Digital computer protection of railway traction network

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Abstract. The article analyzes the existing system of protection of the traction network. Key aspects of its operation were analyzed. Innovative transition to a digital level of protection was described. Recommendations for further improvement based on the results of experimental operation, taking into account the use of monitoring and increasing the level of automation of the traction network feeder control system were provided.

1. Introduction

The transport system is the most important object of the internal logistics having a significant impact on the development of the infrastructure of settlements and the country as a whole. The turnover of goods transported by the Russian Railways, passenger traffic in large cities, long-distance, interregional transportation is increasing. The mass of trains, speed parameters, power of locomotives and electric trains (EPS) increase due to the needs of society. The level of comfort (e.g., "Sapsan") has increased. New cars were developed for the subway and trams. All innovations increase requirements for reliability of the electric power supply system of electric transport (EPS ET).

1. Load currents are close to short-circuit currents (SC);
2. Load currents are often commensurate with short-circuit currents, variable loads in values and places of application in the traction network;
3. During EPS transitions from a feeder to a feeder, significant current surges ($\Delta I$) with a high front ($di/dt$) may occur;
4. Heterogeneity of the traction network along the length, active and impedance resistances (stations, moving EPS, etc.);
5. The reverse current circuit includes rails (a non-linear ferromagnetic element of an electrical circuit with variable parameters) and a parallel-connected earth with varying conductivity depending on the environment;
6. The need to disable the short-circuit with several switches at the same time, since the traction network has an extensive partitioning scheme powered from several sources, the junction point of adjacent paths (PS and PPS);
7. The low level of thermal resistance of the contact network wires and EPS equipment, immediate
disconnection of the damage site;

8. Mass short-circuit faults on the EPS, whose causes and place cannot be identified, making it difficult to analyze the protection system.

Based on the statistical data of protection of the traction network (PTN) from non-standard faults, we can observe a low level of reliability and the lack of compliance with the requirements of the Electrical Installation Rules (EIR). Russian railways and CET (metro, trams and trolleybus) use overcurrent protection (OP) in which the DC relay is built in. It performs two functions: maximum PTN and current increment protection (CIP). In some cases, special types of protection are used (current-time, thermal, frequency control of the power supply line, analysis of the current frequency and voltage, control of vehicle insulation, tele-blocking).

2. Theory

A test site of the West Siberian Railway (18 traction substations, 70 FKS protection devices) was used: in 2011, there were 4240 protection operations, in 2012 – 4434; in total - 8554 operations.

The numerical characteristics of protection operations were analyzed in [1]:

The average value:

\[ M(x) = \sum_{i=1}^{n} x_i \cdot p_i, \]  
(1)

where: \( x_i \) – random value; \( p_i \) – probability of a random value.

The standard deviation is

\[ \sigma(x) = \sqrt{\sum_{i=1}^{n} (x_i - m_i)^2 \cdot p_i}, \]  
(2)

The dispersion is

\[ D(x) = \sum_{i=1}^{n} (x_i - m_i)^2 \cdot p_i, \]  
(3)

The analysis of experiment results:

Due the fact that each shutdown is an emergency, in 2011, about 350 damage to the contact network devices should have occurred. In accordance with the system of failures accounting (KASANT), 24 failures in the form of damage to the equipment and 10 failures of the EPS occurred over the past year.

The total number of failures \( N_F \):

\[ N_F = N_{FTS} + N_{FCN}, \]  
(4)

where \( N_{FTS}, N_{FCN} \), the number of failures of traction substations, contact network accounted by CASANT. The total number of protection operations \( (N_{OP}) \):

\[ N_{OP} = \kappa N_F + \kappa E N_{FES} + \kappa N_{NF} + N_{FPO}, \]  
(5)

where \( N_{FES} \) – the number of failures of power supply; \( N_{NF} \) – the number of non-accounted failures; \( N_{FPO} \) – the number of false protection operations; \( \kappa \) – the coefficient accounting repeated unsuccessful switching of the BV equal to 3. \( \kappa_e \) – the number of reclose on fault.

According to the analysis of fault protocols, \( \kappa_e \) is equal to 5. Except for the single switching, the operator can switch the BV in the telemechanical system.

In accordance with (5), let us calculate the number of false protection operations as

\[ N_{FPO} = N_{OP} - \kappa N_F - \kappa E N_{FES} - \kappa N_{NF}. \]

\[ N_{FPO} = 4240-3*24 + 5*10 + 3*50 = 3968. \]

During 2011, along the power supply distance (70 TS feeders), there were 3,968 false alarms of protection devices and only 232 correct alarms out of 4,240, the average number of false alarms was 330 per month, and the number of short circuit alarms was 19.

3. Theoretical Background

In the domestic energy sector, the reliability criterion for PD is a relative number of correct operations expressed in percentage terms (the share of correct operations). The number that complements this
indicator to 100 is the relative number of redundant and false operations (%). In the experiment, the relative number of correct protection operations was about 10%, and false (unnecessary) protection operations was about 90%, which confirms the unsatisfactory work of the existing protection system.

