Calculation of Settings for the Control Systems of Insulation in Power Distribution Grids with Voltage of 6 or 10 kV in Conditions of Uncertainty

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Abstract. The article deals with the calculation of setpoints for control systems insulation installed in all power distribution networks with voltage of 6 or 10 kV. It is shown that on the basis of fuzzy sets, the calculation of setpoints may be carried out even in the face of uncertainty. The efficiency of the system insulation monitoring based on measuring parameters of the electric network is largely determined by proper selection of the setpoint, i.e. the value of the insulation resistance of the network relative to the earth, in which it is necessary to disable a particular part of the network where a further reduction of the insulation resistance is unacceptable.

1. Introduction

It is well known that insulation resistance of the network relative to the earth changes continuously and depends not only on the qualifications of personnel operating this network, the quality of its construction, but also from the industry sector network of its execution.

The distribution network of the specified voltage can be for urban, mining, agricultural purposes or operated in industrial plants. In execution, they are divided into aerial, cable and mixed, containing both cable and air stations.

2. Theoretical Part

In relation to the networks 6, 10 kV (in terms of control of isolation) are the most developed is the question of the choice of setting for protection against single-phase ground faults [1, 2]. However, for systems of control isolation, this approach is not applicable. When choosing the settings of protection against single-phase earth fault is produced:

- the calculation of capacitive current connections, equipped with protection;
- definition of the capacitive current of the entire network;
- calculation of the current setpoint by condition sensitivity and selectivity [2].

With the capacity of the network phase 1.5 µf/phase and voltage of 6.3 kV at the lower area protection, it can be taken the following values: for primary zero sequence current is 0.1 A, for secondary zero sequence voltages – 2.5 V, which corresponds to the level of active insulation resistance of 50 ohms/phase [1].

In this setting, as shown by own research, it is almost impossible to exploit the most of the networks with voltage of 6 kV or 10 kV.
As applied to electrical networks with isolated neutral voltage 6, 10 kV for control systems isolation (MIS), currently used or recommended in the future, the question of the choice of setting is considered only in [3]. Specified in this work is the approach based on the measurement of insulation parameters of the network relative to the ground using the method developed by authors, the setpoint is taken somewhat less than the received insulation resistance values (the value of this "slightly less" is not justified).

This method of preset selection cannot be recommended for widespread use because it requires measurements in existing installations. In addition, defined in this way, the setpoint can affect the reliability of the SKI. The latter will be due to the fact that the change in network configuration, such as disabling certain connections, would increase the insulation resistance of the network relative to the ground. In this case, the decrease of insulation resistance can be seen CAL at a stage when prevention of overlap (breakdown or other damage) of the insulation is impossible. Such a provision nullifies the main advantage of continuous monitoring of isolation – prevent the appearance of voltage on metal parts of naticoidea or life-threatening voltages of touch and step.

The specified observation allows us to formulate additional requirements to the selection algorithm set point [4]:

- the algorithm must not contain the requirement that a preliminary measurement of the insulation resistance of the network relative to the ground;
- the algorithm should consider the network configuration, i.e. setting a SKI needs to have adaptability.

To construct the algorithm of the choice of setting should also take into account the causes and patterns of decline of insulation resistance as in OTL, and in cable networks.

Electrical networks vary much more with active component in aircraft, of the insulation resistance of the network phase relative to the earth that caused by direct impact of environmental factors on overhead lines. If contaminated insulators, the drop wire on the hook of the insulator decreases the active component of the insulation resistance of the network phase relative to the earth. Capacitive component of the resistance in such networks changes slightly, because the length of a particular line in the course of its operation is not modified, and the arrow of the SAG of wires in networks of 6 or 10 kV is low because of the relatively short distance between supports (≈50-60 m) and the small weight of the wire. However, in such networks there are cases of roll supports, then the arrow is significantly increased SAG of the wires, which leads to lower capacitive insulation resistance of the network phase relative to the earth.

