} - the currents in the phases of the first and second lines with the short circuit at the first.

At the same time short-circuit current to the site is leaking in two branches: on the faulty line; intact on one or two lines and the faulted line section on the other side. The current in the first branch may be expressed as

$$I_{k1}^{p} = E / \left[(l - l_{cz}) \cdot z_0 \right],$$

and in the second

$$E \Big/ \left[\left(\frac{l}{n-1} + l_{cz} \right) \cdot z_0 \right],$$

where: n - the total number of parallel lines; z_0 - resistivity of the line; E - EMF of the power source

The current in the intact line

$$I_{k2}^{p} = E / \left[(l + (n-1) l_{cz}) \cdot z_0 \right].$$

Current lines of phase short-circuit on the tires opposite substation

$$I_{k}^{p} = E / (l \cdot z_0).$$

Then, on the basis of the above, we obtain:

$$\frac{1}{1-x} - \frac{1}{1+(n-1)x} = 0,2. \tag{8}$$

Regarding (8), an equation with respect to x, we find that if the line includes two (n = 2), x = 0,1, if the three - x = 0,08, four - x = 0.06.

Cascade coverage is reduced by using a more accurate current sensors by reducing the tripping current, for example, if the current sensor has an accuracy of 2% in the first case, x=0.06, the second - x=0.04, the third - x=0.03.

Conclusions

The proposed protection only rebuilt from the unbalance current, does not require voltage circuits, behave correctly by broken wire one-way ground fault in networks with grounded neutral circuit and two points in a network with isolated neutral, have a cascading action zone, not more than 0.1 line length. If the information on the current in the lines of the current sensors used with errors lower than traditional current transformers, the coverage area of the cascade can be significantly reduced.

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