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Protection from Short Circuits of Parallel Connections Outgoing From Electric Stations' Buses

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Abstract: In the article the authors propose main and back-up protections of two and three parallel lines controlling ratio of currents in the phases of all connections of open distribution unit of electric station. The main ones protect from all kinds of short circuits, back-up ones - from one-phase short circuits. It is shown that for identification of a damaged line it is sufficient just to compare the currents in the same phases, for example, for correct functioning of the main one it is necessary to compare the currents in the lines with idle current, of the backup - it is necessary to evaluate the value of ratio of combinations of currents on the side of the lowest tension of boost transformers and the direction of power of zero sequence on the lines. The algorithms of functioning in the form of analytical expressions made on the base of verbal formulation of conditions of actuation with the use of logics of algebra. The algorithms take into consideration the necessity of acceleration of back-up protection with one-phase short circuit on the one of the lines. Flow harts of these algorithms are provided. The operation of these types of protection in different modes and their sensitivity are tested. It is shown that behave themselves in a right way even with disconnection of a wire with one-side earth short circuit and their sensitivity is higher than with traditional ones.

Key words: Currents ratio · Direction of power · The lowest voltage · Power transformer · Sensitivity · Protection · Short circuit

INTRODUCTION

Industrial disasters connected with operation of relay protection, take place more and more often, for example, the emergency situations in the USA in 1996, 2003, in Italy (2003), in Moscow (2005) [1-3]. As a rule they start from a short circuit to earth or with a strike of a lightning. One of the lines of electric station (ES) which bear big load switches off in more than necessary amount, overload of other lines takes place during which distant protection commonly used here [4-7] is actuated more than necessary (it is the result of faults in the high voltage lines). Now it is quite time to argue that to increase the robustness (reliability) without special methods - only by means of implementation of microprocessor devices of relay protection (MDRPs) will not be a good solution in the nearest future, as the best practices in operating have shown that the hopes laid upon MDRPs vanished completely [8]. Taking into consideration that MDRPs soon will take the first place among other means of protection, increase of their reliability is of utter importance. As we know [9,10] maximal effect from the use of MDRPs can be achieved if we use backup, when the signal for switching-off of the electric station is transmitted if 2 of 3 available backup protections with different principle of operation are actuated. But use of this variant for backup protections of lines is difficult because of their limited number and the need to reserve transformers of current (TA), which are not in enough quantity on the line for backup. In the article we propose reserved (back-up) protections for two and three parallel lines, outgoing from electric stations' buses (Figure 1), which operate on the basis of control of phase currents' ratio from the side of lowest voltage of transformer (Tr1, Tr2) of ES (electric station) blocks which feed these lines.

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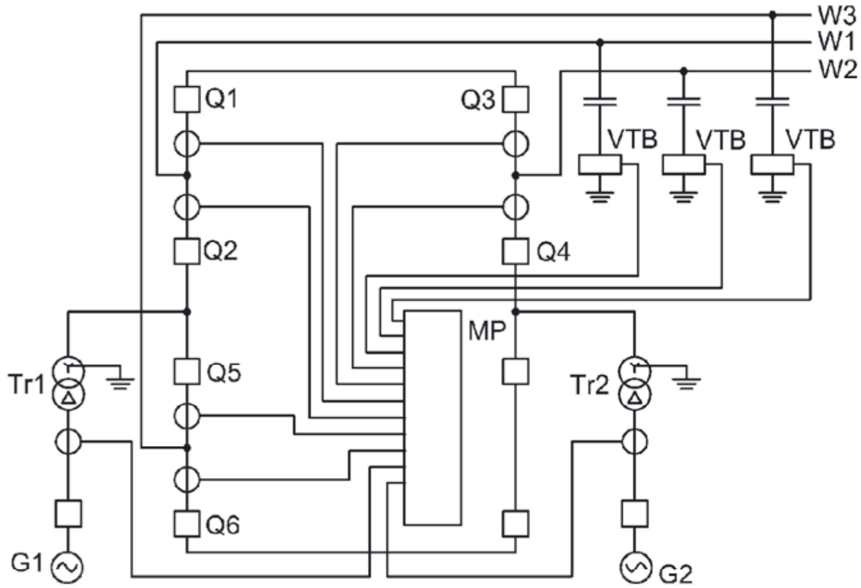

Fig. 1: Diagram of distribution device with 3 parallel lines; voltage takeoff block (VTB), microprocessor (MP).

