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PROTECTION OF A TWO-CABLE LINE FROM SINGLE PHASE-TO-EARTH FAULT WITH ABSOLUTE SELECTIVITY

Abstract. At present, if the line has two cables, during its protection from single phase-to-earth fault one zero sequence current transformer worn simultaneously on both cables or one per cable is used in isolated neutral system. In this case, the secondary coils of these transformers are connected in parallel or in series. If the conditions for selecting the operation threshold set out in are fulfilled, the operation zone of such protection applies both to the entire line and to all its consumers. As a result, the protection of such a line has a relative selectivity.

This article substantiates the relevance of the protection of a two-cable line from single phase-to-earth fault with absolute selectivity; develops the method of its protection based on measuring the difference of the zero sequence currents in this line cables; provides for the choice of the mode of this line operation, in which the unbalance current in the current relay is maximal; proposes a method for calculating the current relay operation threshold, as well as evaluates the protection insensitivity zone and its dependence on the number of connections on the substation bus bars.

Keywords: two-cable electric line, single phase-to-earth fault, protection method, protection operation threshold.

Introduction. In urban and industrial power supply systems, most of the electric power is distributed to consumers through cable networks with a voltage of 6-10 kV. At the same time, up to 75-90% of the total number of electrical damages in these cable networks is due to single-phase to ground fault (SPGF) [1-3], which are often the primary cause of more severe accidents, accompanied by significant economic damage. At the same time, the current of the SPGF is small, since it is caused by the cable cores capacitance relative to the earth [4-6]. In this regard, in accordance with the EIC (Electrical Installation Code), the existence of an SPGF is allowed within two hours, while the relay protection from SPGF can act both on the trip and on the signal [7, 8].

As you know, cable networks of large cities and powerful industrial enterprises are complex, and their configuration depends on the location and number of power sources (PS), switchgears (SW) and electricity consumers (EC), technological conditions of the production [9,10]. A significant role in such cable networks is played by communication lines, which are used to redistribute electricity between power sources and switchgears in a city or industrial enterprise. Such lines are equipped with two switches, and some of them are made in the form of two or more cables.

At present, if the line has two cables, when implementing its protection [1, 2, 11] from a single-phase to ground fault (SPGF) [12, 13] one core balance current transformer (CBCT) is used in networks with isolated neutral. It is worn simultaneously on both cables or one CBCT per cable. In this case, the secondary windings of these transformers [14] are in parallel or in series aiding. When the conditions for selecting the trigger threshold set out in [1, 2, 11] are fulfilled, the protection zone of such protection applies both to the entire line and to all its consumers. As a result, the protection of such a line has a relative selectivity.

At the same time, selective disconnection of the damaged network element is a fundamental requirement, which is required for relay protection of 6-10 kV cable networks from SPGF [7]. In this regard, two directional maximum residual current protections with a step-by-step selection of the response time of type ZZP-1 or MiCOM are established for each communication line. Such protections have a relative selectivity, and to ensure their operation, a zero-sequence voltage source is required [15, 16]. In relay protection [17, 18], this voltage is obtained from the secondary winding of a three-phase voltage measuring transformer of NTMI type connected to an open triangle.

Therefore, due to the constantly changing number of connections, the calculation of operation thresholds of directional current protectors on the communication line buses is rather complicated and depends on many factors. In this regard, it is not always possible to build the protection so that they adequately respond to the SPGF in a network with such a line. In addition, failure of protection at one of the stages can lead to a long and time-consuming search for the reason of the protected line disconnection. Moreover, in a rather complex network, the search time can exceed the two-hours regulated by EIC.

Largely, the listed problems can be avoided by using protection with absolute selectivity on communication lines. In addition, to improve the reliability of power supply, protection with absolute selectivity in some cases can be used as a backup.

Thus, the development of protection with absolute selectivity from single-phase to ground fault in a line of two cables, which does not require a zero-sequence voltage source is relevant.

Principle of operation of device. It is possible to obtain absolute selectivity [11] if the secondary coils of the zero-sequence transformers are connected in parallel-opposition or series-opposition. That is, to use the cross-differential principle of constructing line protection on zero-sequence currents.

The scheme of such protection is shown in Fig.1, where the protected two-cable line with two ZSCTs is designated as W1, and the remaining lines of the cable network are replaced by one equivalent, which is designated as $W\Sigma$. At the same time, for simplicity, it is considered that ZSCTs have a transformation ratio equal to one.

