Improving the reliability of the relay automation system for power facilities

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Abstract. The main reasons of the false (incorrect) operation of the microprocessor relay protection system are analyzed in the article. The methods of increasing the reliability indicators of the relay automation system are presented. Analysis of statistical data submitted by PAO Rosseti showed that the probability of failure-free operation of microprocessor relay protection systems is not lower than 0.998. Increasing the reliability of microprocessor protection systems does not dictate the revision of the Electrical Installation Rules, but requires the use of high-quality cable products with normalized technical characteristics, the transition to a digital data transfer format with the limitation of the number of variables fed through one serial channel. Exemplary upper and lower bounds are established for the cost of improving the reliability of the microprocessor system. For example, reducing the failure rate by half will require increasing the capital costs of protection from electromagnetic interference by about (3-4) times. Preservation of the reliability level of the microprocessor system in the process of operation is possible only if the planned measures are taken to assess the electromagnetic situation. As shown by statistical data, the most likely cause of incorrect operation of relay automation is atmospheric phenomena (lightning). Therefore, at the stage of estimating the electromagnetic state, it is necessary to pay attention to the state of the earthing system, and the fault diagnosis is most rationally performed by the half-division method, considering the probability of failure-free operation.

1. Introduction
The proposed article reflects the opinion of the authors, which was formed on the basis of the results of the survey and assessment of the electromagnetic situation in the branch "Yuzhnoyarskaya GRES" of "Inter RAO - Electric Power Generation".

The transition to a new technology always raises certain doubts of the personnel, who for a long time served the technique of the previous generation. Therefore, the introduction of microprocessor relay protection devices causes quite specific fears of false triggering of microprocessor systems in case of short circuits, for example, on the 110 kV side or for reasons of: working along the excavator proximity; atmospheric phenomena (lightning); and even the use of mobile communication devices as a source of electromagnetic interference. This is explained by a different level of signal power that can disrupt the operation of the controls: for an electromechanical relay, this energy is 10–3 J, while at the same time for microprocessor systems 10–7 J.
2. Research problem statement
A comprehensive approach to the development of modern relay automation systems based on the maximum reliability criterion provides the solution of the following tasks: analysis of possible unfavorable factors affecting the reliability of the system; synthesis of the mathematical model of the relay automation system; external sources of electromagnetic influences, which can have a negative effect on the MP equipment, are as follows: Emergency processes in networks above 1 kV; Lightning discharges into the elements of the lightning protection system of the facility; Other sources of interference, including radio; DC power system

3. Calculation of electromagnetic fields
As an accounting model, an open 110 kV switchgear was adopted. In this case, the parameters of the earthing switches were considered, as distributed, the parameters of the protective devices (overvoltage limiters, external interference filters) as concentrated. In Figure 1 presents the design model of the open switchgear 110 kV of Yuzhnouralskaya TPP.

![Figure 1. The design model of the grounding device of the open distributing device of the South Ural city district power station.](image)

4. Results of short-circuit simulation and calculation of communication adequacy criterion
During measurement of parameters of grounding devices, simulation of short circuit was carried out on the territory of the substation. In the process of modeling single-phase short circuit in networks with grounded neutral a separate current circuit was organized between the remote probe and the electrical apparatus (feeding from the system), as well as grounding the neutral of the power transformer and the electrical apparatus.

In the process of simulating a short circuit exceeding the permissible values was revealed. Isolation of input and output circuits of the installed microprocessor equipment withstands the test voltage of the industrial frequency of 2 kV.

The calculated potential differences will be applied to the isolation of the secondary circuits and (or) to the inputs of the installed microprocessor equipment with a short circuit.

The grounding quality of the equipment is considered satisfactory if the measured resistance does not exceed: \( R(\text{Om}) < 2(\text{kV})/I_{1sc}(\text{kA}) \), where \( I_{1sc} \) is a single-phase (or two-phase for a switchgear with an isolated neutral) short-circuit current on the busbars of the switchgear.

As a criterion of sufficiency of communication with grounding devices of electric devices to which secondary chains are brought, value of resistance of communication was calculated and is equal for open switchgears of 110 kV – 0,08 Om, for open switchgears of 220 kV – 0,1 Om.

For electrical devices, which are not connected to the secondary circuit (portals, bus supports, etc.), the maximum resistance value should not exceed the resistance requirement of the General grounding device of the substation (0.5 Om), according to paragraph 1.7.90 of the rules of electrical installation [1].
5. Hazard assessment of high-frequency component of short-circuit current

According to [2], the highest value of the high-frequency component of the short-circuit current will be 1.2 kA with a short circuit on an open switchgear 110/220 kV.

