Improving the methods of monitoring and automation and mathematical modelling of railway protection

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Abstract. The paper analyzes the electric traction network and its features. The article shows that the use of one type of protection creates dead zones. To ensure reliability of the protection system, along with the maximum pulse protection system, digital terminal should be used.

1. Introduction
During the operation of the traction substation - traction network - electrical stock (TS - TN - ES) system, its individual elements fail due to external influences, personnel errors, wear accompanied by short circuits (SC). The latter cause the flow of currents whose value can be 20-50 kA. At a remote point near the tires of the neighboring substation, they are only 2-6 kA. For the metro and city electric transport, short-circuit currents near the traction substation can be 6–20 kA, and at a remote point, they are 0.6 –2 kA. In this case, long-term permissible load currents can be commensurate with minimum short-circuit currents. To prevent consequences of a short circuit, it is necessary to disconnect the dam-aged element. These functions are performed by the protection system. Protection is the most wide-spread type of automation determining the operation of the TS - TN - ES system and ensuring the reli-ability of power supply. The protection system is on duty waiting for a signal which is transmitted when the parameters exceed specified values (setpoints).

2. Theory
Current protection is based on the determination of the amount of current in the accession pro-tection circuit. Current protection can be maximum current protection (MCP) and current cutoffs (CC). A RDSH, DNS differential relay and a built-in mechanism of a rapid switch react to a smooth and inter-mittent current change in a different way. A current sensor is used which ensures maximum-pulse
protection (MPP). Electric vehicles are equipped with MPP systems. The difference between these protection systems lies in the way of ensuring selectivity.

During a short circuit, the current rate increases. This sign is used to start current protection. Overcurrent protection comes into effect with current rates increasing a certain value.

There are maximum current protection systems in which a time delay is used to ensure selectivity, and current cutoff systems where selectivity is achieved by selecting a response current. The main difference between these types of current protection systems is in the method used for ensuring selectivity.

The overcurrent protection with a time delay

The overcurrent protection is the main protection for power lines installed on power transmission lines, power transformers, cable lines, engines with a power of 6, 10 kV.

![Schematic diagram of the maximum current protection with an independent time delay](image)

**Figure 1.** Schematic diagram of the maximum current protection with an independent time delay

The location of the protection system at the beginning of each line on the power supply side. Fig. 1 shows operation of the protection system in case of a short circuit at point K. The delay time is selected according to the step principle and does not depend on the amount of current flowing along the relay.

Overcurrent protection circuits

Three-phase overcurrent protection at direct operating current

The protection scheme is shown in Fig. 2

Main relays:
Starting body - current relays KA.
The time body - time relay KT.

Auxiliary relays:
KL - intermediate relay;
KH - pointing relay.
Figure 2. The basic three-phase scheme of maximum current protection at constant control current

An intermediate relay is installed in cases where the time relay cannot close the YAT trip coil circuit due to insufficient power of its contacts. The auxiliary switch SQ switch is used to break the current flowing through the disconnecting coil, since contacts of intermediate relays are not calculated for opening.
Two-phase overcurrent protection circuits at direct current

In cases where the overcurrent protection must respond only during phase-to-phase short-circuits, two-phase circuits with two or one relay are used.

Figure 3. Two-phase overcurrent protection circuit at constant control current
Advantages
1. The circuit responds to all interphase faults.
2. Cheaper.

Disadvantages
If necessary, sensitivity can be increased by installing a third current relay. Sensitivity can be increased twice. Two-phase circuits are used to protect against phase-to-phase short circuits and in networks with a low-grounded neutral, while for protection against single-phase short circuits, additional protection systems are used. They respond to zero-sequence current.

One-relay overcurrent protection circuit

![Diagram of one-relay overcurrent protection circuit](image)

**Figure 4.** One-relay overcurrent protection circuit
The circuit responds to all interphase faults.

Advantages
Only one relay.

Disadvantages
- Lower sensitivity in comparison with the two-relay circuit.
- Protection failure in one of three possible cases of a 2-phase short-circuit fault behind a transformer with a connection Y/Δ–11 g.
- Lower reliability - when the only relay fails, the protection system fails. The circuit is used in distribution networks of 6 ... 10 kV and for protection of electric motors.

To improve reliability of protection, NSTU (Russia, Novosibirsk) proposed a new method for selecting protection types in accordance with [3] (in terms of a protection status) and a method for calculating setpoints using mathematical modeling, feeder current monitoring and traction network site protection control.

