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Traversal Protection of Two Parallel Lines without Voltage Path

***Abstract**. Operation algorithm of two parallel lines protection that controls presence of current in their phases has been suggested. Its realizations on microprocessor and semiconducting element bases have been given. It is shown that protection is tuned away only from the unbalance current. Calculation of the value of its cascade action zone is formulated.*

Streszczenie.** Zaproponowano algorytm ochrony dwóch linii równoległych który kontroluje obecność prądów fazowych. Algorytm opracowano wykorzystując układ mikroprocesorowy. **Metoda zabezpieczania dwóch linii równoległych bez ścieżki napięciowej

Keywords: phases, comparison, current, short circuit, realization.
Słowa kluczowe: zabezpieczenie, linie równoległe, zwarcie.

Introduction

Traditionally used for two parallel lines traversal directed differential protection have some faults [1]: necessity of tuning away from maximal load currents and fault-free phase currents, the use of voltage circuit. In connection with this, work has been undertaken for their improvement, for example [2]. But in [2], too, voltage circuits are used, notably both for starting on the voltage of negative sequence, and for the identification of a damaged line. Distance protections are suggested too [3] – [6]. But they, like any other distance protections, have voltage paths, and this may lead even to industrial disasters, for example, in the USA in 1996 [7], when an undamaged parallel line was switched off by the distance protection under and abrupt and long-continued brownout of power. Besides, in the present period of time, the majority of protections is made on a microprocessor element base, which in a number of cases [8] is not characterized by sufficient reliability. To increase its reliability it is necessary to use not simple doubling, as it is a way in Europe, but the principle of domination. This will make it possible to raise the reliability of operation and nonoperation by many times. Maximum effect is achieved if the protections that back up each other have different principles of operation. Taking into consideration all the above mentioned, urgent is not only improvement of well-known protections, but also the development of protections on the basis of new principles. In this article we suggest to use traversal protections for two parallel lines that do not have drawbacks specified above.

Principle of operation and the choice of settings

The suggested protection controls currents in similar phases of lines and the values of their difference. The protection gives a signal about presence of damage on the first line, if the difference between the current in its phase and the current in the similar phase of the second line is larger than the current of imbalance I_{ub} that was determined under the short circuit (SC) on the buses of the opposed substation. It gives a signal to switch off the second line – if the difference between the current in its phase and the current in the similar phase of the first line is larger than the current I_{ub}. These conditions are written down in the following way (a – for the first line; b – for the second line):

(1) a) $I_{p1} - I_{p2} \geq I_{op}$ b) $I_{p2} - I_{p1} \geq I_{op}$

where I_{op}=$k_1 \cdot I_{ub}$, I_{p1} and I_{p2} – absolute values of the current in phases p of the first and second lines (p – A, B or C); k_1 is offset factor, I_{op} – protection operative current.

The value of I_{op} is established in the following way. It should be such as would not allow the protections operate excessively, when short circuits (SC) on the lines are absent, the differences in the currents in their similar phases are maximal. This takes place under three-phase SC on the buses of an opposed substation, when the errors ε_1 and ε_2 of the current transformers and transformer reactors that transform the secondary current of the lines into voltage reach maximal values. We will also take into account the error ε_3 of the device. Then

(2) $$I_{op} = 1.05 \cdot \left(I_k^{ph} \cdot (1+\varepsilon_2) - I_k^{ph} \cdot (1-\varepsilon_1-\varepsilon_2-\varepsilon_3) \right)$$

where I_k^{ph} is absolute value of the current in phases of the lines under three-phase SC on the buses of the opposite substation without the account of the abovementioned errors.

In accord with the existing allowances, let's assume that ε_1=0,1, ε_2=0,02, ε_3=0,02 и k_1=1.05. Substituting these values in (2) we will get the pickup setting

(3) $$I_{op} = 0.17 \cdot I_k^{ph}$$

Here, the protections are actuated to switch off the damaged line, if in addition to (1a) and (1b), consequently, the following inequations are carried out:

(4) a) $I_{p1} \geq k_2 \cdot I_{xx1}$ b) $I_{p2} \geq k_2 \cdot I_{xx2}$

where $I_{xx.1}$ and $I_{xx.2}$ are idle currents of the first, second, third and fourth lines, k_2 is offset factor.

Factor k_2 is taken equivalent to 1.05, considering that current transformers reduces I_{xx}, and the device raises it.