As a result, at SPEF at points k1 and k2 on substation bus bars and the load as shown in figure 1,a, currents $I_{C1.1}$ and $I_{C1.2}$ of zero sequence flowing along the ZSCT CT1 and CT2 will be equal in magnitude and have one direction (figure 1,a). Herewith, current in the coil of the current relay CR is

$$I_{r,k1} = I_{C1.1} - I_{C1.2} = 0 \tag{1}$$

In turn, at SPEF, at any point in the cable line, for example at c3 point, SPEF currents at ZSCT CT1 and CT2 are not equal in magnitude and has the opposite direction (figure 1,b). Further, current in the coil of the current relay CR is

$$I_{r,k3} = I_{C1.1} + I_{C1.2} \tag{2}$$

From which it follows that the protection will only work at SPEF in the interval from ZSCT to the load bus bars. Thus, this protection as a cross-differential protection has absolute selectivity and has a dead band [1, 2, 11]. The dead band magnitude is determined by comparing the dependence $I_{r,k3}(l_{k3})$ and the trip current magnitude I_{tr} as follows.

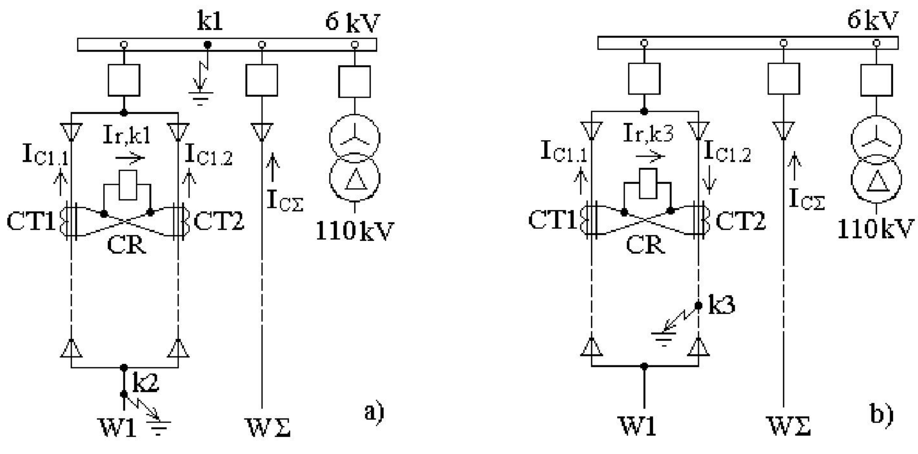

Figure 1 – Currents distribution schematic at SPEF on the substation bus bars and in the protected two-cable line

Sensitivity and area of protection. During operation, the number of connections to the substation bus bars other than the protected line can vary significantly. Consequently, will vary the total magnitude of their capacity C_Σ and the magnitude of currents $I_{C1.1}$, $I_{C1.2}$ as well as their difference in the form $I_{r,k3}$. Current dependencies $I_{C1.1}$, $I_{C1.2}$ as well as their difference in the form of current in the relay coil $I_{r,k3}$ from the location of SPEF c3 point on the damaged cable in the network at $C_\Sigma = 40\,\mu F$, 20 μF and 0 μF are shown in figure 2. These dependencies in accordance with [19] were obtained using Electronics Workbench, a well-known circuit modeling system [20] for a line of two aluminum cables with a core section of 10 mm^2 and a length of l_c equal to 1 km, which have $r_o = 3{,}1\,Ohm/km$ and $c_o = 3{,}1\,\mu F/km$ at nominal phase voltage $U_{ph} = 220\,V$.

Trip current is also determined as for conventional cross-differential protection in the form of

$$I_{tr} = C_k C_r I_{unb}, \qquad (3)$$

where C_k is the coefficient for taking into account capacitive kicks for intermittent SPEF, which, if there is a time relay, is assumed to be 2-3; C_r - the reliability coefficient in accordance with [11] is equal to 1.1-1.2; I_{unb} - unbalance current, i.e. the highest current magnitude in the relay coil, in the absence of SPEF in the protected line.