Principle of Operation and Estimation of Sensitivity: Protection (devices) find out one phase short circuit on the side of higher voltage of transformers (Tr1 and Tr2) checking the current distribution on the lowest voltage side [11]. We propose to judge about availability of short circuit current comparing the following ratios in accident-free modes and one-phase circuit to earth (why we chose them will be clear from written below):

$$(a)\frac{|I_{AT}|+|I_{BT}|-2|I_{CT}|}{|I_{CT}|},(b)\frac{|I_{AT}|+|I_{CT}|-2|I_{BT}|}{|I_{BT}|},$$

$$(c)\frac{|I_{CT}|+|I_{BT}|-2|I_{AT}|}{|I_{AT}|} \qquad (1)$$

where I_{AT}, I_{BT}, I_{CT} - currents in the phases A, B and C on the side of lowest voltage of transformers Tr1 and Tr2.

Let us analyze (1) having in mind the following: the protection must be not actuated with maximal possible value of k_1, got in the result of operations on (1a), (1b) or (1c) if there are no one-phase short circuits but it must actuate in reliable way if the obtained value k^{shc}_1 (shc= of short circuit) is minimal with short circuit. To fulfill the 1st condition it is necessary that in (1) the denominator of the ratio was minimal, the numerator was maximal and for the 2nd condition it must be vice-versa. Taking into consideration the errors of the current transformers (0,1) and asymmetry of currents (0,05 ÷ 0,1) we have k_1=0,44÷0,63 and k^{shc}_1=12,8. These figures are obtained from the following: Let us think that in non-synchronized mode because of asymmetry and saturation of current transformers, for the worst variant we have $I_A=0,81I_{load}$, $I_B=0,81I_{load}$, $I_C=1,1I_{load}$ and with short circuit on the side of highest voltage of the transformer, the current in one of the phases on the side of lowest voltage is not 0, but = $0,1I_{shc}$ and the current transformers in two other phases have saturated, which leads to $I_C=0,1I_{load}$, $I_A=0,9I_{load}$, $I_B=0,9I_{load}$. Substituting the first values of currents into (1a), gives k_1, substituting the second ones - k^{shc}_1.

Sensitivity of protections as a rule is judged by sensitivity coefficient k_{sens} [11].

For current protections this relationship between currents is $k_{sens} = I_{shc\ min}/I_{cur\ act\ protect}$. where $I_{shc\ min}$ = is minimal current of short circuit, $I_{cur\ act\ protect}$=the current of actuation of the protection, which is in fact a threshold - when it is reached it must give a signal for switching-off. In distance protection devices k_{sens} - is ratio of resistances. Thinking in the same way we say that k_{sens} - is a ratio of k^{shc}_1 and k_1. Note the following: fixed value of k_{sens} does not exceed 1,5 for reserved protection devices. In our case $k_{sens} = k^{shc}_1/ k_1=20$ and we should say that this value does not depend on the value of short circuit current in classical interpretation of one-phase short circuit currents, when the currents in free phases are considered to be equal to 0. Consideration of issue of sensitivity of protection with available currents in non-damaged phases will go out of the scope of this article and demand serious consideration. Ratios 1 are chosen after comparison of different combinations of ratios of this kind ($|I_A|/|I_B|$, $|I_B|/|I_C|$, $|I_A|-|I_B|/|I_A|$ etc.) with regard to k_{sens}. Idea to find maximal k_{sens} was based on obtaining of minimal numerator in normal modes and zero in denominator during short circuit.