Software implementation

In accord with the conditions of the response, that were formulated above, the algorithm of protection operation, whose structural scheme for phase A is presented in Fig. 1, is as follows. The currents I_{xx1} and I_{xx2} of no load operation of the first and second lines, the factors of the offset k_1 and k_2, and the imbalance current I_{ub} are introduced. Simultaneously, instantaneous values of six phase currents i_{A1}, i_{B1}, i_{C1} and i_{A2}, i_{B2}, i_{C2} of the first and second lines are processed, after the digital filtration their absolute values I_{A1}, I_{B1}, I_{C1} and I_{A2}, I_{B2}, I_{C2} are established. They are compared with the currents I_{xx1}, I_{xx2} in accordance with the inequations (4a) and (4b). It the currents in the phases of the first line exceed I_{xx1}, and the currents in the phases of the second line exceed I_{xx2}, then implementation of inequations (1a) and (1b) is checked, if this were not the case, the protection does not operate. When implementing (1a) in the first line a signal is given to switch off the circuit-breaking push button Q_1, and when implementing (1b) a signal is given to switch off the circuit-breaking push button Q_2.

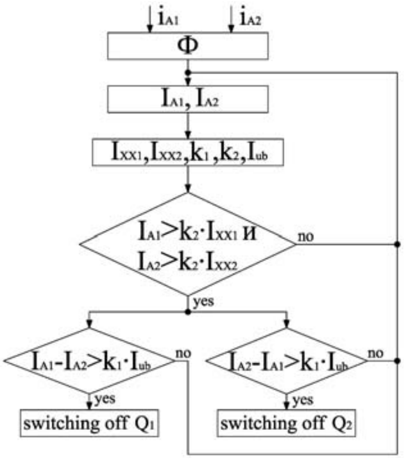

Fig. 1. Operation algorithm of protection of two parallel lines for phase A.

Implementation on logical elements

For the implementation of the device maxiselectors are used. Then I_{p1} is the current in output of the maxiselector for the first line, and for the second line it is I_{p2}.

Fig. 2 and 3 show the connection of measuring elements and the logical part of the protection (in blocks *II* and *III*, elements are the same as in *I*). Current relays *KA*1–*KA*6 control load currents and are connected, like the transducers *ПТ*1, *ПТ*2 of the current, to the transformers *TA*1–*TA*6 of the current. They are tuned away from $I_{xx.1}$, $I_{xx.2}$ and in a normal mode give signals, which testify to the implementation of (4a) and (4b). Blocks 1–6 of the comparison are connected to the maxiselectors *M*1, *M*2, *M*3 and the transducers *ПТ*1, *ПТ*2 give signals during the implementation of (1a) and (1b). Signals from the blocks 1–6 and the current relays come on inputs, respectively, 7 – 12 and 13 – 18 of logic block (Fig. 3), containing elements *AND* 19, 20, 22, 23, *NAND* 21 or *OR* 24, 25, outputs of the latter are connected to the disabling circuit of the circuit-breaking push buttons Q_1 и Q_2 (Fig. 3).

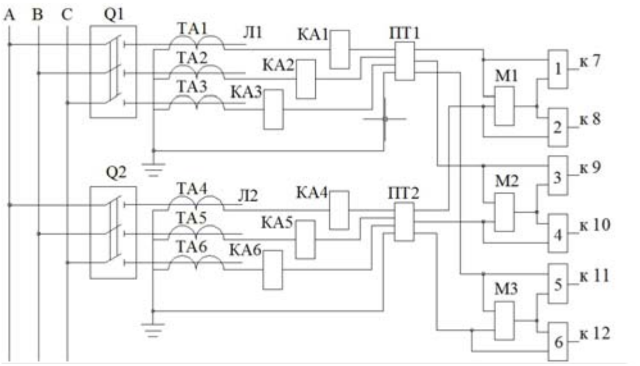

Fig. 2. Connection diagram of measuring elements of two parallel lines protection.

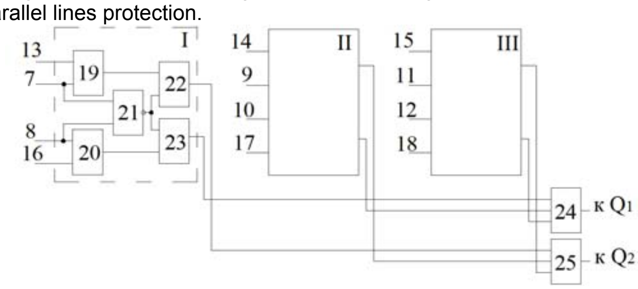

Fig. 3. Principle diagram of the logical part of protection of two parallel lines without voltage path.

Performance analysis

Let us consider the work of the protection (Fig. 2 and Fig.3) of two parallel lines. Let us assume that there was SC to ground of the phase A of the first line. Here, the relays *KA*1 – *KA*6 give signals to inputs 13 – 18 of logic block. Inequation (1a) is implemented, because I_{A1}>I_{A2}, the latter is seen on the oscillogram (Fig. 4) taken on the complex ВМК РВ ЭЭС (all mode real time simulation complex of electric power system) (similar oscillograms were obtained for other types of SC, but they are not given in the article). That is why block 2 gives a signal to input 8 of logic block. Consequently, on input of element *OR* 24 there appears a signal and the circuit-breaking push button Q_1 is disconnected.