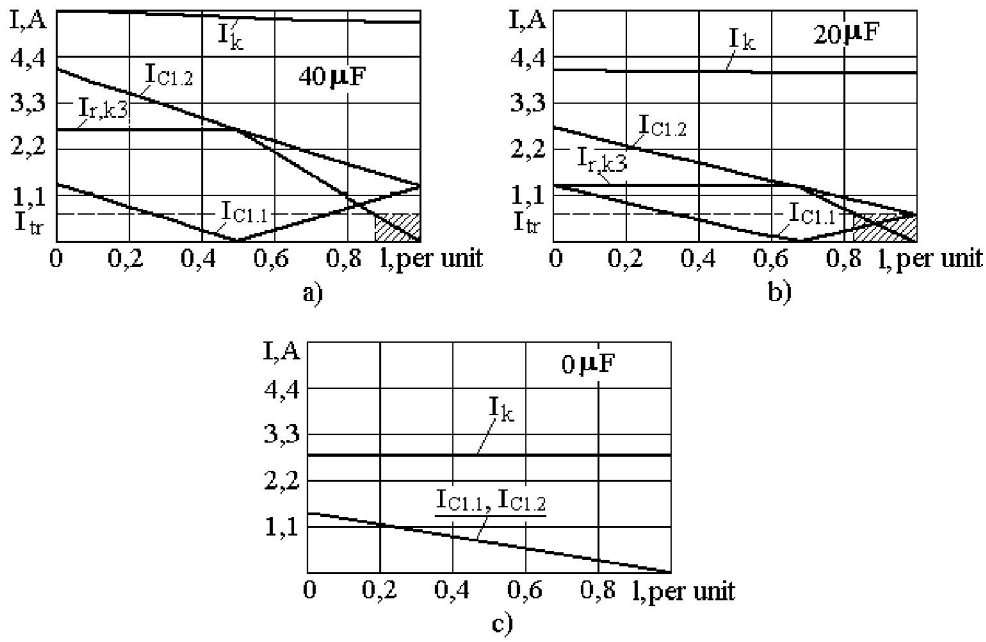

Figure 2 – Modeling results using zero sequence current difference

As is known, ZSCT, like conventional current transformers, has measurement errors that are caused by non-identical characteristics of magnetization by a number of other causes caused by their manufacture and installation. These measurement errors are made up of errors in both current and angle. Measurement error magnitude is largely dependent on the type of ZSCT. However, when determining the operation threshold and putting protection into operation, it is considered that the difference between the measured losses from the initial magnitude should not exceed 10% of the current and 7^0 of the angle [7].

Results. As during the operation the number of connections to substation bus bars can vary, from the scheme in Fig. 1,a and the dependencies in figure 2 it becomes clear that the greatest current magnitude I_{gr} will be at SPEF at point k2, when the sum of the capacitive currents of all available connections to substation bus bars, except for the protected line will flow through ZSCT. In this case, the unbalance current in the relay coil is equal to

$$I_{unb} = I_{C\Sigma} C_{err} , \quad (4)$$

where C_{err} - is ZSCT error coefficient, in calculations taken equal to 0.1.

Thus, for the previously considered line of two aluminum cables with the capacity of all other connections C_{Σ} = 40 μF, the unbalance current will be 0.3 A, and the current tripper will be 0.66-0.72 A. Then, taking into account figures 2,a and 2,b the dead band size at C_{Σ}=40 μF and 20 μF will be approximately (0,12-0,13)l_c and (0,18-0,196)l_c.

Conclusion. Thus, an increase in the number of connections on substation bus bars, which leads to an increase in the total magnitude of their capacity C_{Σ}, is accompanied by an increase in zero-sequence currents through ZSCT at SPEF in any cable of the protected line, and, consequently, by the increase of the current $I_{r,k3}$ in the coil of the current relay CR and the reduction of the dead band zone size. At the same time, disconnection of all connections from the substation bus bars leads to the fact that the current $I_{r,k3}$ in the coil of the current relay CR sets to zero (figure 2,c), and the protection becomes insensitive to SPEF. However, this is entirely permissible, if the substation is equipped with non-selective SPEF occurrence signalization.

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ЗАЩИТА ЛИНИИ ИЗ ДВУХ КАБЕЛЕЙ ОТ ОДНОФАЗНОГО ЗАМЫКАНИЯ НА ЗЕМЛЮ С АБСОЛЮТНОЙ СЕЛЕКТИВНОСТЬЮ

Аннотация. В настоящее время если линия имеет два кабеля, то при реализации ее защиты от однофазного замыкания на землю в сетях с изолированной нейтралью используют один трансформатор тока нулевой последовательности, одеваемый одновременно на оба кабеля или по одному на кабель. При этом вторичные обмотки этих трансформаторов соединяют согласно параллельно или согласно последовательно. При выполнении условий выбора порога срабатывания изложенного в зоне действия таких защит распространяется как на всю линию, так и на всех ее потребителей. В результате защита такой линии обладает относительной селективностью.

В данной статье обоснована актуальность защиты линии из двух кабелей от однофазного замыкания на землю с абсолютной селективностью, разработан ее способ защиты, основанный на измерении разности токов нулевой последовательности в кабелях этой линии. Приведен выбор режима работы этой линии при котором ток небаланса в реле тока максимален и предложен метод расчета порога срабатывания реле тока. Дана оценка зоны нечувствительности защиты и ее зависимость от числа присоединений на шинах подстанции.

Ключевые слова: электрическая линия из двух кабелей, однофазное замыкание на землю, способ защиты, порог срабатывания защиты.

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