Methods of improving the reliability of distribution networks 6-35 kV

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***Abstract* – The causes of damage to distribution networks are considered and the main methods for insulation condition monitoring as well as fault detection and location are described.**

Key words – distribution network, insulation, ground fault, power supply systems, reliability.

I. Introduction

At present, requirements to the reliability and continuity of power supply for industrial enterprises are increasing. The reliability of power supply systems is largely determined by the failure-free operation of transmission lines, and the distribution networks 6-35 kV constitute a considerable part of them. It is known that most faults that occur in the power supply systems (about 80%) fall exactly on the distribution networks. The distribution networks fault analysis shows that up to 60-90% of all failures are the ground faults.

The purpose of this study is to analyse the up-to-date methods used to improve the reliability of power supply systems and electrical safety conditions of the maintenance personnel.

II. Basic Data

The main causes of damageability and insufficient security levels of power supply systems, of both service personnel and people and animals contacting with them are [1]:

- imperfection of power supply schemes;
- imperfection of rules of operation and their proper execution;
- absence of protective signaling systems dealing with the single-phase short circuits on the ground;
- absence of diagnostic systems for assessing insulation condition;
- high levels of internal overvoltage;
- use of equipment (switching equipment, cables) which exhausted its regulatory resources.

The single-phase ground short circuits represent the most common type of faults in distribution networks. They are dangerous for both the electrical equipment and the staff due to the peculiarities of network and electrical equipment operation.

The ground fault is an asymmetric type of damage and it is characterized by the appearance of zero sequence components in the network. The voltage and the current zero sequence parameters in the transient and steady-state modes depend on many factors, the principal of which is the ground fault and neutral point operation mode.

The danger of single-phase short circuits is connected with a high voltage impact on the phase insulation, including the emergence of significant overvoltages, which may reach up to 1.73 from the phase voltage value during a zero resistance fault. The vector diagram (Fig. 1) clearly shows the phase voltages distribution for ground short circuits.

By the nature of damage, ground faults are divided into metallic (zero resistance) and arc (across the intermittent arc and across the contact resistance at the points of damage).

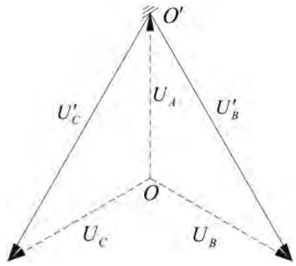

Fig. 1. The voltage vector diagram in a single-phase voltage ground fault

Single-phase ground or enclosure faults result from the aging, mechanical damage or electrical breakdown of the insulation of one of the network phases related to the ground or the enclosure. Therefore the task of providing effective control over the insolation condition, as well as early detection and elimination of defects remains topical so far.

The majority of insulation control devices signal that in the power network there is a decrease of resistance and they aren't able to detect the fault location selectively. Sometimes the problem of detecting the fault location in the insulation is solved by the serial electrical separation of the system elements with subsequent monitoring the insulation resistance of a disconnected element. By using this way of detecting a damaged element there arises a danger of the relay protection and automation malfunction and this requires large expenditures of time and highly qualified personnel.

Depending on the line type (cable or overhead) various methods are used for detecting fault locations. Several classifications of these methods are offered in the literature. The most common methods of detecting fault locations for the underground cables are shown in the following diagram (Fig. 2).

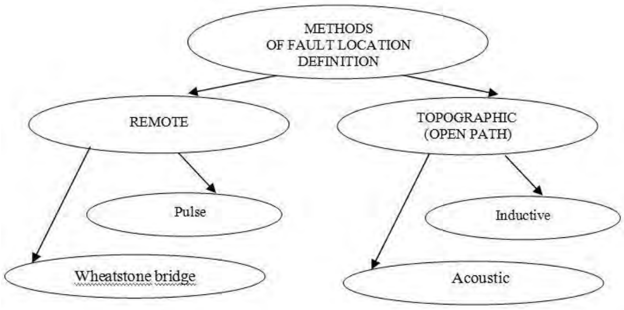

Fig. 2. The most common methods of detecting faults of underground cables

The remote methods can be used for the solution of the following tasks:

- measuring the length of cable or overhead lines of communication, power transmission, monitoring, control, etc;
- measuring the distance to the fault or homogeneity location of the line;
- determining the type of line fault (break, short circuit, leakage in the cable insulation, appearance of the additional longitudinal resistance in the conductors, etc);

measuring the cable line parameters (for example, insulation resistance).

