Research of potential on the grounding device in the network with low-impedance resistive neutral grounding

S S Chervonchenko1,* and A S Brilinskiy1

1 Institute of Energy and Transport Systems, Peter the Great St. Petersburg Polytechnic University, Saint-Petersburg 195251, Russian Federation

* E-mail: serhiichervonchenko@gmail.com

Abstract. The paper discusses the possibility of low-impedance (combined) neutral grounding in the 10-35 kV air network, suggests the logic of the relay protection against single-phase ground faults, and also based on computer simulation of transient processes, the potential of the low voltage network is estimated depending on the current circuit to ground, resistance values of the grounding device and network configuration 0.4 kV. The study is carried out by modeling the real part of the power system of St. Petersburg and the Leningrad region, located in the north-east of the region. Directly considered the distribution network of 110 kV Substation Plodovoe (Substation № 511).

1. Neutral grounding mode of the distribution network
The choice of power supply when connecting new consumers depends on many factors: the size of the plug-in load, the distance of the consumer from the power center, the category of reliability, etc. [1,2,3]. One of these factors is the geographical location of the consumer. For example, if the consumer is located in a rural area, the distribution network is carried out by air lines, and in dense urban areas, by cable lines. In some cases, the distribution network can be represented by both air and cable lines, the so-called air-cable network. As an example of an air-cable network, the power supply scheme of Konevets Island currently being constructed in the Leningrad Region can be given, where the substation 110 kV Plodovoe with the existing distribution network made by aerial lines acts as the power supply center of the island consumers, and the power supply to the island’s consumers will be provided by two 10 kV undersea cable lines from the distribution point located in Vladimirskaya Bay to the distribution transformer substation located on the island (Figure 1).

The existing grounding mode of the neutral network of 10 kV substation 110 kV Plodovoe is an isolated neutral. When choosing the grounding mode of the neutral networks 6-35 kV, you must follow the existing rules [4,5]. According to [4,5], “compensation for capacitive ground-fault current should be applied at values of this current in normal mode in the networks voltage 3–20 kV networks with reinforced concrete or metal poles on overhead power lines, and in all 35 kV networks - more than 10 A”. In the considered distribution network, taking into account the inclusion of the cable line, the magnitude of the single-phase ground-fault current will be about 25 A. Therefore, it is necessary to provide for installation of arc-suppressing coil in the network, for example, with smooth regulation and automatic tuning according to [6], which are connected using a neutral grounding transformer.

However, the presence of an arc-suppressing coil entails some complications [7], namely:
- the need to perform the calculation of network unbalance;
- when tuning an arc-suppressing coil to resonance (100% compensation), it is possible to increase the magnitude of the neutral displacement voltage above the allowable values.

One of the possible solutions to this problem is the implementation of low-impedance neutral grounding in this air-cable distribution network.

The advantages [8,9,10] of low-impedance resistive neutral grounding are:
- absence of arc overvoltages of high multiplicity and multi-site damage in the network;
- reduction of the probability of electric shocks to personnel and unauthorized persons in a single-phase ground fault;
- almost complete exclusion of the possibility of transition of single-phase fault to a multi-phase fault;
- simple performance of sensitive and selective relay protection against single-phase ground faults based on current principle.

Low-impedance resistive grounding of the neutral of network is carried out using a special neutral grounding transformer with a star / delta winding connection circuit or through a zero-sequence oil-grounding oil filter. The resistor is connected between the zero point of the high voltage winding and the ground loop.

**Figure 1.** Single line diagram of the distribution network of the substation 511 Plodovoe.
2. Simulation of a distribution network
In this work, the existing 10 kV electrical distribution network of the substation Plodovoe is modeled and researching in the ATPDraw software package. [11,12]. In this variant, in order to reduce the disconnection time of a single-phase ground fault and limit the level of overvoltage, two resistors are connected to the neutral terminals of 110/35/10 kV transformers and two more resistors to a 10 kV distribution point (Figure 1).

The computer model takes into account the geometry of the location of the 10 kV overhead line, made by a bare wire (the location of the phases on the vertices of a multi-sided triangle) and a self-supporting insulated wire (the arrangement of the phases in a plane parallel to the ground), and also location of cable lines in the ground.

