Grounding device for electrical networks and electrical installations in the Arctic regions

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Abstract. The article is devoted to the features of the system grounding and device of electrical networks (EN) and electrical installations (EI) in the continental zone of the Arctic. The traditional grounding devices providing grounding of EN and EI in the Arctic regions are ineffective or their device is impossible. These conclusions are defined by parameters of climate and properties of soil in the considered zone. The most important parameters of climate are a wide year temperature difference and big depths of soil frost penetration caused by it. Soil has very high electrical resistance and has the big hardness and density. During the cold period which has big duration (up to nine and more months) there is a soil frost penetration on tens of meters, forming areas of so-called permafrost. The conditions listed above make very difficult or impossible the use of traditional ways of the protective grounding device according to regulatory requirements. Methods of researches for the Arctic zone soil such as a method of a trial electrode and vertical electric sounding are described. Their advantages, shortcomings and application conditions are given. Special ways of the device of protective grounding such as natural grounding conductors, chemical, deep laying, portable, with application of a way of warming of a surface and zone around grounding conductors, ways of special processing of soil are offered. Conditions of their application and feature of the device are given. Each of the offered ways has restrictions of field of use. So, for example, natural grounding conductors are possible in the presence of reinforced concrete foundations. Justifications for using certain materials for grounding conductors are given in the work. Coverings are suitable for soil conditions of the Arctic copper or zinc. The usage of copperplated steel grounding conductors is possible.

1. Introduction.

At the moment many countries show interest in development of the territory of the Arctic. The increasing need of the world economy for energy and mineral resources makes these plans strategic[1,2]. The Arctic is a unique territory with high economic potential including enormous reserves of hydrocarbon raw materials, minerals, a strategic sea way and other resources. At the present moment the Arctic is a low-populated and remote territory with poorly developed infrastructure. The social and economic development of the Arctic zone will demand the development of power industry and the important place in this development will be taken by EN and EI. Important issue at EN and EI operation is safety of personnel and strangers from action of electric current. Safety can be ensured by different technical ways of protection of an electric unit and organizational and technical measures [3-6].

Treat organizational and technical measures:
- unavailability of current carrying parts of an electric unit;
- application of blocking;
- use of signaling and the warning signs of safety;
- individual protection equipment and others.

The listed organizational technical measures can't provide security of personnel from action of electric current.

Ensuring more security of the person requires application of technical ways of protection of an electric unit. Such ways are [8, 11-14]:
- grounding;
- protective grounding;
- the dividing transformers;
- protective shutdown;
- alignment of potentials and others.

All listed ways can be applicable only in the presence of grounding. Protective grounding needs to be applied in the following cases [5, 9, 17-19]:
- at a voltage more than 50 of Vv alternating current mains and more than 120 V in direct current mains;
- in rooms with the increased danger, especially dangerous and in outdoor installations at a voltage from 25do 50 of V in alternating current mains and at a voltage ot60 up to 120 V in direct current mains;
- for all electric units which are in explosive zones, in especially dangerous rooms and in outdoor installations;
- for the transformers used x during the welding works;
- for covers of power cables and in some other cases.

The following parts of electric units and the equipment are subject to grounding:
- metal parts (cases) of electrical machines, lamps, measuring transformers;
- control panels and distribution at a voltage over 25 V of alternating current and more than 60 V of a direct current;
- portable and the mobile electric tool (metal cases) and electric equipment installed on moving mechanisms and other electric equipment.

Regulatory requirements of safe work of EN and EI are provided at observance of the following indicators:
- electrical resistance of grounding;
- voltage of touch of the person to the case of an electric unit.

Regulatory requirements to resistance of the grounding devices (R) of electroinstallations up to 1000 V when grounding neutral depend on values of specific resistance of soil (ρ) and for the linear voltage of a source of current of 220 V make:
- for ρ up to 100 Om*m the value R is equal 8 Ohms;
- for ρ more than 100 and less than 1,000 Om*m the value R is equal 0.08ρ Ohm;
- for ρ more and equal 1000 Ohms * the value R is equal to m 80 Ohms.