The pulse method is based on the theory of pulse signals distribution across the line. When it is used in for underground cables, the so-called probe electrical pulse is sent and the time of travel of the pulse is measured from the moment it is sent to the moment it comes back being reflected from the fault location. The signal propagation speed depends on the insulation between conductors. If the line is homogenous and doesn't contain any faults, the pulse signal smoothly travels from the beginning of the line to its end. If there are inhomogeneities on its way (for example, breakdown of insulation between conductors), a part of the pulse energy passes through this heterogeneity, and another part is reflected and begins to propagate in the opposite direction – to the beginning of the line. In the case when the line is short-circuited or broken, the whole pulse energy is reflected and returned to the beginning of the line. By measuring the delay time of the impulse sent and accepted from the line, it is possible to determine the distance to the fault location.

The Wheatstone bridge technique, based on a direct current or an alternating current of frequency from a few to several hundred hertz, is used to measure the cable insulation resistance, loop resistance (two conductors shorted at the end), cable capacity, distance to fault location, distance to the high-resistance insulation leakage of the line.

The topographical methods are used to detect the required location on the track, that is, topographic points of the fault location.

The induction method is based on the principle of sound recording from the ground surface which is created by electromagnetic fluctuations when the current of sound frequency (800 – 1200 Hertz) is passing through the cable conductors.

The acoustic method is based on recording the sound vibrations over the fault location that occurring in the fault location due to the sparks from electrical impulses that are sent to the cable line.

The greatest efficiency can be achieved by the joint use of both remote and open path methods.

When solving the problem of network protection from the single-phase short circuits, one of the main objectives is to optimize the neutral, as the way of neutral grounding not only determines the operating conditions of network insulation, but also affects the functioning of the automation devices and relay protection, as well as the principles of their construction, on the basis of which, in their turn, concrete structures and schemes of ground fault protection devices are created. The lowest level of operational reliability corresponds to the networks with a fully insulated neutral.

Besides, the compensation of capacitive currents of a single-phase ground fault is widely used in order to increase the reliability of electrical networks 6-10 kilo Volt, which allows the current in a fault location to be reduced to the level of an active component and high harmonics, and thus to create conditions for the voluntary liquidation of the network accident.

The experience of operation of electrical networks with automatic compensation of capacitive currents shows that under the single-phase ground faults (SFGF) with currents of more than 100 ampere, the share of faults that pass into the inter-phase short circuits, doesn't exceed 3-5%. Under the SFGF currents of more than 100 ampere, this share increases and at 300-40 ampere and more almost every second single-phase ground fault transfers into the inter-phase short circuits. Therefore, the compensation of only one capacitor component isn't a sufficient condition for the reliable operation of power networks with high single-phase ground fault currents. According to the research data, the average value of a single-phase ground fault current in power networks 6-10 kilo Volt is 125 ampere and in separate power networks (about 5% from the total number of networks) it reaches 400-500 ampere. It should be noted that in connection with the development of cable networks, this, in the long run, leads to an increase of the average value of the SFGF currents. Therefore, to improve the reliability of electric networks, it is necessary to foresee the compensation of an active component and high harmonics of the SFGF residual currents. With the significant value of a single-phase fault current (about 200 ampere and more), the uncompensated current value also increases and there remains a danger of the single-phase circuit transition to the double circuit on the ground or the danger of a short interfacial circuit.

As practice shows, the values of the uncompensated current is enough for the burning of an intermittent arc and for the development of further failure. If to take into consideration that the most significant source of high harmonics are consumers with a non-linear load and their power is constantly growing, there is a need of developing a system of automatic compensation of high harmonics of a short circuit current.

Today, there are two basic principles of active component compensation of the single-phase ground fault current. One of them is based on the creation of the artificial asymmetry in the network and another one – on the introduction of additional voltages into the network. For their implementation a number of statistical devices connected to network elements are known:

- an additional capacity ΔC is connected to the lagging phase;
- inductance ΔL is connected to the anticipatory phase;
- an additional voltage $\dot{U}_{Ad}$, which coincides with the phase voltage of the damaged phase or is ahead of it at a certain angle, is introduced into the neutral through an arc-suppression coil or a single-phase transformer.

The advantage of the passive compensation method is that it can be relatively easily implemented in electric networks of about 1000 Volt. However, its use in networks with the voltage of 6, 10 and 35 kilo Volt is very problematic.