3. Experiment
Protection settings are chosen by comparing parameters of a normal mode at maximum loads and a steady-state short circuit at a given point of the traction network. The choice is based on regulatory requirements for ensuring stability of protection against short circuits. For selective protection, the following conditions are met:
- sensitivity to short circuits within the protected area (internal short circuits);
- isolation from normal operation modes;
- isolation from short circuits outside the protected zone (external short circuits).

The method for selecting settings for traditional protection systems based on maximum impulse protection includes the following main sections:
- analysis of parameters of the power supply traction network;
- selection of design schemes for normal, forced and emergency modes;
- creation of a database for calculating load currents and short circuit currents;
- calculations using the Korteses software package, or other analytical methods;
- selection of a type and areas of primary protection, backup protection capabilities;
- calculation of protection settings;
- control of operation and security of traction network sites.

The method was tested on a real part of the railway.

Verification of reliability of operation of the protection system for traction network sites.
After calculating the settings, it is necessary to check the overlap of “dead” protection zones. The “dead” protection zone is the length of a section where the protection device cannot distinguish short-circuit currents from load currents. They also include a section where one protection system covers a half of the length. “Dead” zones are located at remote points of the CS section.

Figure 4 shows power supply systems installed on each switch.
PS-8, PS-23, PS-26 cover “dead” zones of TP-250, TP-252, TP-241 switches under a normal power supply circuit. For example, the “dead” zone 1 of the RS_{3G} TP-252 protection device is protected by the RS_{4P} PS-8 protection device. If the RS_{4P} PS-8 switch is disconnected, an emergency mode which is not sensitive to the protection of the traction substation will be triggered. In case of a short circuit in zone 1, the RS_{4P} switch is turned off and the power from the TP-240 is not supplied. The RS_{3G} switch is switched on because the protection system is not sensitive, and the short circuit is fed at the remote point.

Figure 5 shows that “dead” zones of protection of the traction network are different due to the fact that the feeder zones have different path profiles, contact wire marks and setpoint values of the
maximum impulse protection of the feeders. When the setpoint is overestimated, the “dead” zone increases, which reduces sensitivity of the protection system. When the setpoint is lowered, the load currents become commensurate with short-circuit currents which reduces selectivity of the protection system and increases false alarms.

Figure 5. Zones of maximum impulse protection in the experimental area of the TS TP-250 – 241: $MPP_1$ – protection zone for the first path, in a normal mode; $MPP_p$ – protection zone for the second path, in a normal mode; $MPP_{1A}$, $MPP_{PA}$ – protection zone for the first and second paths in a forced mode; $l_{MI} \div l_{MA}$ – lengths of the “dead” protection zones in a normal mode; $l_{MP1} \div l_{MP6}$ – lengths of “dead” zones of protection of sectioning posts in a normal mode, $l_{MA1} \div l_{MA8}$ – lengths of "dead" zones of the maximum impulse protection of traction substations in a forced mode.

In a forced mode, track substations may be disconnected. The zones of maximum impulse protection with settings calculated for the normal mode will not be able to protect all inter-substation zones. For this purpose, emergency modes were calculated according to the circuits in Table 3.

The lengths of “dead” zones of maximum impulse protection for the switches of the traction substations in the normal operating mode of the traction network were as follows: $l_{MA1} = 1$ km; $l_{MA2} = 0.5$ km; $l_{MA3} = 2.3$ km; $l_{MA4} = 0.5$ km. For PS switchers: $l_{MP1} = 0.85$ km; $l_{MP2} = 5.2$ km; $l_{MP3} = 5$ km; $l_{MP4} = 0.82$ km; $l_{MP5} = 5.4$ km; $l_{MP6} = 5.2$ km. For traction substation switchers in the forced mode of operation: $l_{MA1} = 5.6$ km; $l_{MA2} = 4$ km; $l_{MA3} = 4.6$ km; $l_{MA4} = 4$ km; $l_{MA5} = 7$ km; $l_{MA6} = 4$ km; $l_{MA7} = 4.1$ km; $l_{MA8} =
3.7 km.

4. Conclusions
Thus, the use of only one type of protection creates a large number of "dead" zones. At the same time, there is no complete provision for the maximum impulse protection of a part of the traction network which can lead to accidental consequences during short circuits. When setting protection set-points, the length of dead zones can be reduced by 20-25%. In order to ensure reliable protection, it is necessary to use digital intelligent terminals along with maximum pulse protection systems.

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