For electrical networks over 1000 V with effectively grounded neutral value of R will make:
- for ρ up to 500 Om*m the value R is equal 0.5 Ohms;
- for ρ from 500 to 5000 Om*m the value R is equal 0.01ρ Ohm;
- for ρ more and equal 5000 Ohms * the value R is equal to m 5 Ohms.

Maximum permissible - levels of voltage of touch and currents are established for ways of current from one hand to another and by hand to legs (tab. 1) [4].

Table 1. Current through a body of the person at 50 V, 50/60 Hz at the smallest values of resistance of the person

| Way of current | Resistance of a human body, | Current through a human body, mA |
|---------------|-----------------------------|---------------------------------|
|               |                             |                                 |
In tab. 2 - 3 dependences maximum permissible touch voltage from influence time for normal and emergency operation are given [4].

Voltage of touch and the current passing through a body of the person at influences no more than 10 min. a day should not exceed the values given in tab. 2.3. Data in the table belong to electroinstallations of all classes of voltage both with isolated, and with the grounded neutral.

Table 2. Maximum permissible levels of voltage of touch and the currents proceeding through a body of the person at the normal (not emergency) mode

| Sort of current                  | U, B Not more than | I, mA |
|---------------------------------|--------------------|-------|
| Alternate 50 Hz                 | 2,0                | 0,3   |
| Alternate 400 Hz                | 3                  | 0,4   |
| Direct                          | 8,0                | 1,0   |

Note. For the persons performing work in the conditions of high temperatures it is (higher than 250°C) and humidity (more than 75%) specified in the table of value should be reduced by 3 times.

Voltage of touch and currents passing through a body of the person at emergency operation of work of electroinstallations up to 1 kV with the grounded or isolated neutral and is higher than 1 kV with the isolated neutral, not have to exceed the values given in tab. 3.

Table 3. Maximum permissible levels of voltage of touch and currents at emergency operation of EI up to 1 kV with the dead-grounded or isolated neutral above - 1 kV with the isolated neutral

| Sort of current                  | Ialt 50 Hz U, V | Ialt 400 Hz U, V | Idir U, V |
|---------------------------------|----------------|-----------------|-----------|
| The normative parameter I, mA   | 0,01 - 0,08    | 0,1             | 0,01      |
| Maximum permissible value of    | 650            | 650             | 650       |
| touch voltage at influence      | 0,2            | 500             | 500       |
| duration, with                  | 0,3            | 250             | 300       |
|                                 | 0,4            | 165             | 350       |
|                                 | 0,5            | 125             | 250       |
|                                 | 0,6            | 100             | 220       |
|                                 | 0,7            | 85              | 170       |
|                                 | 0,8            | 70              | 140       |
|                                 | 0,9            | 65              | 130       |
|                                 | 1,0            | 55              | 110       |
| Over 1,0                        | 36(6)          | 50              | 100       |

Voltage of touch and currents passing through a body of the person at emergency operation of work of electric units over 1 kV with effectively grounded neutral should not exceed the values presented to tab. 4.
Table 4. Maximum permissible - levels of voltage of touch and current at emergency operation -
electric units voltage with a frequency up to 50 Hz voltage above - 1 kV with dead grounding neutral

| Exposure time of t, s | the Maximum permissible level I, mA | Maximum permissible touch voltage, V |
|-----------------------|-------------------------------------|-------------------------------------|
| To 0,1                | 500                                 | 500                                 |
| 0,2                   | 400                                 | 400                                 |
| 0,5                   | 200                                 | 200                                 |
| 0,7                   | 130                                 | 130                                 |
| 1,0                   | 100                                 | 100                                 |
| from above 1,0 to    | 65(50/t)                            | 65(50/t)                            |
| 5,0                   |                                     |                                     |

2. Main provisions.

The safe operation of electrical installations and providing safety of the operating personnel is possible only in case of using the grounding devices meeting regulatory requirements during the whole year [3-9]. All the other types of electrical installation protection such as protective circuit breaking, protective neutralizing, equalizing of potentials and others cannot be used without grounding. The regulatory requirements of safe work of EN and EI are provided by periodic measurements of the following indicators:

- electrical resistance of grounding;
- person touch voltage to the case of electrical installation.