3. Building selective relay protection in mixed networks
The first stage of relay protection is selected based on the time of destruction of the fuse-link under the action of the maximum load current, taking into account the coefficients. Then, to ensure the next selectivity step, a time of 0.3 seconds is added (an empirical value equal to the sum of the duration of the relay protection and the switch off time) and a current setting equal to the value of the corresponding own current of the protected area is taken [13,14]. However, this method of building the operation of relay protection has significant disadvantages:

- when a fuse-insert fuse blows under the action of a single-phase ground fault, the transformer can operate in an incomplete-phase mode, which leads to a “poor-quality” power supply to consumers, overloading of individual transformer windings, and magnetic core saturation.
- large time setting. Considering the possibility of two consecutive single-phase short circuits, the flow time of a single-phase short circuit to ground through a resistor can reach or exceed the permissible flow time of the rated current.

To eliminate the above deficiencies, when calculating the relay protection settings, the absence of the possibility of a fuse-insert fuse breaking out during a single-phase short circuit to ground is assumed. Therefore, when building a selectivity, it is proposed not to build off from the burnout time of the fuse-link, but to set the current setting and protection response time to 0.3 seconds, which leads to a decrease in the time of relay protection.

In addition, we will take into account the fact that, in order to improve the reliability of the electrical network, installation of reclosers can be provided both for partitioning lengthy sections of transmission lines and for disabling branches that are subject to frequent damage. Additionally, in order to reduce the time to search for the locations of damages, it may be possible to install a monitoring system for electrical energy quality indicators [15,16] and short-circuit current indicators.

4. Research of the potential removal to the low voltage network
To substantiate low-impedance resistive neutral grounding, it is also necessary to carry out an assessment of potential «transfer» to the low-voltage network.

According to [4], the grounding resistance of the poles should be no more than 30 Ohms, and the neutral conductor of the 0.4 kV network should be re-grounded every 200 m. The single-phase short-circuit current in the network is assumed to be 200 A.
The process of single-phase short circuit in a medium-voltage network is considered directly in front of the step-down transformer substation. In this emergency mode, a voltage (U1-U3, potential) of a certain value arises in the 0.4 kV network in a neutral conductor, whose value in normal mode is 0. Due to this phenomenon, a current flows through the grounding device of the overhead line poles (grounding will be performed every 200 m) (I1-I3) and a closed loop is formed. The calculation was performed for three different configuration options for a low-voltage distribution network:

- number of outgoing lines - 10 pcs., length - 400 meters, index 1 (U1, I1) in Figures 2-4;
- number of outgoing lines - 10 pcs., length - 800 meters, index 2 (U2, I2) in Figures 2-4;
- number of outgoing lines - 20 pcs., length - 400 meters, index 3 (U3, I3) in Figures 2-4.

The authors of the article [17] mistakenly believe that the potential created by the damage current on the grounding device of a transformer substation can be estimated by simply multiplying the short-circuit current by the resistance value of the ground wire. According to the method [17], the voltage on the grounding device will be U = I(1) × Rgr TS = 200 × 4 = 800 V. However, according to the calculations, the voltage on the grounding device will be 193.5 V, which proves the incorrectness of
the method proposed in the work. The grounding of the transmission line supports together with the 0.4 kV distribution network ensures the spreading of short-circuit current and significantly reduces the potential at the grounding device.

Reducing the resistance of the grounding circuit of a transformer substation from 4 to 2 Ohm reduces the potential carried by the consumer to the network by 20%, and from 4 to 1 Ohm - by 44%. However, this condition in terms of the grounding device is relevant only for designed or reconstructed facilities of the power supply network.

To ensure the selective operation of the relay protection of 110 kV outgoing from the substation Plodovoe overhead lines of 10 kV, a single-phase ground fault current of about 50 A is sufficient. However, when long cable lines (cable inserts) are added to the electrical network, a recalculation of the sensitivity coefficient is required due to its decrease and adjustment of the settings. If the outgoing line is a mixed cable-air outgoing line, then in order to fulfill the condition of the sensitivity factor, it is necessary to increase the single-phase short-circuit current, which in turn increases the value of the potential «transfer» to the low voltage network [18,19]. To solve this problem, it is proposed to install, in addition to a low-impedance resistor, an arc suppression coil to reduce the magnitude of capacitive currents (measured by current transformers) from which the relay protection is tuned.

