The Study of the Effectiveness of Strengthening the Traction Power Supply System of the Northern Route of the Eastern Polygon of the Russian Railroads

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Abstract. The train-handling capacity of the limiting section of the traction power supply system of the Northern route of the Eastern polygon of the Eastern Siberian Railroad has been estimated, taking into account the prospective amount of traffic for 2025. Due to insufficient train-handling capacity of the section and inconsistency of voltage level in the overhead system, the parameters of traction power supply system operation mode were studied using the mathematical simulation method in the Fazonord software application and the mathematical simulation method in the Kortes software application using various technical means of amplification. The simulation results allowed us to determine the most optimal amplification methods that meet the task set. It was proved that the method of increasing the transmitted power from 220 kV power line to 110 kV line through the autotransformer installed for their connection at the new traction substation of the limiting long section corresponds to the purpose of ensuring the required train-handling capacity of the limiting section in the best possible way, taking into account the prospects for development of both the external power supply system and the system of traction power supply. At one of the traction substations of the section under study it is required to install an additional power transformer for parallel operation. The specified combination of technical amplification means brings the parameters of traction power supply system into compliance with the requirements.

1. Introduction
One of the most important development lines for railroads in Russia is to optimize and increase the train-handling capacity, as every year the freight turnover on the electrified railroad transport increases, as follows from the strategy of development of railroad transport in the Russian Federation to the year 2030.

This strategy was developed in accordance with the Order of the Government of the Russian Federation dated 06/17/2008 No. 877-r [1]. The essence of the development and the strategy implementation is to modernize the transport system, to improve the safety of the shipment process, to optimize freight traffic and increase train-handling and carrying capacities, in particular, of the East Siberian Railroad by reducing the length of "bottlenecks" – the elements whose train-handling capacity factor exceeds the following values:
- for single-track sections – 0.85;
According to the forecast of the Russian Railways, JSC itself, the freight turnover will amount to 3050 billion ton-kilometers with a 1.46-fold growth (against the level of the base year 2007), passenger traffic will increase 1.16-fold exceeding 202 billion passenger-kilometers. Accordingly, Figure 1 shows the growth dynamics of the operational freight turnover from 2007 to 2020. On the basis of the data of Russian Railways, JSC the freight traffic as a percentage has increased by 39% as compared with the initial year of 2007 and continues to grow.

![Figure 1. Dynamics of freight turnover growth by years to 2021.](image_url)

This paper studies the effectiveness of amplification the traction power supply system (TPSS) of the Northern route of the Eastern polygon of the East Siberian Railroad [2, 3] as exemplified by the GS – KSH section to implement the train handling in compliance with the prospective amount of traffic for 2025.

2. Problem statement

Today, according to the strategy for the development of railroad transport worldwide, freight traffic increases every year. Electrified railroad transport accounts for most of the freight traffic, and this is under the assumption that most electrified railroad lines were laid in the last century and designed for lesser freight turnover.

One of the most important issues in ensuring normal operation of the power supply system is to maintain the voltage level in the traction network within the specified limits. The emergence of modern heavy-tonnage trains and the increase in the daily amount of traffic, significantly increase the load on all elements of the traction power supply system. Some sections of the overhead system operate at the edge of their train-handling capacity [4, 5, 6, 7, 8, 9, 10]. The current load in the system increases significantly, therefore, the heating of equipment is more intense, the voltage level in the overhead system decreases and power losses increase. Decreased performance of the traction power supply system indicates the need for its amplification.

The GS – KSH section under study is 212.7 km long, and is double-track and electrified by the AC with a voltage of 1×25 kV. Power supply of this section is performed from six traction substations. The peculiarity of the section is the connection of most of the traction substations to 110 kV single-chain power transmission line. There are two sectioning points in the middle of the ISZ of (inter-substation zones) KZH – VD and CHR – KSH sections, RCH and SI, respectively. The profile of the double-track GS – KSH section is hilly with excessive gradients: the maximum height of the slope in the GS – ZB area is 8.8 ‰, which is 7 km long, the maximum height of the slope in ZB – KZH area is 8.6 ‰, which is 10 km long, in the KZH – VD area the height of the slope is 9.4 ‰, which is 2 km long.

At all traction substations of the section power transformers TDTNZh-40000/110-71U1 are installed. The traction substations ZB, KZH, VD, KSH are equipped with shunt compensation devices (SCD)
having power of 3,000 kVAR. Series capacitor banks (SCB) are connected to the sucking booster at traction substations KZH, VD, KSH. Thus, due to the complex profile of the section; its TPSS is equipped with reactive power compensation devices.

At the same time, until recently, freight traffic of moderate intensity was carried out along the Northern route of the Eastern polygon.

Currently, there is an acute issue of unloading the main route of the Eastern polygon [11] and the management of heavy-tonnage trains operation along the Northern route; the said heavy-tonnage trains weighing 7100 tons and more.

In this regard, the urgent task is to study the possibility of TPSS train-handling capacity with regard to the perspective amount of train traffic with the necessary minimum inter-train intervals. This is confirmed by the experimental attempts to handle a train weighing 7,100 tons along the section under study in 2020, during which significant difficulties were revealed in handling the train of this weight on KZH – VD.