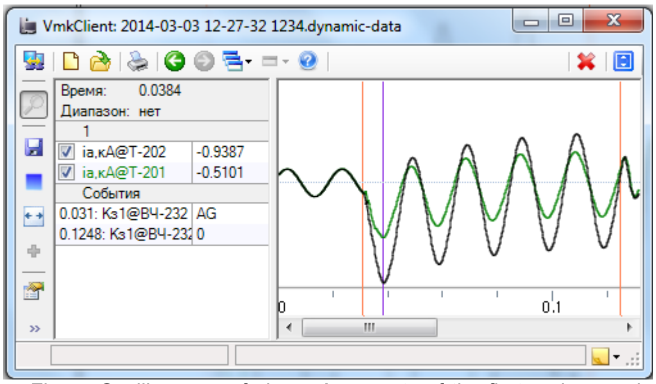

Fig. 4. Oscillograms of phase A currents of the first and second lines under one-phase SC on the first line.

Under a two-phase SC, for example between the phases B and C on the second line because of the presence of current in the undamaged phases of relays *KA*1 – *KA*6 give signals. Conditions of activation of blocks 1 and 3 are fulfilled. That is why, elements 19, 21, 22, 25 give signals, and the circuit-breaking push button Q_2 is disconnected.

In double ground faults in the networks with isolated neutral, for example, of phase A of the first line in the zone of cascade action and phase C of the line that goes from the buses of the opposite substation, after the disconnection of the first line from the powered substation, currents in its phases B and C are absent. That is why relays *KA*2 and *KA*3 are not actuated. Here, *KA*2 and *KA*3 are the currents in the rest of the phases, and relays *KA*1, *KA*4 – *KA*6 give signals to inputs 13, 16 – 18 of logic block. Because here I_{A1}>I_{A2} of element *OR* 24 gives a signal for disconnection of Q_1.

The work of protection under other modes is analyzed similarly.

Implementation of protection without current transformers

Let's note that protection can be implemented without current transformers. Here, the source of information about currents in the phases of lines can be inductance coils (IC) that are put near the current-conducting wire phase at a safe distance.

The condition of protection activation is written down as is shown above, but instead of currents in the phases of lines EMF are compared, that are obtained on the outputs of the respective IC. In the expressions (1), (4) instead of the actuating current I_{op} actuating EMF E_{op} is written, instead of I_{p1}, I_{p2}, I_{xx1} and I_{xx2} – their proportional EMF E_{p1}, E_{p2}, E_{xx1} и E_{xx2}.

The value E_{op} is calculated similar to (2), but instead of ε_1 influence of error ε_4 is considered, which is caused by the inaccuracy of establishing IC, and I_k^{ph} is changed for E_k^{ph} - the absolute value of EMF on the outputs of IC, directed by the current in the phase of the line under a three-phase SC on the buses of the opposite substation.

Sensitiveness

Traditionally sensitiveness is evaluated [1] by the value $l_{c.z}$ of the cascade action zone ($l_{c.z} = l \cdot x$, l is the length of the line, and x is its part from the end of the line to the beginning of the cascade action zone) and the coefficient k_s of the sensitiveness of the starting elements ($k_S = I_{sc.min} / I_{op}$, where $I_{sc.min}$ – is minimal current of the short circuit in the point of damage in the zone of cascade action after the disconnection of the line from the supplied substation, I_{op} is current of protection actuation). Using (1) and (3), for protection of two parallel lines, let us determine $l_{c.z}$, assuming that SC happened on the border of the zone of cascade action. Then, $I_{p1} - I_{p2} = 0.17 \cdot I_k^{ph}$. Here, current flows to the point of SC by two branches: by the damaged line; by the undamaged line and along the part of the damaged line on its other part. The absolute value of the current in the first line can be expressed as $I_{p1} = E / \left(l - l_{c.z} \right) \cdot z_0$, and in the second – $I_{p2} = E / \left(l + l_{c.z} \right) \cdot z_0$ (z_0 is electrical resistivity; E is EMF of the electric power supply). The current in the phases of the line under SC on the buses of the opposite substation is $I_k^{ph} = E / l \cdot z_0$. Then, proceeding from the stated, we get:

$$\frac{1}{1-x} - \frac{1}{1+x} = 0.17 \quad (5)$$

Considering (5) as an equation in reference to x, we will find x=0,085. Using the same reasoning, we will find the value of the cascade action zone of protection that gets information from IC.

Conclusions.

The suggested protections are not tuned away from maximal load currents and the currents in undamaged phases; they do not use voltage paths, they have zones of cascade action about 10% of the line length, and they behave correctly in various modes.

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