These measurements are carried out during the entire period of operation of installations. These indicators depend on characteristics and temperature of soil and also on design data of the grounding device.

As power sources in the Arctic regions generally diesel power plants of single power up to 1000 kW are used. Power distribution is carried out on voltage 6-0.4kV. For this type of electrical installations the safety is ensured by application of working and protective grounding while the current spreading resistance has to be equal from 0.5 to 40 Ohms. Standard values of artificial protective grounding are provided by deepening of a certain number of grounding conductors (steel cores, corners, strips, etc.) in soil. At the same time the number of grounding conductors and the depth of their laying depend on soil characteristics and temperature conditions in which the device is operated [5,6,10].

One of the key parameters defining the number of grounding conductors in the device is the resistivity of soil. For typical soil of Europe and characteristic indicators of climate the value of resistivity can be up to 103 Ohm*m and the number of grounding conductors can be up to 20-40 units.

The number of grounding conductors (n) can be calculated by the formula [7,8]:

\[ n = \frac{R_1}{R_2 \cdot K_1} \]  

(1)

where \( R_1 \) – electrical resistance of a single electrode (grounding conductor);
\( R_2 \) – permissible resistance of protective grounding;
\( K_1 \) – electrode efficiency factor that is determined by the number of electrodes and the distance between them.

The electrical resistance of a single electrode (R1) can be calculated by the formula:

\[ R_1 = \frac{R_3}{2\pi l} \left[ \ln \left( \frac{2l}{d} \right) + 0.5 \ln \left( \frac{4h+3l}{4h+l} \right) \right] \]  

(2)

where \( R_3 \) – electrical resistivity of the ground;
\( l \) – electrode length;
\( d \) – electrode diameter;
h – depth of electrode laying;

Total electrical resistance of the grounding device (R0) can be calculated by the formula:

$$R_0 = \frac{(R_1 \cdot R_4)}{(n \cdot R_4 \cdot K_1 + R_1 \cdot K_2)}$$

(3)

where R4 – resistance of the strip connecting all the electrodes;

K2 – strip efficiency factor that is determined by the distance between electrodes and strip length;

The resistance of the strip connecting all the electrodes (R4) can be calculated by the formula:

$$R_4 = \frac{R_5}{2\pi \ln\left(\frac{2l_2}{hb}\right)}$$

(4)

where R5 – electrical resistivity of strip metal;

l2 – length of strip connecting all the electrodes;

b – strip width.

Special requirements to the grounding EN and EI devices in the Arctic conditions are caused by the climate of the Arctic and characteristics of its soils. Soil of the continental Arctic is presented by the following types:

- disperse coherent such as ice and soil formation (mainly loams with power over 10 m);
- disperse incoherent (mainly sands, gravel, sandy loams, is more rare loams, clays);
- carbonate; rocky, semi-rocky (about a half of all soil).

The main distinctive feature of soil of the Arctic zone is the availability of multifrozen soil. Due to the existence in composition of soil of ice, they undergo seasonal thawing and this state promotes easing of bearing capacity, creep and sag.

The climate is characterized by a wide year temperature difference (from −620°C in winter and up to +400°C in summer in some areas of Sakha Republic Yakutia). The cold period has big duration (up to nine and more months). At the same time the specific electrical resistance of soil increases in ten and more times [9,10].

The listed above characteristics of soil in the conditions of low temperatures possess very high resistance up to 50*10^4 Om*m and respectively the settlement number of grounding conductors can make hundreds of units. Besides, soil has also high hardness and density that creates difficulties while laying grounding conductors. During the cold period soil freezes through on tens of meters and for effective use of grounding conductors they have to be put lower than depth of frost penetration. The listed above conditions of the device of the grounding devices meeting regulatory requirements in the standard practice for the most adverse conditions of its operation (the cold period of the year in the Arctic) turn out to be very difficult or impossible in most cases.