3. Analysis of the train-handling capacity of the existing TPSS of the GS – KSH section

In order to determine the train-handling capacity of the existing TPSS with regard to the prospective amount of traffic for 2025, simulation modeling was used in the KORTES software application.

In this case, the following train bunches schedules were organized:

– in the even direction: 5 trains of average weight of 4,553 tons with an interval of 30 minutes, then a package of 5 trains of 6,000 tons – 7,100 tons – 4,000 tons – 7,100 tons – 3,000 tons with an interval of 10 minutes, then 5 trains of average weight of 4,553 tons with an interval of 30 minutes;

– in the odd direction: 5 trains with an average weight of 2,370 tons with an interval of 30 minutes, then a bunch of 5 trains with a weight of 1,700 tons – 6,000 tons – 1,700 tons – 4,000 tons – 1,700 tons with an interval of 10 minutes, then 5 trains with an average weight of 2,370 tons with an interval of 30 minutes.

The computation results of the minimum voltage in the overhead system $U_{os}$ for the inter-substation zones of the studied area, are provided in Tables 1 and 2.

### Table 1. Minimum voltages at the locomotive current collector $U_{os}$ when computing the train-handling capacity using a bunch schedule showing the actual amount of traffic.

| Inter-substation zone | Path | $U_{os}$, kV | 3-minute |
|-----------------------|------|-------------|----------|
| GD - ZB               | 1-st | 23.85       | 24.76    |
|                       | 2-nd | 22.90       | 23.70    |
| ZB - KZH              | 1-st | 21.37       | 21.49    |
|                       | 2-nd | 20.30       | 21.63    |
| KZH - VD              | 1-st | 18.73       | 19.76    |
|                       | 2-nd | 18.26       | 19.36    |
| VD - CHR              | 1-st | 22.68       | 22.88    |
|                       | 2-nd | 22.36       | 22.73    |
| CHR - KSH             | 1-st | 22.23       | 22.54    |
|                       | 2-nd | 21.63       | 22.59    |
Table 2. Minimum voltages at the locomotive current collector $U_{os}$ when computing the train-handling capacity using a bunch schedule showing the perspective amount of traffic.

| Inter-substation zone | Path  | $U_{os}$, kV Minimum | 3-minute |
|-----------------------|-------|----------------------|----------|
| GD - ZB               | 1-st  | 23.79                | 24.62    |
|                       | 2-nd  | 22.75                | 23.70    |
| ZB - KZH              | 1-st  | 21.37                | 21.49    |
|                       | 2-nd  | 19.14                | 19.78    |
| KZH - VD              | 1-st  | 17.87                | 19.08    |
|                       | 2-nd  | 17.88                | 18.64    |
| VD - CHR              | 1-st  | 22.60                | 22.79    |
|                       | 2-nd  | 22.28                | 22.90    |
| CHR - KSH             | 1-st  | 20.92                | 21.33    |
|                       | 2-nd  | 20.74                | 21.52    |

Thus, the results obtained in the simulation modeling [12] confirm the presence of the minimum voltage limiting in the overhead system (OS) of ISZ; ZB – KZH and KZH – VD, ISZ of CHR – KSH are also noted to be somewhat below the norm of 21 kV. Consequently, it is necessary to continue the amplification of the section GD – KSh in order both to pass trains with a weight of 7,100 tons at present, and to manage the necessary amount of traffic in the future in 2025.

4. Analysis of TPSS amplification methods for the section under study

There are several options of amplifying the system of traction (TPSS) and external power supply (EPS) systems [13, 14, 15, 16, 17, 18, 19, 20]:
- amplifying wire in the traction network of grade A – 185. This measure is used to increase the OS cross-section due to the increase in the current value;
- series capacitor bank (SCB) at a traction substation (TS) [13]. Series capacitor bank allows to increase voltage level in overhead system (OS) and reduces the unsymmetry coefficient. Series capacitor bank is connected to the lagging phase or sucking booster and, by compensating the inductive resistance of TPSS traction power supply system with capacitive resistance, increases the voltage level in the feeder zone, which in turn, leads to the symmetry of currents in the transformer phases;
- shunt compensation device (SCD) in the traction network. The use of a shunt compensation device makes it possible to compensate for reactive power and increase the voltage level in the OS. This is done by reducing the reactive component of the current, which causes the increase in the power factor and reduces voltage and power losses;
- a shielding wire in the traction network. Shielding wire allows you to increase the level of voltage in the OS by compensating the value of mutual inductance resistance;
- sectioning point (SP) is designed for electrical connection of OS sections to reduce power losses, for selective disconnection of one or more sections of the railway OS in case of its (their) being damaged or to solve the above tasks in parallel;
- parallel connection point (PCP) is designed for electrical connection of OS sections of mains tracks of a double-track section of a railroad line to reduce voltage and power losses in the overhead system;
- installation of an additional power transformer (PT) at a traction substation to ensure a parallel operation. When the PTs are connected in parallel, the total power of the traction substation (TS) is increased and the resistance of the PTs is reduced. The system is less prone to overloads;
- construction of an additional TS in the most problematic ISZ, which significantly increases the capacity of TPSS;
- installation of an autotransformer (AT) at the TS.