The protection identifies where short circuit took place, on the lines outgoing from ES and on the adjacent lines or in open distribution device of ES in the direction of power of zero sequence. To determine it the currents from transformers and voltage from voltage takeoff blocks (VTB) connected to the lines through condensers are fed to the microprocessor (MP) (Figure 1), to this microprocessor the currents from transformers of low side Tr1 and Tr2 are fed too. For acceleration of offered reserved protection devices when short circuit on one of the lines takes place (when one of the lines of main protections or its switch fail) the damaged one is identified by checking the following inequalities (a, b - the first one is damaged; c, d-the second one; e, f-the third).

$$\text{a) } I_{i1} - I_{i2} = I_{sv};\ \text{b) } I_{i1} - I_{i3} = I_{sv};\ \text{c) } I_{i2} - I_{i1} = I_{sv};$$
$$\text{d) } I_{i2} - I_{i3} = I_{sv};\ \text{e) } I_{i3} - I_{i1} = I_{sv};\ \text{f) } I_{i3} - I_{i2} = I_{sv}; \quad (2)$$

where I_{i1}, I_{i2}, I_{i3} are the currents in i-phases of 1st, 2nd and 3rd lines (i = A, B, or C); I_{sv}= set value.

When only 2 lines are available the damaged one is identified by (2a), that second one is damaged is identified by (2b).

With that the set value must be setoff from maximal unbalance current calculated with three-phase short circuit on buses of opposite sub-station - in the same way as with traditional transverse differential protections of parallel lines.

Main protections of two and three parallel lines from one-phase and inter-phase short circuits will identify the damaged one using inequality(2) and checking availability of currents in the phases of lines and comparing it with the idle current. As they are setoff only from the mentioned above currents of unbalance, their sensitivity is much higher than with traditional ones' [11].

Algorithms of Protection: To build algorithms we shall use the method [12], which consists of verbal description of condition of actuating of protection, its notation in logic algebra's symbols and realization of the algorithm on any logical elements or programs. Conditions of actuation of protection of two and three lines can be formulated as follows:

Main protection of 2 lines must be actuated for switching off the first one if there is signal $T_2^{(A)}$ about realization of (2a) for current in its phase A and there is signal $S_{1,2}^{(B)}$ about availability of current in phase A of second line, OR there is signal $T_2^{(B)}$ about realization of (2a) for current in phase B of the first AND there is signal $S_{1,2}^{(C)}$ about availability of current in the phase B of the second, OR there is signal $S_{1,2}^{(C)}$ about realization of (2a) for current in phase C of the first AND there is a signal $T_2^{(C)}$ about availability of current in the phase C of the second. For the second line conditions of actuation are formulated in the same way but with alternation of 1 for 2 and vice versa in indexes.

Backup protection of three lines must switch-off the first one if there is signal $S_1^{(T)}$ or $S_2^{(T)}$ about realization of one of the inequalities (1) for currents in the phases on the side of lowest voltages of transformers Tr1 and Tr2 accordingly and there is a signal $S_1^{(P)}$ about direction of power of zero sequence in the first line towards the buses and there is signal $S_{1,2}^{(A)}$ and signal $S_{1,3}^{(A)}$ OR $S_{1,2}^{(B)}$ and $S_{1,3}^{(B)}$, OR $S_{1,2}^{(C)}$ and $S_{1,3}^{(C)}$ about realization of (2a) and (2b) for currents in the phases A B C of the first line. For the second and third line the conditions of actuation are formulated in the same way but the figures in indexes are exchanged 1 for 2, 2 for 1 and 1 for 3 and 3 for 1 accordingly.

For main protection of the tree and backup protection of two lines verbal description of actuation conditions are the same.

Taking said above into consideration actuation conditions for switching off of the first line are put down in the symbols of logic algebra in the following way ((2a) for main protection of the two lines. (3a) - for backup protection of three):

$$O_1^{II} = T_2^{(A)} \cdot S_{1,2}^{(A)} + T_2^{(B)} \cdot S_{1,2}^{(B)} + T_2^{(C)} \cdot S_{1,2}^{(C)} \quad (4)$$

$$O_1^{III} = \left(S_1^{(T)} + S_2^{(T)}\right) \cdot S_1^{(P)} \cdot \left(S_{1,2}^{(A)} \cdot S_{1,3}^{(A)} + S_{1,2}^{(B)} \cdot S_{1,3}^{(B)} + S_{1,2}^{(C)} \cdot S_{1,3}^{(C)}\right) \quad (5)$$

where O_1^{II}, O_1^{III} are the signals for switching-off of the first line; all variables take values of logical 1, if there is appropriate signal and logical 0 if there are no signal.

For other lines actuation conditions are formulated in the same way as with (4) and (5) taking into consideration necessary substitutions.

