Research of AC Traction Network's Relay Protection Operating Under Heavy Haul Traffic Conditions

P S Pinchukov¹, S I Makasheva¹
¹Far Eastern State Transport University, Seryshev st. 47, Khabarovsk, 680021, Russia

E-mail: pinchukov-pavel@mail.ru

Abstract. Backgrounds and trends of increasing volumes of heavy haul traffic in the Far East of Russia are briefly reviewed. The results of long-term observations of the load conditions parameters of the relay protection gears of AC traction network of Russian Railways Holding are given. Changes that occurred in the operation of the AC traction network’s relay protection during last 10 years in the example of traction substations at the Far East of Russia are considered. The conditions of the experiment and the method of the obtained data processing are described in detail. The need for the development and implementation of relay protection devices with new forms of angular characteristics at Russia's traction networks is justified.

1. Introduction
The heavy haul traffic provides economically most efficient transportation practice of ores, coal and other bulk commodities from their minefields to embarkation points and areas of consumption in the world [1]. For example, a significant part of economy of many countries like China, South Africa, Australia, India, Russia, etc., is sustained by a large and extensive mining industry. Integral to sustaining the mining economy is the transport of mined raw material via freight rail over large distances, typically from the mines to central distribution or processing centers. Due to the heavy tonnage and long distances an enormous amount of energy is required [1-4].

Concerning the Russian Railways, in 2017 the freight through the railway network of set a new record for the entire history of Russia. The cargo turnover reached 2 491.4 billion ton-km, and surpassed the indicators of the Soviet period (from 1917 until 1992) [5]. Additionally, the speed and reliability of cargo delivery also reached in 2017 their maximum historical values. Positive dynamics of growth continues in 2018. So, the cargo turnover increased by 3.9% as compared to the same period of 2017 and in February 2018 stays on the growth stage [6].

Such rapid rates of development were achieved due to the successful implementation of the Development Strategy of the Russian Railways Holding for the period until 2030 [7]. In this Strategy, a key role is exactly assigned to the heavy haul development. The increase in the intensity of transportation by rail is ensured not only by an increase in the mass of freight trains, but also by an increase in the number of freight trains too. Thus, according to the long-term development program, up to 2025 year the share of trains weighing 7100 tons or more from the total number of trains on Russian railways should increase from 2 to 10% [8].

It's generally known that the freight train’s weight is a one of the main indicators of the technical and technological development of the world's railways. Today, for Russian Railways, an intensive freight train’s mass increasing is a feature of development. Thus, in 1970 the average weight of a
The freight train was 2574 tons. Then, in 1988, when the volumes of transportation were the maximum, it increased by 21% and reached 3120 tons. In the end of 2017, the average weight of the train was already 4045 tons, and it is about 30% more than it was in 1988 year [9-10].

Such intensive growth of heavy haul traffic volumes especially actively occurs on the Far Eastern Railway [11]. There are several main reasons for that. Firstly, the Russian Far East development is a national priority of Russia. Secondly, for needs of fast-growing economies in the Asia-Pacific region it is very necessary to increase heavy haul traffic by railways located in Far East of Russia exactly [12].

Indeed, the heavy haul traffic requires considerable power. The AC electric railways transmit this power through a traction network, which is equipped with short-circuit relay protection gears. The regular heavy haul traffic can causes difficulties to relay protection operation in traction network. As an example, the relay protection gears can falsely perceive the increased load current as short-circuit current (SC) due to equal their values. This situation results in the activation of relay protection gears and the switch off the intact section of the traction network. This entails a violation of the transportation process and the stopping of both freight and passenger trains, which leads to severe economic consequences up to creating a danger to human life and health. This phenomena is known as a false tripping, incorrect or superfluous operation of relay protection gears and this undesirable phenomena must be eliminated [11, 13, 14].

2. Materials and Methods

In this study, we used experimental research methods, based on nature measurement of control parameters and subsequent calculation and analysis. The measurements were carried out for feeders of the traction substations located at Far Eastern region of Russia during last 7 years from 2011 to 2017 year [12, 15-18].

2.1. Methods and main points of research

The main purpose of this study is to evaluate the conditions for the relay protection gears operation taking into account the growth rate of heavy haul traffic development. Applied to the feeders of traction network, we want to find answers to the following questions:

1. How much the traction network's load has been increased over the consideration period?
2. Has the stability of the relay protection gears been changed?
3. Do existing relay protection gears have a stability reserve in the prospect of the heavy haul traffic increasing?

Sequential decision assigned tasks will help clearly understand the operating conditions of relay protection gears and, if necessary, to timely adjust their parameters.

2.2. Experimental measurement and the principles of results analysis

In the general case, when the load characteristics of the traction network were changed, for appointed traction network section (or traction substation) the following points can be necessary: a) to measurement the normal mode parameters; b) analysis of the measurement results; c) adjustment of threshold parameters of relay protection gears, under which the triggering occurs. First and foremost, the objects of research should be chosen the substation spacing, which limit the heavy haul traffic.

