Research algorithms for the analysis of transient’s traction DC networks

V E Visyagin¹, K Yu Zhigalov², A I Alchinov² N A Proskuryakov³
¹Novosibirsk State Technical University, 20, Karla Marksa Av., Novosibirsk, 630073, Russia
²V.A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences, 65 Profsoyuznaya street, Moscow 117997, Russia
³Industrial University of Tyumen, 38, Volodarskogo str., Tyumen, 625000, Russia

E-mail: mbv5@mail.ru

Abstract. Oscillograms make it possible to determine parameters of transient processes and analyze operation of protection systems. The article analyzes changes in current rates under various modes of operation of the traction network. When studying emergency processes, it is advisable to analyze disconnections of circuit breakers recorded by digital devices.

1. Introduction
Traction network processes in case of short circuits in feeder F2 are presented in Fig. 1. At t = –17 ms, there is a short circuit in the traction network, and the electrical current rate rises at a speed of up to 345 A/ms. An oscillogram of current and voltage in the traction network is presented. In the mode of traction, the train consumes 2700 A. This rate varies in time (up to 15-20 A/ms) (Fig. 3).

With a further increase in the consumption of traction current, protection system setpoints increase and the overcurrent protection system is triggered. When the high-speed breaker starts, the current flowing through it has a zero value, but the voltage level is 2400 V.

This occurs due to the presence of a two-way power supply circuit.

2. Problem statement
The purpose of the experiment is to analyze the operation of terminal protections, to evaluate its performance, especially protection when analyzing the rate of a current rise in the vicinity of its substation (Fig. 1, Fig. 2, Fig. 3).
3. Theory
The principle of current directional protection is simple and reliable and allows for the selective protection of networks. The combination of current directional cutoffs with directional overcurrent protection makes it possible to ensure protection providing a sufficient short circuit tripping speed, sensitivity and reliability.

Disadvantages of current protection systems:
- large time delays especially near power supplies;
- lack of sensitivity in networks with large loads relative to the frequency ratio of short circuit current;
- dead zones with three-phase short circuits;
- a possible wrong choice of direction if the voltage circuit fails

The phase current depends on the operating mode of the system and does not determine the actual position of the protected object. In the remote protection system, information on a damage is determined by the ratio of voltage and current

\[ \frac{U}{I} = Z, \]

i.e. by the resistance. Under normal operation, this ratio is large, since the voltage is close to the nominal one and the current does not exceed the maximum operating values. Under a short circuit, the voltage decreases, the current increases, the resistance varies at a double rate:

\[ \frac{U}{I} = \frac{U_{max}}{I_{max}} = Z_0 \]

where \( Z \) - resistance from the place of protection system installation to the point of a short circuit.
The remote protection system reduces the resistance value.
The resistance to the short circuit location depends on the distance, therefore, protection is referred to as remote. Resistance to the point of a short circuit does not depend on the mode of operation of the network.

![Figure 2. Three-stage distance protection circuit](image)

During the disconnection, the train was at a greater distance from the second substation, and the current increment was insignificant, the protection system did not respond to it, and the power supply to the section of the contact network remained.

Before the disconnection, the current rise rate did not exceed 10 A/ms. The amplitude of current oscillations did not exceed 10–20 A, the frequency of current oscillations and the voltage level ranged from 200 to 250 Hz. This type of mode has not been described in [2].

Emergency situations, an emergency mode (Fig. 2) arising on the rolling stock located near the sectioning post and remotely from the substation. The substation protection system operated faster, because the train was near the substation. After the high-speed breaker was disconnected, the voltage in the contact network was 700 V. During the disconnection, the voltage dropped sharply to 2800 V, and the current increased. At this moment, the short-circuit location is powered only from the traction substation.

When the current exceeds the overcurrent protection setting, the circuit breaker disconnects the high speed circuit breaker in the substation. The oscillogram (Fig. 3) shows that the current rise rate was only 100 A/ms, since the short circuit occurred at a remote point and on the rolling stock in the inner part of the power circuit. The current rise rate may vary depending on the site.