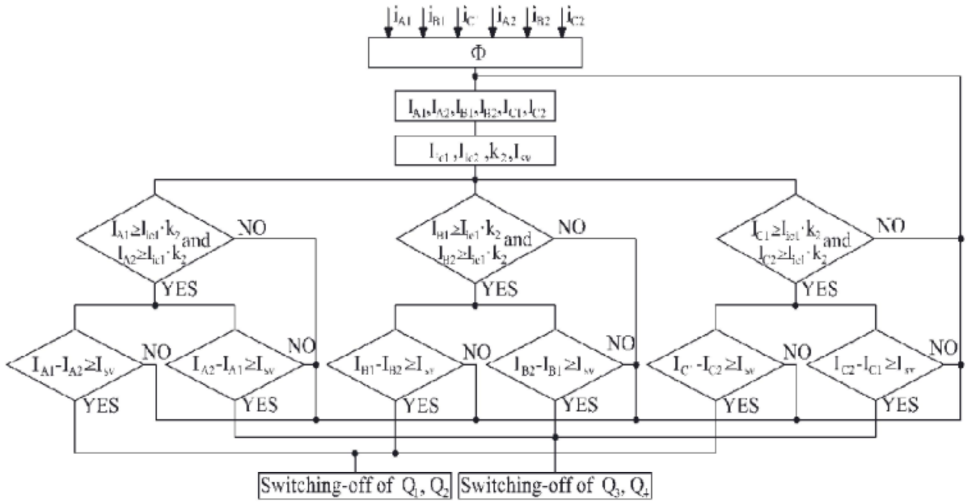

Fig. 2: Structural diagram of algorithm of functioning of main protection

Realization: Figure 2 shows the structure of algorithm of functioning of main protection of two parallel lines. Idle currents I_{ic1} and I_{ic2} are put in for 1st and 2nd lines, set value I_{sv} (current of actuation of protection), coefficient k_2. In parallel instantaneous values of 6 phase currents i_{A1}, i_{B1}, i_{C1} and i_{A2}, i_{B2}, i_{C2} are processed of 1st and 2nd line, after digital filtering their absolute values are found : I_{A1}, I_{B1}, I_{C1} and I_{A2}, I_{B2}, I_{C2}. Then the currents I_A^M, I_B^M, I_C^M are identified. The currents in the phases of the lines are compared with currents I_{ic1}, I_{ic2}. If they exceed them (2a) and (2c) is verified. If 2a is true the switch-off signal is transmitted to the switches Q_3 and Q_5 of the 1st line, if 2c is true - to switches Q_4 and Q_6 of 2nd line.

For three parallel lines algorithm of functioning of protection is put down in the same way. But additionally current I_{ic3} is entered and instantaneous values i_{A3}, i_{B3}, i_{C3} of phase currents of 3rd line are processed. After digital filtering of 9 phase currents their absolute values are compared with the idle currents of appropriate line. If the currents in 2 of 3 similar phases exceed the corresponding idle currents, (2a) and (2b) for the 1st line are checked. If they are true switch-off signal is transmitted to switches Q_1 and Q_2 of 1st line. If they are false then (2c) and (2d) for 2nd line (figures in indexes are exchanged accordingly) etc.

Figure 3 shows structural diagram of algorithm of functioning of backup protection for 3 parallel lines for phase A. The ranges (intervals) $\Delta\varphi_1$, $\Delta\varphi_2$ and $\Delta\varphi_3$ of angles between vectors of voltage and currents of zero sequence corresponding to the power direction towards buses, offset coefficient k_1 and set value I_{sv} are used. In parallel instantaneous current values i_{AT1}, i_{BT1}, i_{CT1} and i_{AT2}, i_{BT2}, i_{CT2} in phases from the side of lowest voltage of transformers are processed, instant current values i_{A1}, i_{B1}, i_{C1}, i_{A2}, i_{B2}, i_{C2} and i_{A3}, i_{B3}, i_{C3} in phases of the lines, the currents i_{01}, i_{02} and i_{03} of zero sequence of 1st, 2nd and 3rd lines and voltage u_0 of zero sequence. After digital filtering the absolute values of all phase currents are calculated - as well as vectors of currents and tension of zero series. The values of angles φ_1, φ_2 and φ_3 $(\varphi_1 = U_0 I_{01} U_0 I_{01})$ are identified and so on.