5. Conclusions
It has been established that the configuration of the 0.4 kV distribution network, together with the re-grounding of the neutral conductor (the requirement of the existing regulatory documents) ensures the spreading of a single-phase short circuit to ground and a significant decrease in the potential at the grounding device. Reducing the resistance of the grounding circuit of a transformer substation from 4 to 2 Ohms can reduce the amount of potential to be removed by 20%, and from 4 to 1 Ohm - by 44%. It is recommended to connect in parallel to the resistor an arc-suppressing coil to compensate for the capacitive currents that occur in cable lines.

It has been proved incorrect to estimate the electric potential on grounding devices by simply multiplying the short-circuit current by the resistance value of the grounding conductor; substantiation of the influence of grounding of power transmission line poles, grounding switches of other connected power facilities and the distribution network configuration on the spreading of short-circuit current and a significant reduction in potential.

References
[1] Korotkov A V and Frolov V Ya 2015 Experimental studies of electrical load schedules of residential electricity consumers in urban distributive power grids. Acta Technica CSAV 4 337–46
[2] Korotkov A V and Frolov V Ya 2016 Calculation methods for determination of electrical load schedules of residential consumers and their indicators. Acta Technica CSAV 1 73–9
[3] Korotkov A V and Frolov V Ya 2016 Methods of determination the electrical load schedules on areas in urban distributive power grids rolov Proceedings of the 2016 IEEE North West Russia section young researchers in electrical and electronic engineering conference 601–3
[4] Electrical Installation Rules. 7th edition (Moscow: Energoservis)
[5] Rules of technical operation of power plants and networks. 15th edition (Moscow)
[6] Standard instruction for compensation of capacitive earth fault current in electric networks 6-35 kV (Moscow: Souztehenergo).
[7] Tokareva S.A and Brilinkiy A S 2017 Features of operation of the distribution network with overhead and cable lines (Preprint)
[8] Fishman V S 2013 Low resistance neutral grounding in networks 6-35 kV Electrical news 2(80)
[9] STO 18-2013. Guidelines for choosing the neutral grounding mode in electrical networks with voltage of 6-35 kV (Saint Petersburg)
[10] Evdokunin G A 2009 Resistive neutral grounding networks 6-10 kV (Saint Petersburg: Terzia)
[11] Shklyarskiy A Y and Solovev S V 2015 Influence of the energy characteristics on the electrical
grid simulation Proceedings of 2015 International Conference on Mechanical Engineering, Automation and Control Systems

[12] Selivanov V N 2019 The use of the program of calculation of electromagnetic transients ATP-EMTP in the educational process Vestnik MGTU 1 107–12

[13] Emelian'tsev A 2006 Relay protection networks. Time selectivity steps Electrical news 3(39)

[14] Shalin A I 2005 Ground faults in networks 6-35 kV Calculation of the settings of non-directional current protection Electrical news 3(33)

[15] Shklyarskiy A Y, Zamyatin E O and Rastvorova J V 2018 Developing of electric power quality indicators evaluation and monitoring intellectual system in 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering 761–2

[16] Kovalchuk M S and Skamyin A N 2017 Developing the System of Monitoring and Diagnostics to Increase the Availability of Equipment IOP Conf. Ser. Earth Environ. Sci., 66

[17] Mayorov A V, Shuntov A V and Osintcev K A 2017 Features of the construction of aerial electrical networks of 20 kV with low impedance resistive neutral grounding. ELECTRICITY. Transmission and distribution 5(44) 78-82

[18] Charlton T, Davies M and Baudin D 2007 Transfer potentials from mv to lv installations during an earth fault, CIRED (Vienna) 0805

[19] Fishman V S 2013 Cable networks 6 (10) kV with SPE-isolation. The occurrence and spread of dangerous potentials. Electrical news 2(80)