According to the experiment result, 47 emergency logs were recorded after the disconnection of the high-speed breaker containing 1080 waveforms. In case of an emergency damaging traction network equipment, oscillograms were recorded additionally. The protocol of emergency disconnections of feeder F2 is presented in Table 1.

For two years, 460 oscillograms were recorded at the power supply site F2. The following factors were determined: minimum voltage, maximum values of the current rise rate, and the transient time until the protection systems triggered by a short circuit starts.

The key criterion was a rate of the current rise during short circuits and restarting. The results were processed using statistical methods for studying random variables.
Figure 3. Oscillogram of the current interruption in the traction network when the maximum current protection is triggered when the train starts: $T_t$ - transient time when restarting

4. Experimental results

The results of statistical studies of oscillograms of emergency disconnections for F2 and F4 are presented in table 1 and table 2. Average values, standard deviations and dispersion of current rise rates were calculated. Fig. 4 and Fig. 5 present parameters of the current rise rate during restarting and short circuits.

Table 1. Parameters of transient processes when the protection system is triggered for section F2

| Parameter                              | Mean value | Standard deviation | Dispersion |
|----------------------------------------|------------|--------------------|------------|
| $\frac{di}{dt}$ at SC, maximum, A/ms   | 481        | 282                | 79549      |
| $\frac{di}{dt}$ at restarting, A/ms    | 28         | 41                 | 1701       |
| $\frac{di}{dt}$ averaged, A/ms         | 174        | 270                | 67110      |
| Current rise time before current       | 25,3       | 23,8               | –          |
| interruption, ms                       |            |                    |            |
Figure 4. Oscillatory processes preceding a short circuit: $T_{OP}$ – time of the oscillatory process, ms.

Table 2. Parameters of transient processes when the protection system is triggered for section F4

| Parameter                                      | Mean value | Standard deviation | Dispersion   |
|------------------------------------------------|------------|--------------------|--------------|
| $\frac{dI}{dt}$ at SC, maximum, A/ms          | 410        | 285                | 80731        |
| $\frac{dI}{dt}$ at restarting, A/ms           | 24         | 23                 | 526          |
| $\frac{dI}{dt}$ averaged, A/ms                | 223        | 281                | 79159        |
| Current rise time before current interruption, ms | 34.3       | 13.7               | –            |

The key parameter was the current rise rate during restarting and short circuits. The results were processed using statistical methods for studying random variables. It was determined that the rate current rise rate is subject to the normal distribution law. It is a random variable.

The statistical analysis of the data on the current rise rate reflects that during a short circuit, mathematical expectations and standard deviations in different parts of the traction network coincide. The key parameter of a short circuit is the current rise rate exceeding the speed of 200A/ms which was confirmed by other scientists.

Short circuits can occur at remote points of the traction network accompanied by changes in the current rate up to 100 A/ms. It depends on the load capacity of a particular section of the traction network and its technical parameters. The critical value of the current rise rate during short circuits will change. Therefore, the use of monitoring when calculating critical loads and choosing the terminal protection
settings for the current rise rate does not ensure reliability, safety and operability of the entire system. It is advisable to conduct a study using an imitation model.

Analyzing the data from the histograms (see Fig. 6), we can see that a sufficient number of values of current rise rates during restarting ranges from 0 to 40 A/ms indicating the non-selective operation of the traction network protection at a specific experimental site. Disconnection of the high-speed circuit breaker is due to the fact that overcurrent protection setpoints have been exceeded. The underestimated maximum current protection setpoint is not able to ensure the passage of heavy trains. The relative amount of correct protection operation was 46% - for F2 TP-252, and 56% - for F4 TP-252.

It was found that there are modes that are not caused by short circuits, but their current rise rates can reach 210 A/ms which exceeds the value of 200 A/ms. These \( \frac{di}{dt} \) occur when re-supplying voltage to the traction network where there is an electric rolling stock.

