Improving the reliability of energy facilities

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Abstract. The article analyzed and identified the main sources of interference, disrupting the work and reliability indicators of the system, which can lead to malfunction of system of microprocessor relay protection and automation for electric stations and substations, as well as elements and actuators of open distribution devices. According to official data, modern microprocessor-based relay automation systems operate with a reliability coefficient that is not lower than 0.998. Further increase in reliability requires the development of technical measures, namely, requires the use of power and signal cables that must meet the requirements for specific parameters of inductance, capacitance and active resistance, and also requires the use of special placement of cross sections of conductors inside the cable. Secondly, it is shown that to increase the reliability of information transmission it is necessary to switch to serial communication channels, but the amount of information per channel should be strictly limited. The estimation of economic indicators of the system and its dependence on the reliability of the system is given. Thus, with an increase in reliability by 1.5-2 times, it is necessary to increase the cost of design and commissioning of such a system by about 2 times. It is recommended to use in addition to the regulated maintenance procedures a mandatory assessment of the level of interference in the system in order to maintain a stable and reliable operation of the relay automation system. Experimental and calculated data confirmed that the most difficult situation to ensure the reliability of the system is associated with thunderstorms and lightning. This circumstance dictates the necessity of evaluation and measuring the parameters of a common system of earthing. The methods of evaluation and diagnosis of faulty components of the system are proposed.

1. Introduction

Modern power stations generating power are controlled by microprocessor-based relay automation control devices. Microprocessor devices operate under the influence of powerful fields of electric and magnetic nature, due to the high level of voltage on open switchgears (up to 1000 kV and above), as well as the presence of atmospheric phenomena (lightning discharges) [1]. All these circumstances indicate the need to develop and implement measures to improve the electromagnetic environment and thereby increase the reliability of the relay automation system [2].

2. Formulation of the research problem

Statement of the research problem. The scientific and technical problem of development of regulated AC drives requires solving the following tasks:

To achieve the goal – to increase the reliability of the system in the article the following scientific and technical problems were solved:
• analysis of modes of operation of relay automation systems on the example of the Yuzhnouralskaya GRES-2;
• selection of the object’s design model;
• calculation of the equipment’s pulse resistance;
• the calculation of levels of exposure to impulse noise;
• calculation of induced interference in short-circuit;
• determination of levels of electromagnetic fields of RF range;
• development of recommendations to improve the electromagnetic environment.

3. Analysis of operation modes of relay automation systems
Construction of the Yuzhnouralskaya GRES-2 is carried out by two launch complexes. In accordance with the project [3], two CCGT units-400 MW are installed at the GRES. Each CCGT power unit under construction with appropriate auxiliary equipment and facilities is a launch complex [4]. Power unit № 2, cells № 1 and № 5 outdoor switchgears OSG-220 kV, OSG-500 kV, distributive shield OSG-500 kV are included in the second launch complex. This section of the project runs under the title "Development of design documentation for re-equipment of outdoor switchgear-500 kV Yuzhnouralskaya GRES - 2" for adjustment of the scheme of power distribution of Yuzhnouralsk GRES-2 [5].

The main electrical equipment of each CCGT-400 unit includes the SGen5-2000H generator, which is interfaced with gas and steam turbines. Circuit generator provides a sulfur hexafluoride generator circuit-breakers manufactured by ABB. Block step-up transformer type TNC-630000/220 UHL1 production of JSC "Zaporozhskiy transformatorny zavod ". Communication of generators with the step-up transformer is carried out by means of closed shielded conductors with natural cooling. With CCGT-400 the installation of operating transformers with split winding type TRANS-32000/35 UHL1, connected by tap conductor from the generator to transformer between generator and switch block transformer is provided.

Within the framework of the second launch complex, two OSG-220 kV cells will be equipped, to which will be connected: power unit No. 2 CCGT-400 (cell No. 5) and AT 500/220 kV (cell No. 1). The connection of CCGT-400 with outdoor switchgear 220 kV and outdoor switchgear 500 kV will be carried out by flexible connection 220 kV. Autotransformers of AOD-CCN-167000/500/220-UHL1 are mounted on the territory of outdoor switchgear 500 kV.

The OSG-500 kV being under construction is to be made by the "single scheme". Two switches will connect 500 kV overhead line Yuzhnouralskaya GRES-2-Troitskaya GRES, 500 kV overhead line Yuzhnouralskaya GRES - Shagol and a group of three single - phase AT 500/220 kV to the OSG-500 kV buses. A group of three single-phase 500 kV shunt reactors is connected to 500 kV buses via a single switch.