The method for analyzing the protection system and the choice of set points can be useful for the operational personnel using the protection system. For example, the West Siberian railway equipped 78 out of 755 feeders with ZZAF-3.3 terminals (1416 out of 5660 feeders of the road network, respectively). The method for determining the type of protection and calculation of set points for existing analog and digital protection (terminals) systems is defined by the instruction of Russian Railways [2] according to which a specific group is used for each type of protection: primary, backup and additional. The main protection system is that which provides protection throughout the entire length of the inter-station zone, and its duration is shorter than that of other protection systems that cover this zone.

The backup protection system (overcurrent protection or maintenance) duplicates the main one; the length of the protected area must be not less than that of the main one, but there is a delay time for its actuation. The main and backup protection systems are implemented using a single electromechanical relay RDSH or can be implemented virtually by selecting a set point [3]. For additional protection, the above mentioned protection systems can be used.

Backup protection (overcurrent protection or maintenance) duplicating the main, the length of the protected area at the backup protection should be no less than that of the main, but there is a delay time for actuation. The peculiarity of ensuring reliable operation is that the main and backup protection are implemented using a single electromechanical relay type RDSH - this is MIZ, and the overcurrent protection or maintenance can be implemented virtually by selecting the set point [3]. As additional protections, the above special protections can be used.

Only a few companies in produce digital control devices, emergency control automation and protection of traction network feeders (hereinafter referred to as "terminal") of direct current with voltage of 3.3kV, 1.5kV, 825V, 750V and 600V for land and underground electric transport [4].

Digital protection systems have a wider range of set points and separate (as opposed to MIZ) absolute current value sensors; current increment $\Delta I$ is calculated by the controller within time $\Delta t$; the processor continuously calculates the rate of changes in current $\frac{di}{dt}$. In a number of devices, it is possible to analyze the heating of wires, establish the distance and place of faults, control the insulation of feeder cables and connect special protection systems through external ports (teleblocking, frequency ones, etc.).

Given the above, there are problems of calculation and selection of specific settings for the protection of a digital terminal. Novosibirsk State Technical University developed a protection method.

1. Analysis of technical parameters of the traction network site;
2. Determination of design schemes for correct, forced and emergency modes;
3. Formation of the database to calculate the control circuit current and load;
4. Calculation "Korteses", or an alternative analytical method;
5. Checking of the parameters that determine the protection system of a specific feeder using a mathematical model taking into account Simulink as part of the MATLAB [6];
6. Determination of a type and areas of primary protection, topology of backup protection capabilities;
7. Calculation of protection settings;
8. Testing of the protection system by constructing a diagram of a zone closure taking into account the operation of at least three types of protection in each zone.

In the systems of electronic protection, a fundamentally new method of determining current increments [4,5] was implemented. It makes it possible to perform protection functions.

The current rise rate $\frac{di}{dt}$ (instantaneous values during the scan time, equal to 2 ms) and current increments $\Delta I$ during time $t$ (average $\frac{di}{dt}$) can be used as an additional protection system.

As a backup type of protection, the remote (U / R) system or current increments $\Delta I$ during time $t$, remote blocking, thermal protection can be used. It is necessary to choose set points by the rise rate and current increment depending on operating modes of the traction network. This parameter was
determined in [1]; for all electric locomotives, it was analyzed in [2]. It can be used for preliminary calculations. At present, most of the digital protection systems are used in the “on signal” mode; the method for selecting protection settings is described in [2].

4. Experiment

In order to set terminal options, the authors developed a system for monitoring current in the traction network [3].

The main purposes of monitoring are as follows:

- detection of changes in current for the most powerful locomotive with a maximum train mass. In order to increase the efficiency criterion in real time and for subsequent analysis, the remote access to terminals was used.
- determination of parameters of changes in currents and voltages when the in the mode of EPS passage in the in-substation zone and in case of damage to the TP, TS or EPS (emergency modes);
- identification of the degree of influence of the modes of operation of vehicles on the parameters used for calculating settings of individual terminal protection systems. Recommendations on protection systems in accordance with [2] for each FCC, settings, their further correction [3] while ensuring normal operation of the protection system in case of faults.

In a real time mode, it is necessary to monitor instantaneous values of currents and voltages. In the monitoring system, PEFMPs are connected to the terminal, creating a permanent connection between the workstation and the FCC terminal [4].

Implementation of the data transfer procedure, automated control and interaction of the terminal is carried out using special software which reads additional information about current and voltage in the form of oscillograms for 300 ms before the transition process in stationary (Fig. 1, a) and emergency (Fig. 1, b) modes. It gives technical parameters characterizing the mode (changes in current, current increment, absolute values of current and voltage, a number of energy quantities).

The data base allows you to record 23 emergencies during one month. This fact complicates the systematic monitoring required to correct settings. The efficiency criterion has been improved by the remote access system used for reading incoming data from all terminals [3].

The screen can be used to observe, record and save materials on continuous changes in the feeder current for subsequent analysis and correction of set points, even in the absence of emergency shutdowns [3]. Figure 1 shows a fragment of vehicle parameters in the mode of EPS transition through the SI.

![Figure 1. Combination of oscillograms of two adjacent feeders for the analysis of currents and change rates when the current collector passes through the SI.](image-url)
5. Conclusions

A method was developed for calculating the FCC protection settings using special software, mathematical modeling and monitoring. Due to changing conditions, we developed a method involving continuous analysis of prompt and effective correction of set points within which one of the functions has a remote access to the terminals.

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