In the cable of electric networks more highly variable component of the capacitive insulation resistance of the network phase relative to the earth. This is due, for example, wetting the insulation of cables. However, most of the networks with voltage 6, 10 kV are mixed, i.e contain and air, and cable lines. Virtually all electrical distribution networks the input transformer in the substation is via a cable box to protect the transformer from lightning surges (pulses). With regard to mixed electric networks it is difficult to say what component of the insulation resistance of the network phase relative to the earth will change more significantly. All of the above evidence in favor of the complete control of insulation resistance of the network phase relative to the earth (or total conductivity of the insulation of the phases of the network relative to the ground). Thus, there is no need to rebuild the algorithm of choice of setting depending on the performance of the network (air, cable, mixed) that will greatly facilitate the process of selecting a setpoint staff. In addition, consideration of both components of the insulation resistance will ensure complete control over any network.

We made preliminary observations allow us to proceed to the formation of the algorithm which, in our opinion, should include the following steps [4]:

1. Determined for the studied distribution network (career, rural, urban network, a network of industrial enterprises) and the type of its execution (air, cable, mixed).
2. The calculation of the expected current single-phase earth fault based on the parameters of the controlled network: linear voltage, lengths of cable and or overhead lines, the number of power transformers, the number of high-voltage motors.
3. The calculation of the capacity of the network relative to the ground.
4. Calculation of capacitive conductivity of the insulation of the phases of the network relative to the ground.
5. Calculation of active resistance of isolation of the mains phase relative to the earth taking into account the coefficient of calming d-network.
6. The calculation of the conductivity of the active isolation network phase relative to the earth.
7. The full calculation of the expected conductivity of the insulation of the phases of the network relative to the ground.
8. Determination of the setpoint using the apparatus of fuzzy set theory.

The algorithm is identical in the normal scheme of power supply.

For the condition of the adaptability of setpoint, you must consider the network configuration, i.e. the number of connections currently control. Thus, the setpoint should change when you connect or disconnect any number of connections. When disconnecting parts connections full insulation resistance of the network relative to earth will increase. However, this is not a sign of improvement of the insulation condition of the network. The increase was due to only disable parts of a line. The old setpoint will not be a guideline for the level of isolation of the remaining accessions. To simplify the procedure for selection of settings based on the above proposed algorithm is composed of a methodology to determine the set point for control system insulation in any power distribution networks with voltage 6, 10 kV, and includes the following stages [5]:

1. Determined the identity of the studied distribution network (career, rural, urban network, a network of industrial enterprises) and the type of its execution (air, cable, mixed). The type of performance of the network will depend on the ratio of the calm network d. For networks consisting primarily of cable lines, soothe the coefficient d is equal to 0,03-0,05. For networks consisting mainly of overhead lines, the calm ratio d is equal to 0.3-0.5.

2. Calculated the expected capacitive current single-phase earth fault based on the following formula:

\[
I_c = U_3 \times \left( \frac{L_e}{10} + \frac{L_a}{350} \right), A
\]

where

\(U_3\) – linear voltage, kV;

\(L_e, L_a\) – the total length of the electrically connected cables and overhead lines, km.

This formula gives the approximate value of the expected capacitive current. For a more accurate determination of its value using another formula:

\[
I_c = 3U_{ph}\omega \left( C_a L_a + C_C L_e + C_s N_s + C_{mp} N_{mp} \right) \times 10^{-6}, A
\]

where

\(U_{ph}\) – phase voltage, kV;

\(\omega\) – circular frequency of the supply voltage, c\(^{-1}\);

\(C_a, C_C\) – capacity per phase in relation to the earth at 1 km of overhead and cable lines, \(\mu F\);

\(C_s, C_{mp}\) – capacity per phase against earth, respectively, high-voltage electric motor and power transformer, \(\mu F\);

\(N_s, N_{mp}\) – the number is connected to a network respectively, high-voltage motors and power transformers.