At outdoor switchgear of 500 kV single-phase core sulfur hexafluoride insulated switches type 3AP2FI-550, current transformers type IOSK 550, capacitive voltage transformers type 550 TEMP, disconnectors D-type BF6-550+2AE BF2 and BF6 D-550+AE BF2, grounding device type ZPPA-500.11/3150 UHL1, connection capacitors, overvoltage limiters type 3EP2 399-3PH43-2NE1 are installed.

4. Selection of the object’s design model
Power consumers 380/220 in the OSG-500 kV and the control building is carried out according to the scheme TN-C-S from RUSN-0.4 kV installed in the control building.

Control cables of control circuits, measurement and alarm circuits on the OSG-500 kV are laid in cable channels, at not less than 10 m in the light from the base of foundations (racks) with lightning rods and voltage limiter.

The following types of 0.4 kV power cables are used on the 500 kV outdoor switchgear:
- APvVGng (unshielded) - trunk line 0.4 kV from distribution unit for internal needs-0.4 kV from DC shielded of the control building to the boxes of food and heating of circuit breakers and disconnectors;
- PvVGng (unshielded) from the feed bins of the drives of the disconnectors to remote control Cabinet drives of disconnectors;
- PvVbSHng (armored) - from source boxes and drive switch’s heating to the central switches control cabinet, from offset drives control cabinets to the drives of the disconnectors and drive disconnector’s heating, from source boxes of disconnectors drives to the heating of cabinets TN.

Under this title, the following low-voltage complete devices are installed in the distributive shield (DS) OSG-500 kV building of the control building:

- automated switches’ control cabinets of all 500 kV overhead lines (OL) and 500 kV shunt reactors (SHR);
- basic protection cabinets of all 500 kV OL;
- backup protection cabinets of all 500 kV OL;
- rack locator cabinets of all 500 kV OL;
- emergency events recorders cabinets of 500 kV;
- cabinets MPA all 500 kV, SS and SHR 500 kV;
- PRD, PRM cabinets of all VL 500 kV;
- counters cabinets OSG-500 kV;
- 500 kV SHR protection cabinets;
- operating current distribution cabinets.

Grounding device (GD) OSG-500 kV is made according to the requirements for the resistance of GD of longitudinal and transverse horizontal grounding of galvanized steel section 50x6 mm, laid at a depth of 0.7-0.9 m, connected to the vertical rod grounding.

5. Calculation of pulse resistance of the equipment
To determine the impulse resistance of the equipment on the switchgear, calculations are carried out in the program "OSG-Project". The initial data for the calculations is:

- grounding scheme;
- parameters of the grounding and grounding conductors;
- the resistivity of the soil;
- the amplitude and frequency of the RF current determined by the results of the calculation in the program "EMI analyzer".

The obtained values of RF current, pulse resistance and reference values of the transmission coefficient are used to calculate the interference at the inputs of microprocessor (MP) devices at the short circuit on the OSG.

When lightning strikes, the following effects of its current are possible:

- reverse overlap with MD on the control cables;
- field interferences on the control cables and the impact of pulsed magnetic fields on the MP device.

The lightning current flowing through the MD creates a high potential on the ground and can cause a reverse overlap of the control cable insulation. The OSG-Project programme is used to calculate this
impact. To do this, a pulsed current source is introduced into the MD circuit at the height of the lightning receiver. The parameters of the lightning current shall be made according to SO 153-34.21.122-2003 [6] \(I_m = 100 \text{ kA}, \tau_0 = 10 \mu\text{s}\). According to the calculation results, the pulse resistances of lightning rods, pulse potentials on the surface of the earth near the cable channels, in the places of installation of MP devices are determined (see table 1).

**Table 1. Calculation results.**

| TT2-EV-1, VL, phase A | TT2-EV-1, VL Troitskaya GRES, p. A-BVS | 382 | 304 | 2000 | 460 | OK |
|----------------------|--------------------------------------|-----|-----|-----|-----|----|
| TT2-EV-1, VL, phase B | TT2-EV-1, VL Troitskaya GRES, p. B-BVS | 380 | 389 | 2000 | 460 | OK |
| TT2-EV-1, VL, phase C | TT2-EV-1, VL Troitskaya GRES, p. C-BVS | 391 | 401 | 2000 | 460 | OK |
| 2-EV-1, VL Shagol, p.A | 2-EV-1, VL Shagol, p.A-BVS | 405 | 319 | 2000 | 460 | OK |
| 2-EV-1, VL Shagol, p.B | 2-EV-1, VL Shagol, p.B-BVS | 402 | 317 | 2000 | 460 | OK |
| 2-EV-1, VL Shagol, p.C | 2-EV-1, VL Shagol, p.C-BVS | 394 | 311 | 2000 | 460 | OK |

The obtained voltage values applied to the insulation of the control cables are compared with the permissible voltage equal to 23 kV for the control cables of the KVVGE type.

