Principles of protection against single phase earth faults in networks with capacitive current compensation

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Abstract. Protections that respond to a constant operating current applied to the network. This principle allows, in addition to the protection itself, continuous monitoring of insulation defects. But the imposition of direct current on the network is common only in networks with a voltage below 1000 V. In relation to 3-35 kV networks, the applied direct current is not used, in particular, due to the fact that the possibility of individual blind grounding of several neutrals of the primary windings of voltage measuring transformers, which can be installed at different substations of the network, is excluded. The protection with the imposition of direct current has most of the elements in galvanic connection with the generator voltage system, which, of course, reduces operational reliability. Moreover, grounding the system can lead to catastrophic consequences. The use of this method is also limited by the fact that special transformers must be installed at each connection, which in turn is very expensive.

1 Introduction

Devices that respond to high- and low-frequency operational current applied to the network. These devices are most widely used in high-voltage distribution networks. The reason for the creation of such protections was the fact that the corresponding harmonics in the natural earth fault current are practically not contained or insignificant. In order to make the level of harmonics in the zero sequence current independent of the operating mode of consumers, an artificial one is applied to the natural short circuit current, usually containing a current with a frequency of 25 Hz and 100 Hz. For selective operation with intermittent arc closure, the use of protections with the imposition of a control current with a frequency of 25 Hz is preferable [1,2].

Devices with a low-frequency superimposed current, unlike many other earth fault protections, with an appropriate choice of the frequency response of their reacting organs, function correctly with stable intermittent arc circuits. In this case, only one electrical value is supplied to the protection – the zero sequence current, and no individual setpoint selection is required depending on the parameters of the protected line.

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2 Materials and methods

This is due to the fact that the low-frequency current is distributed better during short circuits than the high-frequency current, since it is less shunted by the capacitances of intact connections. Several types of such protections have been developed [3]. The principle of protection using a frequency of 100 Hz shows (Figure 1).

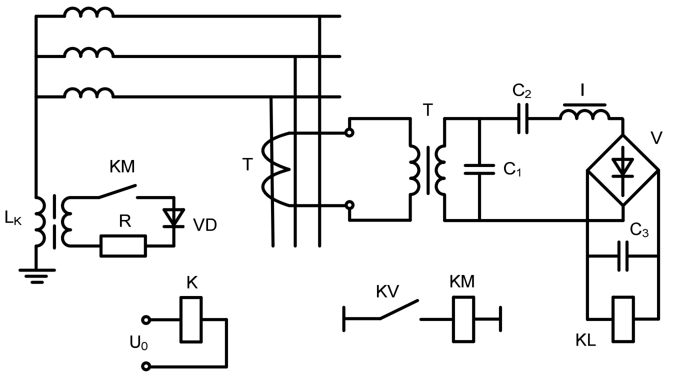


Fig. 1. The scheme of protection using a frequency of 100 Hz.

However, with precise adjustment of capacitive current compensation or close to it, intermittent arcing goes into successive self–canceling insulation breakdowns with a frequency equal to 2-8 half-cycles of industrial frequency. With this type of damage, the protection turns out to be insensitive. In addition, the protection may falsely work when oscillatory processes with frequencies close to 25 Hz occur in the network. The block diagram of the device is shown in (Figure 2).

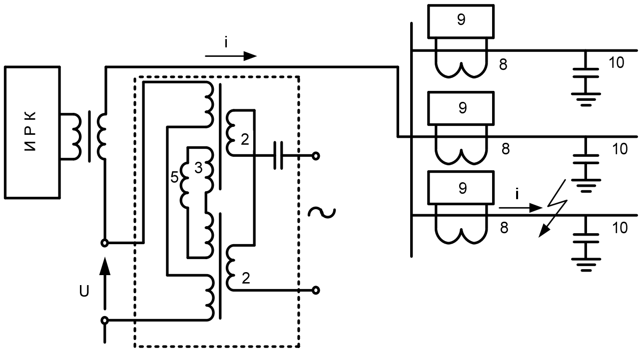


Fig. 2. A block diagram of the protection.

Using this principle, a current protection is performed that reacts to the average value of the sum of the higher harmonic components of the earth fault current.

