Features of the calculation of digital protection of managed rectifier from external and internal damage

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Abstract. The article is devoted to the designing of digital protection systems (a rectifier, a controlled rectifier, an inverter) used to protect converters from external and internal damage. The article shows main areas for enhancing the efficiency of traction substations due to the integration of innovative electrical engineering systems.

1. Introduction

Domestic and foreign manufacturers are developing rectifiers for traction substations of electric vehicles using power semiconductors (PS) of thermistors in controlled diodes and uncontrolled rectifiers and inverters.

Since the 1960s, these devices have been produced. These elements are produced due to their small dimensions and weight, simple operation and maintenance. Due to their air cooling system and natural cooling, it became possible to use them in low temperature conditions. As a result, technical characteristics that increase the efficiency of the converter have been improved.

For example, the NIIEFA-ELECTRA company produces single-PS rectifiers in the shoulder of the bridge scheme for the railway and metro. In the first rectifier produced by Saransk and Riga plants, the element included 24 rectifiers for the voltage of 3300 V (railway) and 8 rectifiers for the voltage of 825 (600) V (metro).

The conversion of three-phase current with a frequency of 50 Hz (industrial frequency) and medium voltage is implemented by a converter to the voltage required for this electric transport. Its structure includes PS units and a transformer. It is impossible to protect the device from all possible types of damage with the help of two types of protection systems.

Converters are equipped with current protection systems which respond to overcurrent in the primary circuit, and a protection system that responds to one type of damage to a transformer or a PS unit: gas, from breakdown of the SPP, overvoltage; overheating SPP, thermal, from overheating of the transformer, PS damage, occurrence of an electric arc in the medium-voltage switchgear cell.
In addition, the protection system should be in compliance with the overload capacity of the PS unit based on its technical characteristics specified by the manufacturer depending on design features and a PS type.

2. Methods and materials

In order to protect the converter (Fig. 1) from various types of short circuit, it must be equipped on the side of the transformer primary winding:

1. The maximum level of two-phase current protection responding to three- and two-phase short circuits at points $K_1, K_2$ and $K_6$ (Fig. 1);

2. The current protection of the reverse sequence signaling and responding to single-phase and two-phase short circuits at points $K_2, K_3, K_4$ and $K_5$ (Fig. 1);

3. On the side of rectified current $K_6$ - protection from short circuits.

![Figure 1. Six a), twelve b) pulse serial circuits and the twelve-pulse circuit of parallel PS connection](image-url)
Uncontrolled rectifiers produced on the basis of diodes allow current to flow in one direction: from the anode to the cathode. As in case of some other semiconductors, the value of the diode current cannot be regulated. The AC voltage is converted by the diode into the pulsating DC voltage. If the uncontrolled three-phase rectifier is powered by three-phase AC voltage, the DC voltage will pulsate.

The output voltage of the uncontrolled rectifier is equal to the voltage difference between the two diode groups. The average value of the pulsating DC voltage is $U_{\text{av. pulse}} = 1.35 \, U$ of the network.

Connection types are shown in Fig. 1.

Domestic and foreign companies produce digital protection and automation units, but the issues of using them are unsolved. Relay-contactor types of systems are used.

The unit is a modern digital device for protection, control and emergency control automation. It combines a multifunctional device that combines functions of protection, control and alarm.

Types of IPR protection:
- Current protection against interphase faults
- Three-phase overcurrent protection against interphase faults
- Current protection against single-phase earth faults
- Maximum current protection against earth faults
- Earth fault protection

In addition to the protection functions, the IPR unit performs other functions. They are as follows:
- Overcurrent three-stage protection against phase-to-phase faults controlling two or three phases.

The option to select a dependent or independent current-time parameter of the third stage. The function of overcurrent protection for each stage is included. When the switch is turned off, the function of the automatic input of acceleration of overcurrent protection is activated
- Directed or non-directed protection against single-phase earth faults (SEF) and control over the zero-sequence current, high-frequency elements and zero-sequence voltage;
- Logical tire protection;
- Protection of load non-symmetry load by the negative sequence current or negative and direct sequence currents $I_2/I_1$;
- Protection against phase failures;
- Control of line voltages and overvoltage;
- Differential current faults;
- Current protection of a zero sequence;
- Control over line voltages and negative sequence voltages;
- Minimal voltage protection.