Calculation results:
1) At single-phase short circuits at outdoor switchgear of 500 kV voltage levels with industrial frequency acting on the insulation of the control cables will not exceed 516 V that is less than the permissible value of 2000 V. Currents flowing through the screens and armor of control cables at short circuit on the OSG-500 kV, will not exceed the values for KVVGEng-401 A, VBBShVng - 582 A and coaxial cable - 283 A, which is less than the permissible values 460 A for cable type KVVGEng, 1800 A for cable type VBBShVng, 670 A for coaxial cable. Examples of calculation schemes with the results of calculations are shown in [7];
2) the grounding conductor and the horizontal grounding conductor made of a steel galvanized strip of 50x6 mm meet the requirements of [8] and [9] on thermal resistance.
3) the calculated resistance of the MD OSG-500 kV is 0.04 Ohms. Considering the seasonal coefficient for the specific resistance of the soil taken equal to 5 [10], the resistance of the MD will be 0.14 Ohms, which does not exceed the permissible value of 0.5 Ohms and meets the requirements of [11, 12].
4) the maximum contact voltage on the switchgear-500 kV is 51 V, which does not exceed the permissible value of 65 V for the duration of the backup protection [13], according [14];
5) after the end of the installation work it is recommended to carry out control measurements to confirm the calculated data [15].

6. Calculation of impulse noise exposure levels

For the calculations used drawings: "OSG-500 kV. Installation drawings. 122N15A-21 UA - 12692-ED, L. 3-5", " Relay protection and automation of 500 kV and 500 kV overhead lines. Explanatory note. 7048/1-1VL-ITR-309-15RE-3 E5, L. 1". The design schemes in the program "EMI analyzer" are shown in [16] and [17]. The soil Resistance is assumed to be 20 Ohm* m.

The following screening factors were considered in the calculations:

- coefficient of shielding of control cables with two-way grounding of screens - 10 [18];
- coefficients of shielding of the buried cable channel for the corresponding sections of routes of laying of control cables - 10 [19].

When laying the shielded cable in the cable channel, the shielding coefficients are multiplied. The results of the calculation of field noise at short circuit are given in the table 2:

**Table 2. The results of calculation of the interference field at short circuit.**

| Cable (circuits) | HF link | HF link | VT circuits | VT circuits | VT circuits |
|------------------|---------|---------|-------------|-------------|-------------|
|                   | chains  | circuits|             |             |             |


Place of the short circuit | KS VL Troitskaya GRES | KS VL Shagol | 1-TN VL Troitskaya GRES | 1-TN VL Shagol | 2-TN VL Troitskaya GRES
--- | --- | --- | --- | --- | ---
RF current at the location of short circuit, kA | 7.8 | 7.0 | 5.0 | 5.8 | 5.5
The voltage at the input of the MP device, kV | 0.18 | 0.12 | 0.04 | 0.05 | 0.03
Maximum Voltage on the input of the MP device, kV | 2.5 | 2.5 | 2.5 | 2.5 | 2.5
Insights | OK | OK | OK | OK | OK

Calculation results:
1) the level of pulse emitted noise from lightning strikes at the inputs of MP devices installed in the DS of the OSG-500 kV will not exceed 1.7 kV, which does not exceed the permissible value for MP equipment tested for the fourth degree of rigidity - 4 kV, according to [20];
2) the potential induced in the cables will not exceed the permissible value for cable insulation - 23 kV, according to [21].

7. Calculation of induced interference in short-circuit
For the calculations in the "OSG" Project used a drawing of "Lightning protection and grounding. OSG-500 kV. Plan. 122N15A-21 UA-12694-ED, L. 2". The scheme of arrangement of lightning rods and equipment OSG-500 kV is shown in [22].
In accordance with [23], to calculate the overvoltage in the MD at lightning, the current amplitude $l_m = 100$ kA and the front duration $t_{fr} = 10 \mu s$ is taken.
The design scheme in the program "OSG-Project" is presented in [24]. The soil resistance is assumed to be $p_1 = 20$ Ohms $\cdot m$, $p_2 = 18$ Ohms $\cdot m$, the depth of the layers $h = 0.8$ m.
The results of the calculation of pulse overvoltages affecting the insulation of cables during lightning strikes are presented in the table 3:

Table 3. The results of calculation of the interference field at short circuit.

| Cable routing | TN 1 SH-BVS | 1-TN VL Shagol-BVS | 2-TN VL Shagol-BVS |
| --- | --- | --- | --- |
| Calculated maximum cable voltage, kV | OSG-500 kV | 8.6 | 4.1 |
| Input MP voltage, kV | M1 lightning current 100 kA, the lightning conductor resistance 0.65 Ohms, the potential at the MD 64.9 kV | 0.86 | 0.41 |
| Maximum voltage, kV | M2 lightning current 100 kA, the lightning conductor resistance 0.66 Ohms, the potential at the MD 66.2 kV | 23.0 | 23.0 |
| Cable | MP | 4.0 | 4.0 |
| Insights | OK | OK | OK |