Other According to the calculation results, the maximum level of high-frequency noise at the inputs of microprocessor equipment can reach 3.5 kV. The calculated value of the noise will not be dangerous for microprocessor equipment tested by 3 degrees of stiffness (2.5 kV according to the "wire-ground" scheme) for resistance to damped oscillatory repetitive impulse noise in accordance with [3]. Power supply of microprocessor equipment of the equipment is carried out by direct current.

The maximum magnitude of the magnitude of the voltage ripple in the DC network was 0.44 V. This value of the ripple amplitude in the DC network does not pose a danger to microprocessor equipment tested for the third and higher (not more than 10% of the rated voltage) degree of stiffness for resistance to DC voltage ripple in accordance with [4].

6. Lightning protection system

The lightning protection system of the substation consists of separate lightning rods and lightning rods installed on the portals [5].

Lightning protection system provides protection against direct lightning equipment and structures with a reliability of 0.95 in accordance with [6] and [7].

7. The calculation of the pulse difference of the potentials at lightning discharge

For open switchgear of the South Ural city district power station on the basis of the data obtained during the trace, was built a calculation model of the grounding device (see figure 1) and calculated the distribution of potentials on the grounding device at the substation with lightning discharge in the lightning protection system of the substation. The calculation was made with the help of specialized registered software "ODS-Project" [8].

When calculating the pulse potential difference, the soil resistivity value was taken to be 86 Om·m, the magnitude of the lightning current pulse amplitude was taken to be 100 kA, in accordance with [9].

The most dangerous from the point of view of electromagnetic compatibility, lightning.

In accordance with the results of calculations, the largest value of the pulse potential difference applied to the secondary circuits and/or to the inputs of microprocessor equipment will occur when lightning is discharged into the lightning mast. In accordance with the data [10] and [11], the attenuation coefficient is taken to be 6 (when grounding the screens of the cables of the secondary circuits on both sides). The value of the pulse potential difference reaches a value of 3 kV [12].

Levels of noise immunity of microprocessor equipment correspond to the 4th degree of rigidity (4 kV) tests for resistance to the effects of microsecond high-energy pulse noise in accordance with [13].

According to the results of measurements, the maximum level of intensity of a continuous magnetic field of industrial frequency was 0.1 A/m.

Magnetic fields of industrial frequency of this level will not be dangerous for microprocessor equipment tested on the fifth (100 A/m) and above the degree of rigidity of the tests for resistance to the effects of a continuous magnetic field of industrial frequency in accordance with [14]).

In the event of a short circuit in the 220 kV network (nearest to the main control panel conductive bus), the maximum level of the short-term magnetic field of industrial frequency in the building of the main control panel will not exceed 50 A/m.

The calculated maximum intensity level of short-term magnetic field of industrial frequency will not be dangerous for microprocessor equipment tested at the fifth (1000 A/m) degree of rigidity for resistance to short-term magnetic field of industrial frequency in accordance with [15].

The magnitude of the pulse amplitude of the lightning current was taken to be 100 kA, according to [16].
In case of lightning discharge in the nearest to the building of the main control panel lightning M1, the highest calculated level of intensity of impulse noise in the room of the main control panel will not exceed 9 A/m, taking into account the coefficient of shielding the walls of the building [17]. This level of pulse noise intensity will not pose a danger to microprocessor equipment tested on the fourth (300 a/m) and higher degree of rigidity for resistance to the impact of a pulsed magnetic field in accordance with [18].

According to the results of measurements, the maximum level of the electromagnetic field of the radio frequency range did not exceed 2 V/m. Electromagnetic fields of radio-frequency range of such level will not be dangerous for microprocessor equipment tested according to the third (10 V/m) and higher degree of rigidity of tests for resistance to radio-frequency electromagnetic field in accordance with [19].

According to the results of measurement in the room of the main board, the level of static voltage was 0.1 kV, which will not be dangerous for microprocessor equipment tested for the third and higher (up to 8 kV – air, up to 6 kV – contact charge) degree of rigidity of tests for resistance to static electricity according to [20].

Measurement of noise occurring in secondary circuits during switching operations in the primary network was carried out using the Fluke oscilloscope [21]. To estimate the high frequency noise oscillography curve of the voltage in the secondary circuit were carried out during the production of switching operations in the networks of 110, 220 kV. The oscilloscope trigger was produced by exceeding the measured value of the voltage in a circuit above setpoint trigger of the oscilloscope [22]. The oscilloscope trigger settings were selected above the normal voltage level in the circuit, but below the noise immunity level of microprocessor equipment [23]. The values obtained during switching operations in the secondary circuits do not exceed the permissible limits [24].