Inequality (1b) is checked. If it is true it is checked if φ_1, φ_2 and φ_3 belong to intervals $\Delta\varphi_1$, $\Delta\varphi_2$ and $\Delta\varphi_3$, accordingly. Then inequalities (2) are checked. For example if (2a) and (2b) are true switch-on state of switches Q_3, Q_4 of 2nd line and Q_5, Q_6 of 3rd line is checked. If even 1 pair of these switches is switched on the protection accelerates that is why time relay TR1 is activated, if they are switched off - TR4. After time delay switches Q_1 and Q_2 are switched off. In the same way protection operates switching off switches of 2nd and 3rd lines. If inequalities (2) are not true TR4 is also activated which provides for selectivity of operation of protection when backup is distant, after time delay both lines are switched off. Time delay of TR1-TR3 will offset from the time of actuation of the first stages of protection of the previous sector and TR4 - from time delay of the 3rd stage.

Algorithm of functioning of protection of two parallel lines is analogous to described above. Signals from TA of the 3rd line are absent in it. Damaged one is identified accordingly to realization of inequalities (2a) or (2c).

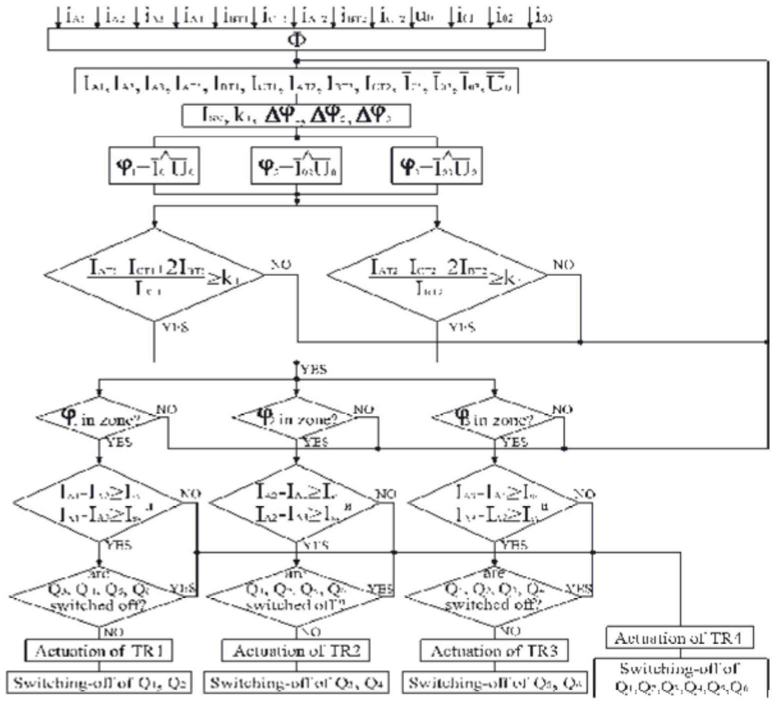

Fig. 3: Structural diagram of algorithm of functioning of protection for three parallel lines.

Analysis of of Operation of Both Types of Protection: Let us see operation of the main protection of 2 parallel lines (Figure 2). We assume that short circuit to earth of phase A of 1nd line took place. At this time currents in phases of all lines are present and exceed corresponding values of idle current. The inequality (2a) is realized because the current in the phase A of the 1st line is higher than the current in the same phase of 2nd line. Therefore the protection is actuated and the switches Q_1 and Q_2 switch off.

If two-phase short circuit takes place (say, between phases B and C on the second line, if there is current in non-damaged phases the currents in the phases of all lines will exceed the appropriate idling currents. (2c) is true. Protection is actuated and the switches Q_3 and Q_4 switch off.

Let us see operation of main protection of 3 parallel lines. With 2-phase short circuit (say, between phases A and B, on the 2nd line), if there are not currents in non-damaged phases, there is no current in its phase. At the same time currents go through other phases and exceed the idling currents of the lines. (2a) and (2b) are checked, which will be true only for currents in phases A and B of 2nd line, as they are higher than currents in the same phases of 1st and 3rd lines. The switches Q_3 and Q_4 will switch off.