3 Results and discussion

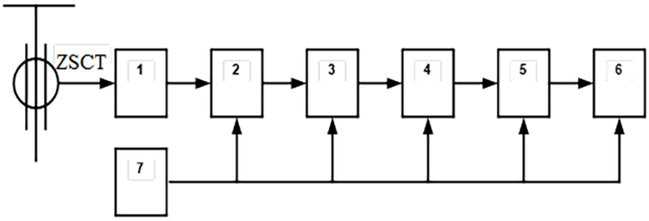
The advantages of the superimposed current principle include:

- the ability to work in a network with isolated and compensated neutral;
- the absence of a dead zone;
- There is no need for individual configuration.
- There are significant disadvantages for all protections performed on the applied operating current:

- the difficulty of detuning from the harmonic components of the zero sequence current, with a frequency close to the frequency of the operational current, the level of which can be 5-10 times higher than the level of the operational response current;
- research and operational experience show that, regardless of the accuracy of setting up compensating devices in networks, there are stable long-term arc circuits accompanied by transients, detuning from which becomes practically impossible;
- influence on the selective operation of Ferro resonance processes;
- the limited value of its own operational signal due to an increase in the level of the fault current;
- difficulties in organizing protection in networks with multiple arc extinguishing devices;
- criticality to amplitude distortions

3.1 Protections that respond to the effective value of the higher harmonics of the steady-state full earth fault current

The components of the higher harmonics in the steady-state current of the zero sequence in a single-phase short circuit are caused by the presence of harmonic components in the electric driving force of generators and distortions due to the nonlinearity of loads. The content of higher harmonics in the zero sequence current of a damaged line is many times greater than in the currents of undamaged lines. This situation occurs both in networks operating with an isolated neutral and in networks with compensation of capacitive currents. Protection is carried out by means of a current relay switched on to a zero-sequence current through a high-pass filter [4,5]. The composition of harmonics and their magnitude depends on the network mode, the number of lines, the voltage level and the nature of the load, which greatly complicates the use of protections of this class.5. The device reacts to the fifth harmonic as one of the dominant natural components of the higher harmonics in the single-phase short circuit current [6,7]. The device works as follows. Using a high-pass filter and a selective filter, a fifth harmonic signal is isolated and fed to the reacting organ, where it is compared with the actuation current. As soon as the signal exceeds the set point, the delay element is started, designed to detach from the transient process, after which the executive body ensures that the device is triggered. The block diagram of the protection is shown in (Figure 3).



1-matching transformer; 2-high-pass filter; 3-selective filter; 4-reacting organ; 5-delay element; 6-executive organ; 7- power supply.

Fig. 3. Structural protection scheme.

The disadvantages of this device include the following:

- ZSCT - Zero sequence current transformers
- influence of connection capacities;
- the effect of transients on relay operation;
- difficulty in operation.

The main advantage of protections using higher harmonic components is the possibility of its use in both isolated and compensated neutral networks. The disadvantages of devices made on the principle in question include:

- Uncertainty in the choice of the actuation setpoint;
- Instability of the nature of harmonics in the earth fault current (the harmonic composition changes with changes in the mode and circuit of the network, the nature of the load, the location of the fault of the closed phase, the transient resistance at the site of damage);
- The effect on the operation of high-frequency ferroresonance processes;
- A sharp increase in the level of higher harmonics when closing through an intermittent.

3.2 Protections that respond to the current and voltage of the transient process

The occurrence of transient currents during a single-phase earth fault is associated with the discharge of the capacitance of the damaged phase and the additional charge of the capacitances of the intact phases [8,9]. In a damaged line, the amplitude of the first half-wave of the transient current is the largest. In compensated networks, the nature of the change in transient currents does not change. This is due to the fact that the rate of increase of the transient inductive current caused by the arc-extinguishing reactor is less than the rate of increase of the transient capacitive current. Thus, the network is uncompensated during the transition process. The considered ratios make it possible to perform zero-sequence current protection in compensated networks, acting depending on the transient current. The selectivity of the protection action is ensured by detuning its actuation current from transient values of capacitive currents (1)

$$I_{pc} = K_m \cdot 3I_t \tag{1}$$

Where, K_t=2.0, ...2.5.

To perform protection, it is necessary to use a relay capable of detecting short-term transient current pulses, for example, a tyratronic one. In networks where the transient fault current is commensurate with the transient current of an intact line, it is difficult to protect the required sensitivity. Sensitivity can be increased by applying directional relays or compensating for the transient capacitive current of an undamaged line. The use of this principle makes it possible to achieve independence of the operation of protection against neutral grounding mode, selectivity in radial and closed, overhead and cable networks in all modes of single-phase earth fault, fixation of both stable and unstable circuits. There are several principles of building defenses of this class. Devices that respond to: the direction of power in the first half-period of the transient process; the polarity of the first half-wave of current and voltage of the zero sequence; the appearance of a high-frequency current.