The SEF is a combination of hardware and software, a specialized real-time computing machine of high reliability.

The microprocessor terminal hardware converts analog signals (current and voltage of the secondary circuit) into digital signals (analog-digital conversion), while the software module performs specialized terminal functions. Mathematical processing and filtering of signals, starting bodies and the logical part of starting bodies are performed by a specialized software.

3. Results

Before choosing a type of protection, it is necessary to calculate short-circuit currents. Let us assume that all currents and their parameters are known (Fig. 2). Protection is determined by the following sequence

$$I_{\text{av}} = (3...5)I_{n,e} \quad (1)$$

$$K_U = \frac{I_{c,\text{max}}^{(2)}}{I_{s,p.}} \geq 2,$$

where $I_{c,\text{max}}^{(2)}$ is the minimum two-phase short-circuit current at the terminals of the transformer primary winding, on the side of RU-10 KV tires.
Figure 2. Vector diagram of currents. a - three-phase short circuit; b - two-phase short circuit; c - single-phase short circuit; d - two-phase short earth circuit; e - double earth circuit at different points.

The electric current with a time delay on the RT-40 relay and without a time delay on the РНТ or BMPP relay taking into account the connection circuit of the rectifier:

for the zero circuit

$$I_{av} = \frac{K_o I_{dn}}{K_m} = \frac{0.41 K_o I_{dn}}{K_m},$$  \hspace{1cm} (2)

for the three-phase circuit

$$I_{av} = \frac{K_o I_{dn}}{K_m} \sqrt{\frac{2}{3}} = \frac{0.816 K_o I_{dn}}{K_m},$$  \hspace{1cm} (3)

for the two-phase twelve-pulse parallel circuit

$$I_{av} = \frac{K_o I_{dn}}{2 K_m} \sqrt{\frac{4}{3} + \frac{2}{3}} = \frac{0.788 K_o I_{dn}}{K_m},$$  \hspace{1cm} (4)

for the two-phase twelve-pulse serial circuit

$$I_{av} = \frac{K_o I_{dn}}{K_m} \sqrt{\frac{4}{3} + \frac{2}{3}} = \frac{1.577 K_o I_{dn}}{K_m}. \hspace{1cm} (5)$$

where $I_{dn}$ – the nominal current, А;

$K_t = V_{31}/V_{32}$ – the transformer ratio;

$K_o$ – the overload ratio equal to 1.5 or 2 depending on the type of electric traction (from the converter passport)

Time delay is 0.4 ÷ 0.5 s.
When using the BNT relay, it is necessary to calculate the number of BNT turns. The electric current of the relay taking into account the transformation ratio of current transformers is

\[ I'_{av} = \frac{I_{av} \cdot K_{sh}}{K_{nm}} \]  \hspace{1cm} (6)

The number of turns is pre-determined by BNT or DTO according to the following formula:

\[ W'_p = \frac{AW_{cp}}{I'_{cp}} = \frac{100}{I'_{cp}} \]

Where \( AW_{cp} \) – Amper turns of the relay BNT (according to the relay passport).

The number of turns is approximated to the nearest larger value \( W_p \) indicated on the BNT scale

\[ I'_p = \frac{AW_{cp}}{W_p} = \frac{100}{W_p} \]  \hspace{1cm} (7)

Primary current \( I_{pc} = \frac{K_{nm}}{K_{sh}} I'_p \).

4. Conclusion
Integration of innovative electrical automation and protection devices will improve the ability to monitor the condition of equipment, expand its functions and increase efficiency. It is necessary to take into account the algorithm and connection circuits of the conversion (traction) transformer and the PS, to set the protection and automation system.

Based on the data obtained, we can conclude that the relay protection is more reliable. Each protection subsystem is independent in the operational DC circuits, input and output circuits, signaling and control circuits. It contains power supplies, logic circuits, signaling, controlling and diagnosing devices units.

Repeated starts of the PS will consume maximum current. If in one part of the circuit at a remote point current of the second PS is consumed, probability of exceeding the load can be critical which will disconnect the vehicle.

It was suggested using the PS for traction substations; the ambient air temperature is 10 to +40 °C, average current is more than 1000 A and reverse voltage is of class 24 (2400 V) for the metro and of class 30 for the railway transport. Atmospheric and switching PS voltage drops can occur at traction substations. Continuous self-monitoring and diagnostics functions ensure high protection.

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