Calculation results:
1) Pulse voltage from lightning strikes applied to the inputs of MP devices will not exceed 1.46 kV, which does not exceed the permissible value for MP equipment tested on the fourth degree of rigidity - 4 kV, according to [25]. Examples of calculation schemes with the results of calculations are shown in [26];
2) the potential applied to the insulation of cables will not exceed the permissible value - 23 kV, according to [27];
3) the potential on the MD near the cable channel will not exceed the permissible value of the electrical breakdown voltage of 100 kV/m, according to [28].

8. Calculation of IF magnetic field
The sources of the magnetic field intensity of industrial frequency are power equipment and PS busbar.
For the calculations used drawings "OSG-500 kV. Arrangement of equipment. 122N15A-21 A-12693-ED, L. 2", "Master plan and on-site networks and communications. Flexible connection between outdoor switchgear 220 kV and outdoor switchgear-500 kV. Installation drawings. 122N15A-20 HG-1022-ED L. 2". Current single-phase fault in the network 500 is 22,33 kV, 220 kV 47,08 as.

Calculation results:
1) the nearest source of the magnetic field intensity of industrial frequency to the distributive shield of the OSG-500 kV are flexible communication buses between the OSG-220 kV and the OSG-500 kV. In the normal mode of operation of the equipment (current 3150 A on buses 220 kV) the maximum value of the magnetic field of industrial frequency in the room distributive shield OSG-500 kV will not exceed 2.68 A/m [29, 30].

2) for MP equipment installed in the distributive shield OSG-500 kV, the magnetic field generated by the tires 220 kV flexible connection between the OSG-220 kV and the OSG-500 kV, in emergency mode (at short circuit) does not exceed the permissible value for the equipment tested on the fourth degree of rigidity - 300 A/m, according to [31, 32].

9. Determination of the levels of electromagnetic fields of RF range
Protection against external electromagnetic fields of RF range is provided by the following technical solutions:

- Metal cladding of the UAV building;
- Placement of MP devices in metal cabinets.

The greatest impact of electromagnetic fields of RF range on the MP device occurs when using portable radio transmitters near the MP equipment. In this case, possible sources of interference may be portable radio stations, cell phones and radiotelephones of the DECT standard.

According to the results of measurements [33] background intensity of RF electromagnetic fields in the air force building will not exceed 1.4 mV / m.

10. Development of recommendations to improve the electromagnetic environment
According to [34, 35], portable radio stations "Vertex Standart" are used as communication devices at the Yuzhnouralskaya GRES-2. These radio stations can operate with four output power values: 5W, 2.5 W, 1W, 0.25 W. Depending on the value of the output power limits are set for the use of the radio near the MP devices. The intensity of the electromagnetic field of the RF range, created by radio stations "Vertex Standard", will exceed the permissible value (10 V / m) when used:

- closer than 1.5 m from the MP devices - at a radio power of 5 W;
- closer than 1 m from the MP devices - at a radio power of 2.5 W;
- closer to 0.7 m from MP devices with the power of the radio station 1 watt;
- closer than 0.35 m from the MP devices - with a radio power of 0.25 watts.

11. Conclusion
The article analyzed and identified the main sources of interference, disrupting the work and reliability indicators of the system, which can lead to malfunction of system of microprocessor relay protection and automation for electric stations and substations, as well as elements and actuators of open distribution devices. Further increase in reliability requires the development of technical measures, namely, requires the use of power and signal cables that must meet the requirements for specific parameters of inductance, capacitance and active resistance, and also requires the use of special placement of cross sections of conductors inside the cable. Secondly, it is shown that to increase the reliability of information transmission it is necessary to switch to serial communication channels, but the amount of information per channel should be strictly limited. The estimation of economic indicators of the system and its dependence on the reliability of the system is given. Thus, with an
increase in reliability by 1.5-2 times, it is necessary to increase the cost of design and commissioning of such a system by about 2 times. It is recommended to use in addition to the regulated maintenance procedures a mandatory assessment of the level of interference in the system in order to maintain a stable and reliable operation of the relay automation system. Experimental and calculated data confirmed that the most difficult situation to ensure the reliability of the system is associated with thunderstorms and lightning. This circumstance dictates the necessity of evaluation and measuring the parameters of a common system of earthing. The methods of evaluation and diagnosis of faulty components of the system are proposed.

These actions have been tested at the Yuzhnouralskaya GRES 2 (Yuzhnouralsk) and have shown their effectiveness.

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