More expedient are the following ways of the device of the grounding devices such as natural grounding conductors, chemical, deep laying, portable, with application of a way of warming of a surface and zone around grounding conductors, ways of special processing of soil.

To determine more precisely the resistivity in the field on which installation of grounding conductors is planned, it is necessary to carry out preproject surveying works. Such researches are usually carried out on the platform where electrical installation or the production building will be placed. Determination of features of soil in this territory and the location with the lowered electrical resistance of soil is the result of carrying out researches. During these researches it is important to find a thin conductor layer in the earth according to the results of methods of vertical electric sounding and electric profiling. In these cases it is applicable to use the plane electrodes immersed in this layer as grounding conductors.

As methods of researches for soil of the Arctic zone the methods such as a trial electrode and vertical approach electric sounding are used. It is expedient to lead multilayered structure of soil to two-layer structure. Parameters of this scheme can be determined by a method of a trial electrode. The technology of work consists in installation of single grounding conductors (vertical or horizontal) some sizes provided by the project on the grounding device. The method allows production of earthwork during the convenient climatic period. However the method does not give values on soil indicators outside installation of single grounding conductors. Now this method is applied only in case of low power installations. At the same time, the resistivity of a blanket of the earth is small. It is
expedient to apply a method of a trial electrode as additional to a method of vertical electric sounding. This method is applied when the electric structure of the earth has complex structure such as numerous inclusions (lenses) of soil with other resistivity in comparison to the main layer and sharply changing power of layers in the horizontal direction. The method of electric sounding allows to build schedules of the change of specific electric resistance with the depth. For the considered types of soil at vertical electric sounding the grounding conductor can plunge up to 50 m.

The features of climate and characteristics of soil in the continental Arctic make useful such natural grounding conductors as concrete foundations of household and industrial buildings, casing pipes of gas wells, pipelines on the carrying-out support and other metal and grounded designs belong. When using pile reinforced concrete foundations for stability they are connected in uniform including a uniform of electrical circuit by application of arc welding.

In the presence of near installation site of the grounding device at admissible distances of soil with a small resistance the device of portable grounding is expedient.

In some cases grounding conductors can be put around the grounded equipment the so-called loop grounding. For the purpose of alignment of potential in a contour, it is possible to install horizontal grounding conductors here.

The method of warming the surface of the earth in areas around the grounding devices reduces the electrical resistance of the soil in the cold season. During the warm period of the year filling of the platform over a grounding conductor installation site is made. It is possible to use sawdust, slags, polymeric materials, household waste, etc. as heat-insulating materials.

The thickness of a layer should be selected according to calculation results and technological capabilities. For protection from moisture hit the warmed surface can be covered with a polyvinyl chloride film. For heating of soil around grounding conductors special electric heaters are installed.

Grounding conductors of deep laying allow to lower or remove dependence of resistance of protective grounding on seasonal fluctuations of temperatures. The depth of installation can be up to 10-15 meters. At these depths there can be ground waters and due to humidity the electrical resistance of the grounding conductor will decrease. Besides, at such depth temperature can also matter positive that leads to decrease in resistance of soil. The technology of installation of deep grounding conductors is the following: the well is drilled on depth where tests of soil have lower resistance. In free space of wells clay (loamy) solution can be filled in. It is necessary to provide installation of the grounding conductor during warm season for the purpose of decrease in electrical resistance of the grounding conductor due to the best contact with soil. It is expedient to fill the well with hot solutions. The limitation of this method usage is the great depth of the soil with low resistance. For a right choice of the place for grounding conductors of deep laying it is necessary to use data of a geoelectric section of the earth which is carried out during predesign researches on the site of an object. Advantages of grounding conductors of deep laying consist in stability of values of resistivity of soil as seasonal fluctuations of temperatures do not reach laying depths.

The chemical grounding devices can be used to many soil of the Arctic having in most cases high resistivity. The chemical grounding conductor consists of a copper pipe with openings which is filled with electrolytic salt. At the same time:

- prevention of frost penetration in soil around the grounding conductor is provided;
- the conductivity of soil increases;
- there is a reduction of the area for placement of a grounding device, thanks to construction features and mounting of a chemical electrode;
- device service life increases.