1. Given that the initial data used the length of cable and overhead lines, and to more accurately determine the values of current it is desirable to consider the capacity and number of transformers and high-voltage motors, the expected capacitive current single-phase earth fault is determined by the combination formula:

\[
I_c = U_3 \times \left( \frac{L_e}{350} + \frac{L_a}{10} + \sqrt{3}\omega \left( C_s N_s + C_{mp} N_{mp} \right) \right), A
\]
Information about $C_n$, $C_{ap}$ refer to the literature. Capacity values for a certain phase of individual elements of the power system are given in table 1, [6].

| Name                                         | Capacity Of SD, $\mu F \cdot 10^{-3} (nF)$ |
|----------------------------------------------|---------------------------------------------|
| Asynchronous motors with squirrel-cage motors with power up to 260 kW | 9-12                                        |
| Asynchronous engines with phase rotor power up to kW 250-630 | 10-14                                       |
| Synchronous motors of an output 425-525 kW  | 15-20                                       |
| Transformer substations with transformers with a capacity of 10-100 kV | 0,43-0,55                                   |
| Transformer substation with transformers power 100-630 kV | 0,55-1,22                                   |
| Excavators ECG-4; SE-4                       | 12,5-16                                     |
| Excavators AUG-6; ASH-14/65                  | 24-30                                       |
| Switch points RVNO, LCC, ACNE                | 67-88                                       |
|                                              | 0,5                                         |

It should be noted that in the above formula does not take into account the insulation resistance section of the tire relative to the ground. This resistance can be considered capacitive and active part neglected because of its large magnitude. This is because the insulators and other elements that affect the resistance of the isolation section of the tire relative to the ground, placed inside a closed distribution device, i.e. sufficiently insulated from the effects of the environment. When determining the capacitance relative to the ground section of the tire depends on the type of switchgear, the arrangement of the busbars inside the switchgear, the distance from the tires to the metal earthed structural elements of the cell.

However, the capacitance of a single cell of a switchgear, or CSR relative to the earth is less than a few $nF$, which allows us to neglect this value. For example, when the number of cells switchgear is not less than 15, the increase in leakage current will be about 0,025 mA, even when the total length of outgoing lines only 1.5 km will be approximately 0.003 %.

2. Is determined by the capacity of the network relative to the ground

$$C = \frac{\sqrt{3} I_C}{U_d \cdot \omega} \cdot [\mu F]$$

(4)

3. Calculated the conductivity of the capacitive insulation of the phases of the network relative to the ground

$$b_C = \omega C, Sm$$

(5)

4. Calculated active insulation resistance of the network relative to the earth $R$ to the coefficient of calming d-network. In this case it is used to calculate the upper limit (0.05 or 0.5) is recommended above the range of d for this type of network, because with a larger value of $d$ is obtained the smallest value of resistance of insulation of the network

$$R = \frac{1}{d \cdot \omega \cdot C}, [k\Omega]$$

(6)

5. Calculated the conductivity of the active isolation network phase relative to the earth
6. Is determined by the expected conductivity of the insulation of the phases of the network relative to the ground

\[ Y = \sqrt{g^2 + b^2}, \text{Sm} \]  

7. Next, to determine the setpoint it will use the apparatus of fuzzy set theory. The estimated expected conductivity of the insulation of the phases of the network relative to the earth is a point estimate of the total conductivity of the insulation of the phases of the network relative to the ground. It can be presented in the form of a fuzzy number with a triangular task of membership function \( \mu_{\bar{X}}(x): [0.1] \rightarrow [0.1] \) (Figure 1).

8. For a fuzzy number \( \bar{X} \) specified by the low \( X' \) and top \( X'' \) the boundaries that satisfy the conditions [7]:

\[
\forall \delta > 0 \quad \mu(X') = 0; \quad \mu(X' - \delta) = 0; \quad \mu(X' + \delta) \neq 0;
\]
\[
\forall \delta > 0 \quad \mu(X'') = 0; \quad \mu(X'' - \delta) \neq 0; \quad \mu(X'' + \delta) = 0. \tag{9}
\]

![Figure 1. A fuzzy number with a triangular task of membership function](image)

\( X' \) and \( X'' \) calculated using the following formulas:

\[
X' = X - \beta(x);
\]
\[
X'' = X + \beta(x), \tag{10}
\]

where \( \beta(x) \) is determined depending on the category of Junior significant digit of the number \( X \).