The content of experimental measurements, analyses and results are shown on the example of the substation spacing of the Russian Far Eastern Railway. In our measurements we are used a analyzer named"Рецьц-UF2М" [19], which allows to measure through the current and voltage transformers the main parameters of the traction network feeders. As a result, for each feeder of the traction substation under consideration, the following points were measured:

• I - effective value of current strength; in ampere, A;
• U - effective value of the voltage; in volt, V;
• ϕ - angle of phase shift between current and voltage; in electrical degreases.

Every time during the measurement for each feeder of traction network more than 200 thousand experimental values for each of the investigated parameters of the normal mode has been recorded.
Further, the values of the resistances measured by the distance protection zones from the measured characteristics were calculated. Namely: the active resistance (R), reactance (X), and impedance (Z) were fixed.

After that, from all of the obtained values some special operating periods were identified. In these periods the highest values of the feeder's current were fixed. Then, for the periods the special graphics were calculated and constructed in the form of graphical dependencies: the load zone in the plane of complex resistance. Thereby resulting in processing of experimental data measured for each feeder about 5000 points were plotted on the graphs.

3. Results
The summarized research results for the last years of the period 2011 and 2017 are shown at figure 1.

As shown at figure 1, the distance protection of the traction substation N traction network feeder consists of four zones. The blue and red dots at the figure 1 represent the resistivity zones (load zones) that are measured by the distance protection in normal mode. The principles of the relay protection gears operation is based on the requirement to operate only in the event of an emergency. Therefore, the relay protection gears should not react to the zones of traction substation normal operation - that is, to the red and blue zones indicated at figure 1.

As you can see at figure 1, in 2017 compared with 2011, the load zone has significantly expanded and shifted lower along the ordinate axis. At the same time, the minimum resistance measured by the relay protection gears under load conditions has changed significantly. So, in 2011 its value was equal to 86 Ohms, and in 2017 its value became equal to 42 Ohms. To understand how the conditions for the relay protection gears operation have changed, it is necessary to analyze the changes in these minimum impedances, measured by them in the load zone.

The changes in minimum impedances of the relay protection gears, measured by them in the load zone, can be calculated by equation (1):
\[
\left( \frac{Z_{2011}}{Z_{2017}} \right) = \frac{86 \text{ Ohms}}{42 \text{ Ohms}} = 2.04
\]

(1)

So, value of minimum impedance, measured by relay protection gears in the load zone, has been changed and increased in 2.04 times. It is interesting to note that the traction network feeder load at the substations, located in the freight-stressed areas, has been increased even more - up to three times [17].

At the same time, part of the load zone, as shown at the figure 1, falls into the zone of relay protection gears operation. According to the data of 2017, the load zone is already in the immediate vicinity of the zone of relay protection gears operation.

4. Discussion
At present, in Russia, one of the criteria which is ensuring a stable functioning of relay protection is the coefficient of detuning reliability - \( K_n \). The coefficient \( K_n \) is calculated as the ratio of the minimum impedance, measured by relay protection gears in the load zone, to the resistance of zone number 3 (the existing setting of relay protection gears). This coefficient \( K_n \) is standardized by a normative document [20]. According to the requirements of [20], the coefficient of detuning reliability \( K_n \) must be equal to or greater than 1.2.

In our example, the existing setting of 35 Ohms shown at figure 1 as the beginning of the green arc along the ordinate. For 2017, the coefficient \( K_n \) can be calculated as the ratio of 42 Ohms to 35 Ohms and we get \( K_n=1.2 \). Thus, there is no reserve for detuning the relay protection gears in traction substation N. Since the load of the traction substation’s feeders will continue to increase under heavy haul traffic conditions, it is expected that the load zone will enter angle triggering characteristics of relay protection gear. This fact most likely leads to increasing the number of incorrect or superfluous operation of relay protection gears.

The problem is aggravated by the fact that the existing relay protection gears have load angle characteristic of the keyhole type [13]. This relay protection type was developed in the 60-70s of the 20th century for other, much smaller, railways cargo flows. The relay terminals types, whose are operated on the Russian Railways and named as БМРЗ and ЦЗА, are inherently analogues of old types of relay protection gears such as УЭЭФМ or АЗ [13, 21, 22]. This is a reason that they cannot provide stability operating in heavy haul traffic. Therefore, there is a need to create protection gear with new forms of angle characteristic in AC traction network of Russian Railways.

5. Conclusion
Summarizing the results of long-term observations of the AC traction network's relay protection gear operating under heavy haul traffic conditions, full-scale tests and analytical calculations, we can conclude the following points:

1. For the consideration period (from 2011 to 2017) the traction network's load has been increased about in 1.5 ÷ 3 times. Due to the intensive growth of the heavy haul traffic, the value of the traction network current became commensurate with the short-circuit currents.
2. Relay protection gears stability has been changed and greatly decreased. This is explained the weak tuning of these gears angular triggering characteristics from the traction substation’s load zone.
3. In the prospect of the heavy haul traffic increasing the existing relay protection gears haven’t a stability reserve.
4. There is an urgent need for the development and implementation new relay protection gears with new forms of angle characteristic in AC traction networks of Russia.

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