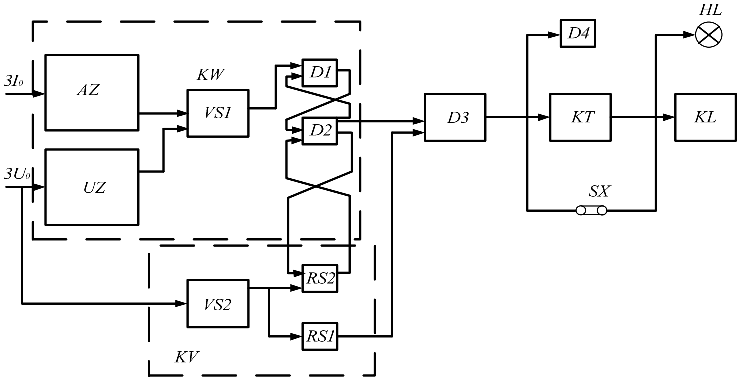


Fig. 4. Block diagram of alarm type protection.

Devices that respond to the direction of power in the first half-cycle of the transient process, designed for selective signaling of stable and unstable earth faults in compensated and uncompensated 20- 35 kV radial and closed networks with one or more power sources. It is also applicable in 6-10 kV networks, including those with a shutdown action. A block diagram of the protection shows (Figure 4).

The protection consists of:

- KW-pulsed power direction relay, KV- starting relay reacting to the voltage of the zero sequence of the industrial frequency; Z1, Z2 are notch frequency filters that pass frequencies of the order of 1 kHz and higher; U1 is an annular phase-sensitive circuit that determines the power sign; D2 is an executive single-vibrator that is triggered by a single-phase short circuit in the protection zone; D1 is a blocking single-vibrator that performs short-term blocking of the KW relay in case of higher short circuits; U2 is a rectifier; D4 is a trigger; D3 is an additional blocking trigger, triggered by a zero sequence voltage and with a delay allowing the KW relay to fix the power sign, performs its additional blocking for the duration of the short circuit, designed to ensure the correct behavior of protection by continuous blocking from the moment an external intermittent earth fault appears until it is eliminated, and also to prevent the protection from tripping during switching in conditions of a stable short circuit; D5-element "And" with zero sequence voltage memory; H is a lamp signaling the presence and occurrence of a short circuit in the protection zone; B is a counter that records the number of earth faults; K is an output relay; E is a time relay.

Protection provides:

- operation when a steady or unstable ground fault appears in the protection area;
- automatic return after the disappearance of a single-phase short circuit;
- light alarm in case of an earth fault in the protection area;

The protection can be triggered falsely under the following conditions. As is known, at the initial moment of the earth fault, the free components of the current and voltage of the zero sequence are shifted in phase by 90 electrical degrees. The following initial conditions are possible:

- 1 - the voltage of the damaged phase at the moment of closure is close to zero;
- 2 - reaches the maximum value.

In the first case, when the amplitude of the first half-cycle of the current is significantly greater than the amplitude of the zero sequence voltage, the output power of the phase-sensitive organ will be low. In this case, the protection may not work due to insufficient output signal. In the second case, the amplitude of the first half-cycle of the zero sequence voltage may be insufficient to trigger the protection. The influence of angular errors in zero-sequence current and voltage circuits, leading to distortions of the natural phase shift between them, further worsens the reliability of such protections. Therefore, in case of single-phase short circuits near zero and maximum voltage of the damaged phase, it is quite possible for failure to operate.

4 Conclusion

The considered principles of protection against single-phase earth faults allow us to draw the following conclusions.

1. In order for the protection against single-phase earth faults to meet the requirements of selectivity and sensitivity when changing the neutral grounding modes, it must be carried out on the principle that eliminates the dependence of the sensitivity of the protection on the phase of the current relative to the voltage of the zero sequence.
2. The protection of networks with an isolated neutral must have sufficient sensitivity, noise immunity and thermal resistance, allowing its use in networks with a short-

circuit current of 0.5 A and above, when currents of the order of 20 A flow during one second during double earth faults.

3. Directional protections manufactured by the industry are usually designed to work in networks with an isolated neutral. With low-resistance grounding, these protections operate at the boundary of the actuation zone. At high resistance, they lose sensitivity (due to operation at non-maximum sensitivity angles). For example, in case of short circuits through the transient resistance in the windings of motors, transformers.

Due to the supposed advantages of protections reacting to the active component of the fault current, their development is relevant.

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