The method, based on the inclusion of an additional source in the neutral of the compensating network, is devoid of this disadvantage; its advantage lies in the simplicity of controlling the input voltage value. Its disadvantage consists in the impact of the compensation devices of an active component on the setting of an arc-suppression reactor.

It is necessary to realize the compensation of the fault current active component under high values of the total ground fault current. Let's consider a scheme of replacement of the three-phase power network, showing only the active component of the process flow in a single-phase ground fault mode (Fig. 3).

Under the single-phase ground fault, on a neutral of the network there appears the voltage $\dot{U}_0$, conditioned by the phase voltages $\dot{U}_A$, $\dot{U}_B$, $\dot{U}_C$ of the network and the inducted voltage $\dot{U}_{Ad}$. The ground fault is equivalent to the inclusion in the fault location of the source, the voltage of which is equal to the damaged phase voltage $\dot{U}_{PF}$ and is opposite in the phase.

After that, in the fault location there appears an active component of the ground fault current $\dot{I}_A$, for the compensation of which the value $-\dot{I}_A$ is used.

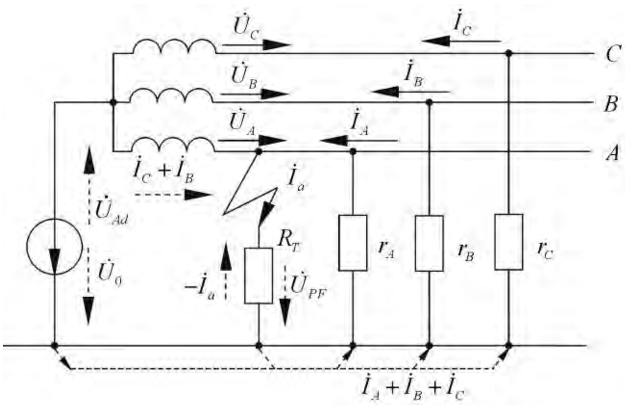

Fig. 3. The compensation process scheme of an active component in the three-phase network

The condition of accurate setting of a compensation mode is the equality of neutral voltage $\dot{U}_0$ and faulty phase voltage $\dot{U}_{PF}$. In this case, the only current which will flow through the resistance circuit R_T, will be the current, characterized by the presence of high harmonics. To restore the normal operation mode of the compensated network after the emergency shutdown or self-liquidation of the ground fault, it is necessary to reduce the value of the input voltage $\dot{U}_{Ad}$ to zero. This will decrease the neutral voltage $\dot{U}_0$ and the voltages relating to the ground on the damaged and undamaged phases will be restored.

In addition to the main frequency, in the damaged network there appear additional components of high harmonics currents.

With the ground fault, capacities of wires of undamaged phases relative to the ground are switched on the linear voltage. This ensures a high level of harmonics in the ground-fault current passing through the capacities as the capacities are much lower resistance for them than for the current of the main frequency.

In the case of phase-to-ground fault, the ground fault current depends on the equivalent EMF generator, which is equal to the phase voltage in the point of damage in the previous mode. The equivalent circuit of the distribution network is shown in Fig. 4:

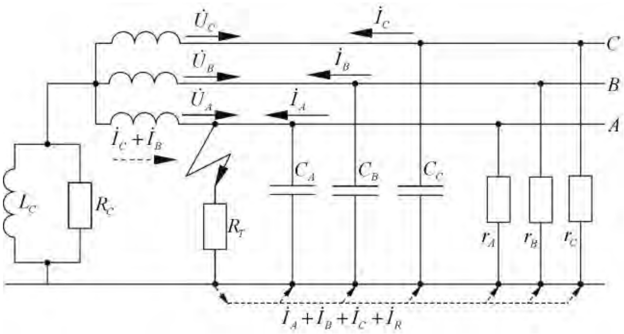

Fig. 4. The distribution network circuit with the compensated neutral for single phase ground faults through the contact resistance

The only natural harmonic sources of the ground fault current, which should be taken into account, are the phase voltage distortions in the point of damage under the zero-sequence open-circuit generated by the consumer loads with non-linear characteristics. The natural current of each harmonic of the v-th order that closes in the damage point is:

$$I_{v1} = \frac{U'_{pv1}}{\sqrt{R^2 + \frac{1}{3C\omega v^2}}} = \frac{I_c U'_{pv1} v}{U_{pv1}\sqrt{\left(\frac{Rv}{X_c}\right)^2 + 1}} \qquad (1)$$

where U'_{pv1} – a set of possible voltage harmonics; I'_c – the operating frequency component of the capacitive current line in the absence of damages (in an expression $X_c = \frac{1}{3C\omega}$).