Let \( q \) – the discharge of the lower significant number \( r_q \) number \( X \). Breaking the possible values of \( q \) into classes of residues modulo 3, we get equivalence classes \( \{Md, d \in \{0,1,2\}\} \), were \( d = q(mod\ 3) \) – the remainder of the division \( q \) to 3.

On the basis of statistical studies it is determined that \( \forall x \in Z \) from the interval \([0.99]\) value \( \beta(x) \) was found as shown in table 2.
Table 2. Values $\beta(x)$ for two-digit numbers

| $X$                          | $\beta(x)$                |
|------------------------------|---------------------------|
| 1, 2, 3, 4, 6, 7, 8, 9       | 0.46x                     |
| 10, 20, 30, 40, 60, 70, 80, 90 | $(0.357 - 0.00163x)x$     |
| 35, 45, 55, 65, 75, 85, 95   | $(0.213 - 0.00067x)x$     |
| 5                            | 2.8                       |
| 15                           | 6.45                      |
| 25                           | 6.75                      |
| 50                           | 24                        |
| Other two-digit numbers      | $1/2(\beta((x/10)\cdot10+5)+\beta(x-(x/10)\cdot10))$ |

[*] – the integer part of the number.

When $X \in M_0$:

$\beta(X) = \beta(X) \cdot 10^{q-2}$

When $X \in M_1$:

- $r_{q+1} = 0$: $x = r_q \cdot 10$; $\beta(X) = \beta(x) \cdot 10^{q-1}$;
- $r_{q+1} \neq 0$: $x = r_{q+1} \cdot 10 + r_q$; $\beta(X) = \beta(x) \cdot 10^{q-1}$.

When $X \in M_2$:

- $r_{q+1} = 0$: $x = r_q \cdot 10$; $\beta(X) = \beta(x) \cdot 10^{q-2}$;
- $r_{q+1} \neq 0$: $x = r_{q+1} \cdot 10 + r_q$; $\beta(X) = \beta(x) \cdot 10^{q-1}$.

When $X$ is a decimal fraction, this algorithm is applied to the mantissa of the fraction, and then ignored its order [8].

As the setpoint conductivity $Y_{yest}$ was adopted by the upper border of fuzzy number. If the desired set point for resistance, on the contrary, it is necessary to choose the lower bound of a fuzzy number.

4. It should be noted that the larger the value of the point estimates, the greater will be the value $\beta(x)$, i.e. for a large value of the lower and upper bounds will be different from the value point estimates. For example:

- When $K = 10$ $\beta(K) = 3.4$;
- When $K = 100$ $\beta(K) = 34$;
- When $K = 1000$ $\beta(K) = 460$;
- When $K = 10000$ $\beta(K) = 3400$.

The meaning of the above is as follows. When the expected insulation resistance is large, then you can select the setpoint significantly lower value. When the expected insulation resistance is low enough, then it is unacceptable to take the set point is much lower than expected, because the level of insulation in the network is initially low.

3. Conclusions

Formulated additional requirements to the algorithm of selection of the setpoint:

- the method of selection of the setpoint must not provide for provisional measurement of the insulation resistance of the network relative to the ground;
- when selecting the setpoint must take into account the network configuration, i.e. setting a SKI needs to have adaptability.

Developed a methodology to determine the set point for control system insulation in any power distribution networks with voltage 6, 10 kV.
For the condition of the adaptability of setpoint, you must consider the network configuration, i.e. the number of connections currently control. Thus, the setpoint should change, when you connect or disconnect any number of connections.

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