After disconnection of wire, say, of phase A of 1st line with short circuit to earth from the opposite side realization of both (2a) and (2b) will not be possible for every line - the protection is not actuated.

In a case of switching off of 1st line from the opposite side, there are no currents in all three phases of 1st line. It means that currents in it are less than its idling current and. as the currents in the phases of other lines are equal, (2a) and (2b) are not true for them and protection is not actuated.

Let us see operation of protection of three parallel lines, say, when one-phase short circuit in phase A of 2nd line takes place, when all the lines are switched on. At this time the currents in phases B of both transformers from the side of coil connected in triangle manner are absent. And (1b) is true. Angle φ_2 is in the zone (direction of power towards buses), that is why further on the currents in the phases of the same name are compared. The current in phase A of 2nd line is higher than currents in the same phases of 1st and 3rd lines. Therefore (2c) and (2d) are true and TR2 is actuated. After time delay the switches Q_3 and Q_4 switch off. When one-phase short circuit on the line outgoing form the buses of opposite sub-station takes place (1b) is true, angles φ_1, φ_2 and φ_3 are in the set intervals and (2a)-(2f) are not true. That is why TR4 is actuated and after time delay the switches Q_1 and Q_6

switch off. At one-phase short circuit, say, in phase A on the outputs of Tr1 the currents in the phase B of both transformers are also absent. And (1b) is true. The angles φ_1, φ_2 and φ_3 are out of the set intervals (the power is directed from the buses) and the protection is not actuated. In a case when the 1st and 3rd lines are switched off and one-phase short circuit on the line outgoing from the buses of opposite sub-station takes place the (1b), (2c) and (2d) are true, the angle φ_2 is within set interval, but switches Q_1, Q_2 and Q_5, Q_6 are switched off. That is why protection is actuated and switches Q_3 and Q_4 switch off after time delay of TR4.

Operation of backup protection of 2 parallel lines is analogous.

Inference:

- On the base of proposed ratios it is possible not using current transformers of parallel lines to construct for them backup protections from short circuit to earth with sensitivity which does not depend on these currents if we admit that in non-damaged phases they are equal to zero.
- Proposed types of main protection of 2 and 3 parallel lines are more sensitive than traditional transverse differential directed protection.

REFERENCES

1. Koshcheev, L. and V. Semenov, 1997. System disasters in the West Energy Community of the USA. Electricity, pp: 10.
2. Alekseev, B., 2005. System collapses and the measures for their prevention. Electric Stations, 4: 78-83.
3. Kovalev, V. and V. Ivakin, 2006. Regarding system collapse in the energy networks of central region of Russia on the 25th of May 2005. Electricity, 9: 52-54.
4. Blumschein, J., M. Kereit, T. Sezi, G. Steynberg and Y. Yelgin, 2011. "Schutz von Parallelleitungen eines elektrischen," EP patent.
5. Jongepier, A. and V. Sluis, 1997. Adaptive distance protection of double circuit lines using artificial neural networks. IEEE Transactions on Power Delivery, 12: 97-105.
6. Yi Hu, D., Novosel, M. Saha and V. Leitloff, 2002. An adaptive scheme for parallel-line distance protection, IEEE Transactions on Power Delivery, 17: 105-110.
7. Hupfauer, H., P. Schegner and R. Simon, 1996. Distance protection of unsymmetrical lines. European Transactions on Electrical Power, 6(2): 91-96.
8. Gurevich, V., 2009. Reliability of Microprocessor-Based Relay Protection Devices: Myths and Reality. Serbian Journal of Electrical Engineering, 6(1): 167-186
9. Gurevich, V., 2012. A new criterion needed to evaluate reliability of digital protective relays. Journal of Electrical Engineering, 63(5): 332 - 336.
10. Fedossev, A., Relay Protection of Electric energy systems. Networks Relay Protection. Mosow: Energocomizat.
11. Bass, E. and V. Doroguntsev, 2002. Relay Protection of Electric energy systems. Mosow: Publishing house of MEI.
12. Polyakov, V., S. Zhukov and G. Proskurnin, 1979. Theoretical foundations of building of logic part of relay protection and automatics of energy systems. Moscow: Energy.