In all the cases, when high harmonics of voltage or of current impose on each other they are joined with the component of the basic harmonic squared, that is, the resulting value, obtained as a result of addition, is equal to the square root of the sum of the squares of all the components of different frequencies.

Hence, it follows that even a relatively small harmonic voltage can cause a significant component of the ground fault current. If, for example, a phase voltage contains the ninth harmonic which is equal to 2% of the total voltage, it produces a corresponding harmonic current equal to 17.8% of the capacitive current of the main frequency. In addition to the considered methods, there are other ways of determining the level of high harmonics in the ground fault current.

An important integral element of security and reliability of electrical safety systems is the knowledge of the condition of insulation networks and electric installations. All the presently known methods of determining the insulation parameters of electrical installations and networks can be classified as follows:

- using the operating voltage of an electrical installation as a measuring one;
- using the voltage of an external source of industrial frequency as a measuring one;
- using the voltage of an external source of a non-industrial frequency as a measuring one.

In practice, for monitoring of insulation the indirect methods are used, that is, the total insulation resistance of a certain network, related to the ground, is calculated by the value of a single-phase short circuit current. Various methods of measuring the single-phase ground fault currents can be divided into direct and indirect ones and it is recommended to apply indirect methods of measuring the short circuit currents more widely.

The insulation characteristics of electrical networks are directly connected with the values of fault currents and the mode of transient processes under the most common damages – the single-phase ground faults. In this regard, it is possible to state that monitoring of the insulation parameters is associated with the processes:

- of localization (shutdown) of places with damaged insulation – monitoring of the total active insulation resistance in the distribution network;
- of minimization (the capacitive component compensation of the ground fault current and the control over the compensating device setting) of the fault current values – monitoring of the total insulation resistance in the distribution network;
- of optimization of the network neutral modis, that is, management of the quality of the distribution network in order to suppress transient ferroresonance processes which accompany the emergency modes.

The continuous and automatic control of values of electric network insulation components (of the active and capacitive ground insulation resistance of the main phases, the inductance of the compensating device) will allow the emergence of dangerous conditions in the distribution network to be prognosed. The system of continuous insulation monitoring is necessary for the realization of these tasks.

The essence of the method of the continuous and operational control over the electrical network ground insulation and its elements is that the two operational sinusoidal signals are imposed on an electric network relative to the ground, the frequencies of which are not equal and they differ from the commercial ones. On the controlled areas (a line or an affixion) and also in the place of operational source connection, the devices are installed the purpose of which is to remove and process the corresponding signals. After the calculation on the basis of a pre-set program the signals corresponding to the insulation values and to the controlled areas of the power supply system are sent.

Thanks to the micro-computer, this method can be used:

- for the operational measurement of the active insulation resistance level of both the whole power network system and each of the affixions of the distributive network;
- for the operational measurement of the related to the ground capacity level of both the whole power network system and each of the affixions of the distributive network;
- for the operational measurement of the arc suppression coil inductance values (compensating devices);
- to carry out selective leakage protection or protection from ground faults in power systems (quarries and mines) regardless of the configuration and mode of operation of the neutral in the network;
- for the automatic setting of a compensating device in resonance with the distributive network capacity.

Many devices of the relay protection and automation use the method of symmetric components. The operation principle of the zero sequence current transformer is based on the addition of current values in all three phases of the protected area. In a normal (symmetric) mode the sum of the phase currents is zero.

When a single-phase short circuit emerges, currents of zero sequence appear in the network and the sum of currents in the three phases won't be zero. This will be fixed by a measuring device (for example, an ammeter) connected to the secondary winding of the zero sequence transformer.

The components of the reverse sequence emerge with the appearance of any asymmetry in a network: a single-phase or two-phase short circuit, phase breakthrough, load asymmetry. The zero-sequence components occur during the ground faults or breakthrough of one phase or two phases. In the case of the phase-to-phase fault the zero sequence components (currents and voltages) are equal to zero.

Each of the considered methods has its advantages and disadvantages.

Conclusion

Improvement of the existing methods as well as the development of the new techniques and tools of monitoring the insulation condition as well as detecting and liquidating the faults in distribution networks will increase the power supply reliability and improve the conditions of indirect energy security in the distribution networks 6-35 kV.

References

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