![Figure 5](image.png)

**Figure 5.** Monitoring of the traction network in case of non-selective activation of the protection system: a – disconnection of the high-speed switch from maximum current protection; b - a signal to turn off the high-speed switch from the PSTN.

The monitoring made it possible to identify a case when an electric locomotive VL-10K with a train weighing 5830 tons passes through the control system and increases the current rate (the maximum current protection setpoint is 4000 A is exceeded), the BV F4 switch is disconnected (Fig. 11.22, a). After six seconds, the high-speed breaker turns on again (Fig. 7, b). The level of the current rise rate was 210 A/ms, but there was no short circuit in the area; therefore, the electric rolling stock was not disassembled. Due to the fact that the electric train operator did not choose the electric locomotive power supply circuit for a more favorable voltage supply mode with a large number of rheostatic resistances, it caused a sharp surge of electric current. After false operations of the protection system, successful automatic restarting can be observed. Normal operation of the protection system should not allow false alarms; when choosing settings, this situation must be taken into account.

5. Conclusion
An analysis of operation and monitoring of the traction network allows you to explore technical parameters of transients and their physical processes in emergency and normal modes. When studying emergency processes, it is advisable to use shutdown protocols of high-speed switches.
For 2 years of research, more than forty protocols were recorded. Using the oscillograms, a statistical analysis of the current rise rate in the traction network in case of short circuits and during restarting of the electric rolling stock was carried out. Boundary average values and standard deviations of the current rise rate were determined: they are in the range of 170 ÷ 210 A/ms for short circuits, and 20 ÷ 70 A/ms for the normal mode.

When studying the normal operation of the traction network, continuous monitoring of current and voltage parameters is required. Recording of instantaneous values of traction network parameters using an oscilloscope will allow for an analysis of modes of the electric rolling stock, movements through the control system, and engine restarting near the traction substation.

References
[1] Bykadorov A L, Zarutskaya T A and Muratova-Milekhina A S 2015 Increase of efficiency of short-circuits fault location in traction networks of alternating current on the basis of information technologies. *Bulletin of transport of the Volga region* 6(54) 15-19
[2] Filyushov Yu P, Zonov P V, Malozemov B V and Wilberger M E 2011 Energy efficient control of an alternating current machine. *The Polzunovsky Herald.* 2011 2 45-51
[3] Kuznetsov S M 2005 *Traction network protection of SC current.* (Novosibirsk: NSTU) p. 352
[4] Kuznetsov S M 2011 Setting of electronic security with simulation model corrected. *Transport Science, Technology, Management.* VINITI 12 30-34
[5] Kuznetsov S M, Demidenko I S, Yaroslavtsev M V and Krivova A O 2009 Mathematical model study of traction network dynamics of direct-current railway with train starting. / Scientific transport problems of Siberia and Far East. NSAWT 2 324-327
[6] Malozyomov B V, Vorfolomeyev G N and Schurov N I 2005 Reliability and diagnosing electrotechnical systems. *In the collection: Proceedings - 9th Russian-Korean International Symposium on Science and Technology, KORUS-2005* 347-350
[7] Ivanov G Ja and Malozyomov B V 2005 Reliable power saving electric drive of wide application. *In the collection: Proceedings - 9th Russian-Korean International Symposium on Science and Technology, KORUS-2005* 330-332
[8] Shchurov N I and Wilberger M E 2011 Spectral analysis of rectifier unit current for unbalance and non-sinusoidal supply voltage *Transport: science, technology, management* 12 41-43
[9] Mischenko T M 2011 The mathematical stimulation of transient process in a.c. - system “electric-traction network - LOCOMOTIVE”. *Transport: science, technology, management* 12 105-109
[10] Anurov V I 2008 Modeling of transient processes in case of short circuit in the traction network and the presence of electric locomotives on the feeder zone. *Electro. Electrical engineering, electric power industry, electrotechnical industry* 2 16-18
[11] Konovalov G V, Kosovtseva T R, Tsybizov Alexey A V 2017 Spatially-oriented air-blast supply in the augmented mode *International Journal of Mechanical Engineering and Technology (IJMET)* 8(11) 1143–1151