Soil of the considered zone depending on the breeds forming the soil contain the carbonate and salts dissolved by water and they have subacidic or alkalescent reaction of the environment which causes corrosion of grounding conductors.
Corrosion resistance of the device can be increased by following ways:
- prevention of moisture hit especially to places of connections of a grounding device elements;
- insulating materials used in technological connective operations of a grounding device elements should be corrosion resistant also;
- taking into account possible emergence of galvanic effects at contacts of a grounding device with metals.

The general requirements to grounding devices are the following conditions:
- grounding devices should provide operation term within 20-30 years;
- the mechanical durability of all device elements and places of their mounting (welding and other ways of connection) should be provided during the entire period of operation;
- all component parts of the devices should maintain the currents running through them (they should to have sufficient thermal stability);
- they should have sufficient corrosion resistance in aggressive soil.

An alternative of the grounding device, in the absence of a possibility of its installation, is creation of conditions of reliable isolation of the person from current carrying and metal parts of electrical installation (barriers, covers, protections and others).

3. Conclusions
The territory of the Arctic zone and Far North of Russian Federation is rather difficult due to its engineering geological conditions. Only the fifth part from total area, is suitable for installation of the grounding devices meeting requirements of accident-free operation and safety of the personnel operating EN and EI requirements.

At design stage and during performance of the grounding devices in regions of low temperatures the following problems are known: features of temperature conditions of soil; a phase condition of water in a time of these breeds; considerable seasonal fluctuations. In winter time the resistivity of layers of the earth which depends on soil type, the highest that complicates the device of grounding.

Decrease in electrical resistance requires application of various ways of special processing of soil:
- saturation by salt solutions;
- processing of electrodes fine coal;
- replacement of a part of soil with material with the increased conductivity;

When using natural grounding, reinforced concrete foundations, which provide a constant well-conducting environment, can be used. Large seasonal changes in temperature, typical to the Arctic, require to install grounding devices to a great depth. This method allows to reduce electrical resistance and consumption of metal on grounding devices.

References
[1] Burlov V G and Popov N N 2017 Management of the application of the space geoinformation system in the interests of ensuring the environmental safety of the region. Advances in the Astronautical Sciences 161 p 751-760
[2] Istomin E P and Abramov V M 2017 Knowledge database in geoinformation management of the territory development International Multidisciplinary Scientific GeoConference Surveying Geology and MiningEcology Management SGEM 17(21) p 951-959
[3] Bugsdorf V V and Yakobs A I 1987 The grounding devices of electrical installations
[4] Mankov V D and Zagranichniy S F 2007 Protective grounding and protective zeroing of electrical installations
[5] Motusko F Ya 1983 Protective devices in electrical installations
[6] Borisov R K Grounding devices of electrical installations
[7] Maksimenko N N and Popov A A 1987 Calculation and operational control of the parameters of grounding devices in the Far North region
[8] Karyakin S I 1983 Protective devices in electrical installations
[9] Kostruba C I 1983 Measurement of electric parameters of the earth and the grounding devices
[10] Zaytseva N M and Zaytsev D S 2008 Dependences of specific electrical resistance of soil on humidity and temperature Electricity 9 p 30-34.
[11] Bukharov A I and Petunin V V 1989 Bases of safe operation of electroinstallations
[12] Mankov V D and Foreign S F 2011 Types of protection that ensure the safety of EC
[13] Bychkov A M and Ivanov V G 1981 Electrical Safety Handbook
[14] Manoylov V E 1991 Electrical safety bases
[15] Korabilev V P 1985 Electrical safety devices
[16] Krikun I V 1973 Testing of grounding devices and zeroing devices of electrical installations
[17] Karjakin R N 1998 Standard bases of the device of electroinstallations
[18] Electrical Shock Safety Criteria 1985 Proceedings of the First International Symposium of Electrical Shock Criteria
[19] Biegelmeier G and Kriefer K H 1996 Schutz in elektrischen Strom