8. Analysis of the results
According to the results of experimental and calculated determination of the electromagnetic environment under the conditions of electromagnetic compatibility of modern equipment at the substation, the following conclusions can be identified: The configuration of the grounding on object does not correspond to requirements of normative and technical documentation; Grounding of the room of the main Board of management conforms to requirements of normative and technical documentation; The Resistance of the grounding device does not exceed the permissible values; The existing grounding slopes do not fully meet the requirements of thermal stability; Measured short-circuit noise levels can be dangerous for installed microprocessor equipment; The Pulse potential difference from the high-frequency component of the short-circuit current is not dangerous for microprocessor equipment; All equipment at the substation is grounded; The contact Voltage does not exceed the permissible values; The voltage Parameters in the DC power supply meet the requirements of regulatory and technical documentation; Lightning protection system provides protection against direct lightning strike; Impulse noise during lightning strikes in the lightning protection system of the substation will not pose a danger to the equipment; Levels of intensity of continuous magnetic field of industrial frequency, short-term magnetic field of industrial frequency, pulsed magnetic field and electromagnetic field of radio frequency range are not dangerous for microprocessor equipment; The Level of static electricity is not dangerous for the installed microprocessor apparatus; Pulse noise exceeding the levels of noise immunity, when switching in the secondary circuits is not fixed.

9. Recommendations for electromagnetic compatibility of microprocessor equipment
It is not recommended to attach the protection Of the open switchgear to the General grounding device (item 1.7.93 of the rules of the device of electrical installations [25]), in order to avoid carrying out of potential and possible touch of the person who is not on the open switchgear [26]. To exclude electrical connection of the external fence with the grounding device, it is necessary to disconnect the places of welding of the grounding device and the fence [27]. At the same time, the distance from the
fence to the elements of the grounding device located along it from the inside, outside or on both sides, must be at least 2 m [28]. If these conditions cannot be fulfilled, the metal parts of the fence should be attached to the grounding device and to perform a potential equalization along the entire length of the fence. To do this, a horizontal grounding device should be laid on the outside of the fence at a distance of 1 m from it and at a depth of 1 m. This grounding device should be attached to the grounding device at least four points [29].

In order to meet the requirements of paragraph 1.7.90 of the electrical installation regulations and to improve the overall metal connection of the 220/110 kV open switchgear, additional earthing devices must be installed [30]. The recommended earthing devices shall be made of steel with a cross-section of at least 221 mm² for an open switchgear of 110 kV and a cross-section of at least 126 mm² for an open switchgear of 220 kV. Recommended earthing devices should be welded to the existing ones at all detected intersections [31]. The recommended grounding conductors shall be laid at a depth of 0.5 - 0.7 m. Places of input into the soil should be protected from corrosion. It is recommended to use as natural grounding conductors of a way of rolling of transformers. Places of breaks the rail must be connected by a flexible conductor.

The lightning Receivers M1, M2, M3, M4 according to the requirements of the rules of the device of electrical installations, shall be attached to the General grounding device [32]. When using searchlight masts as lightning rods, wiring to them on the site from the point of exit from the cable structure to the mast and then on it should be carried out with cables with a metal shell or cables without a metal shell in the pipes [33]. Near the lightning rod structure, these cables must be laid directly in the ground for at least 10 m.

Single lightning receivers, which are not connected to the secondary circuit is not Allowed to attach to a common grounding device [34].

Thus, two solutions are possible: to connect the grounding conductor of these lightning receivers in a common grounding device or to dismantle the secondary circuits from them.

According to the results of calculations, additional requirements for the implementation of grounding have been developed [35].

To improve equipotentiality and reduce the proportion of short-circuit currents flowing through the shields and cable sheaths in the short sections between the primary equipment and the corresponding intermediate clip cabinet (control), it is necessary to ground the metal structures of the intermediate clip cabinets (control) on the metal cable channel in accordance with the design drawing. In addition, the metal structure with cabinets on 220 kV open switchgear should be additionally connected to the nearest horizontal grounding device using a grounding conductor made of galvanized steel with a section of 50x6 mm.

10. Conclusion

It is not recommended to connect the switchgear assembly to a common grounding device, in order to avoid potential transfer and possible contact of a person not on the outdoor switchgear. It is necessary to disconnect the places of welding of the memory and the fence to exclude the electrical connection of the external fence with the grounding device. In this case, the distance from the fence to the elements of the grounding device must be at least 2 m.

If these conditions cannot be met, the metal parts of the fence should be connected to the grounding device and equalize the potentials along the entire length of the fence. Horizontal earthing switch should be laid from the outside of the fence at a distance of 1 m and at a depth of 1 m. This earthing switch should be connected to the grounding device in at least four points. The lightning detectors must be connected to a common earthing arrangement. When using projector masts as lightning conductors, the electrical wiring to them from the point of exit from the cable structure to the mast and then along it should be made with cables with a metal sheath or cables without a metal sheath in the pipes.
Acknowledgement

South Ural State University is grateful for financial support of the Ministry of Education and Science of the Russian Federation (grant No 13.9662.2017/BP).

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