AT is a type of PT, which has one winding on a multilayer core. It differs in that the part of the winding is common to both the primary and secondary sides. In the load condition, a part of the current is transmitted directly from the power supply and the remainder is transmitted from the action of the device itself. In this way, the AT acts as a voltage controller. Application of AT is a powerful means of amplification, first of all, of external power source (EPS), but it also produces a significant impact on the parameters of the TPSS operation mode.

In order to amplify the EPS of the section under study, it is proposed to install AT of ATDTNZh-63000/220/100 grade at the territory of the additional TS of RCH to provide electrical connection between 220 and 110 kV transmission lines and increase the power transmitted to the 110 kV OPL.

Proposals on construction of this additional TS are explained by a complicated profile of ISZ of KZH – VD, a considerable distance between traction substations KZh and VD, that is 59 km long, and, accordingly, by existence of restrictions for the minimum voltage at this ISZ.

The need to organize communication through the AT at this substation with the 220 kV OPL is due to the fact that the connection of this TS to the 110 kV OPL can only be done by the same method as the neighboring TS, because the OPL is single-chain, and this significantly limits the transmitted power.

The construction of an additional TS of RCH and its communication through the AT with the 220 kV OPL will lead to a change in the values of short-circuit power (SC) [21, 22] at the inputs of all traction substations of the section under study. To reassess the SC power, a model of the combined EPS and TPSS of this section was developed for Fazonord software application, presented in Fig. 2.

![Figure 2](image)

*Figure 2. Model of the power supply system of the section under study.*

The short-circuit power values, obtained in the course of mathematical simulation in Fazonord software application, are presented in Table 3.
Table 3. SC power values, taking into account the AT.

| Name of TS | SC power before installing the AT, MVA. | SC power after installing the AT, MVA. |
|------------|----------------------------------------|----------------------------------------|
| GD         | 2450                                   | 3758                                   |
| ZB         | 817                                    | 1145                                   |
| KZH        | 518                                    | 920                                    |
| RCH        | 579                                    | 1068                                   |
| VD         | 458                                    | 832                                    |
| CHR        | 590                                    | 907                                    |
| KSH        | 1319                                   | 2719                                   |

As we can see, the values of short-circuit power at the inputs of all TSs, taking into account the additional TS of RCh, indicate a significant increase in the power transferred from the 220 kV network to the 110 kV network, and, consequently, in the strengthening of the TPSS of the section analyzed.

The individual study of the above-mentioned methods of TPSS amplification did not bring the desired result in terms of voltage level in the OS. Therefore, the analysis of combined variants of both EPS and TPSS amplification was performed. The most favorable results were obtained when using two combined options of amplification, presented in Table 4.

Table 4. Evaluation of combined options of amplification.

| Amplification methods | Interval between trains, min. | ISZ with minimal voltage at the current collector | Minimal voltage at the current collector, kV |
|-----------------------|-------------------------------|-----------------------------------------------|---------------------------------------------|
| The construction of TS of RCh at ISZ of KZH – VD and switch into parallel operation of additional PT at TS of KSh | GD - ZB | 22.87 |
|                       | ZB - KZH                      | 21.33                                      |
|                       | KZH - RCH                    | 21.83                                      |
|                       | RCH - VD                    | 23.01                                      |
|                       | VD - CHR                     | 22.56                                      |
|                       | CHR - KSH                    | 21.59                                      |
|                       | GD - ZB                     | 23.07                                      |
|                       | ZB - KZH                     | 21.22                                      |
| Construction of TS of RCh with AT at ISZ | KZH - RCH | 22.38 |
|                       | VD - CHR                     | 23.25                                      |
|                       | CHR - KSH                    | 21.23                                      |
|                       | RCH - VD                     | 23.23                                      |
|                       | VD - CHR                     | 23.23                                      |
|                       | CHR - KSH                    | 21.23                                      |

5. Conclusion
In connection with the perspective increase in the amount of traffic on the Northern route of the Eastern polygon for 2025, with an increase in the weight of heavy-tonnage trains, the limitation of the train-handling capacity of the TPSS on the section GS – KSH with the minimum OS voltage was revealed.

To solve this problem, it was proposed to amplify both the EPS and TPSS by building an additional traction substation Rch on the ISZ of KZH – VD and connecting this substation not only to the nearby 110 kV OPL, but also to the 220 kV OPL via AT. In addition, in order to remove train-handling capacity constraints, it was proposed to install an additional PT at the TS of KSh for its parallel operation with one of the main PTs when trains weighing 7,100 t or more are handled. In this case, when handling the prospective amounts of traffic in 2025, the voltage in the OS will increase at the limiting ISZ of KZH – VD by 25.2 – 30.1 % and will correspond to the minimum permissible value.
The proposed technical solutions will make it possible to amplify the TPSS of the Northern route section under study [23, 24] and bring the TPSS in compliance with the requirements of the program of railroad transport development in the Russian Federation to the year 2030.

6. References

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