The Influence of Unbalanced Loads in the Electrical Network on the Operation of Transneft PJSC Power Consumers

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Abstract — **The study focuses on an assessment of the power quality of electrical consumers of Mariinsk substation of the Transneft–Western Siberia JSC and Skovorodino OPS-21 of Transneft–East LLC in the power systems adjacent to the Trans-Siberian Railway and Baikal–Amur Mainline. The dynamics of bringing the power quality indices at the OPS-21 to the normalized values of the State Standard (GOST 32144-2013) when using SVC-20/20-10 at this station is shown. The design solutions of the Round Table "Low quality of electricity in 35-220 kV electrical networks supplying electrified railways and public consumers. Technologies for its normalization" were noted within the framework of the International Forum "Electrical Networks", Moscow, November 22–25, 2022.**

Index Terms — **power quality, electric network, unbalanced loads, power consumers.**

I. Introduction

The quality of electricity in the electrical networks of electric power systems and power supply systems is one of the most important aspects determining the reliability and efficiency of power supply to consumers. This is especially true for the electricity consumers of Transneft PJSC in the power systems adjacent to the Trans-Siberian Railway (Transsib) and Baikal-Amur Mainline (BAM). A significant share of the load of the trunk networks of Siberia and the Far East, feeding the Transsib and BAM, is electrified traction of "Russian Railways" JSC.

The dynamic development of railways, including high–speed ones, leads to a significant increase in the share of traction load in the load of the power system. This is especially relevant at present in relation to the instructions of the President of the Russian Federation V.V. Putin to expand the capacity of the Eastern Section (Vostochny Poligon in Russian): BAM and Transsib.

Currently, the modernization of the Eastern Section is one of the largest infrastructure projects in the Russian Federation. The first stage of the project provides for an increase in the carrying capacity of the BAM and Transsib in the direction of seaports and border crossings of the Far East to 144 million tons in 2021. The implementation of the second stage will increase the annual capacity of the railways to 180 million tons by 2024.

II. Traction Power Supply System Case Study

The traction power supply system of the railway has a negative impact on the electrical networks. This is because the electric rolling stock is a sharply alternating single-phase load having a low power factor and causing current and voltage distortion both in the traction power supply system and in the external 110 kV and 220 kV networks feeding traction substations. The specific features of the traction load include the oscillatory uneven nature of the load during the day and a significant distortion of the sinusoidal current and voltage waveforms.

The second negative factor aggravating the effect of traction load on voltage quality is the large length of power

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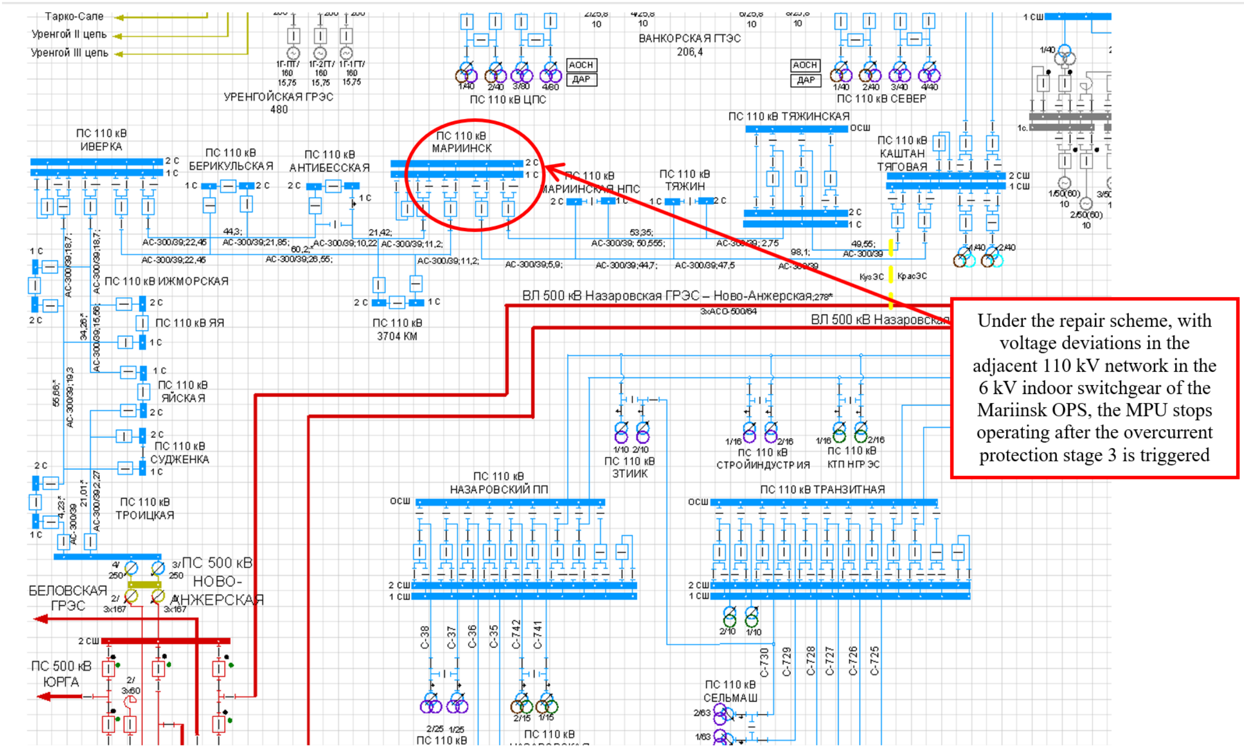

Fig. 1. Power supply scheme of the Mariinsk OPS.

transmission lines and their distance from power sources, which determines the low short-circuit power in the electrical network and, accordingly, the high sensitivity of voltage to distortion currents from nonlinear, asymmetric, and sharply alternating consumers. At the stage of implementation of the Eastern Section project, the power of the distorting load of Transsib traction substations will only increase in the near future.

Currently, there are problems with the quality of electrical energy at the facilities of Transneft–Western Siberia JSC, which lead to failures (emergency shutdowns of the OPSs). For example, at the Mariinsk OPS under repair conditions (when the transit transmission is interrupted, the 110 kV “Tyazhinskaya” substation and 110 kV “Kashtan” traction power substation (TPSS) are disconnected (due to the withdrawal of the 110 kV Iverka–Mariinsk overhead line with a branch)), we fix significant distortions of power quality indices (PQI):

- negative voltage deviations (the standard is no more than 10%):

dUA(−) = 28.66% (18.07.2022);

Alice(−) = 13.55% (18.07.2022);

- positive voltage deviations (the standard is no more than 10%):

dUC(+) = 10.13 (19.07.2022);

dUVS(+) = 10.04 (07.19.2022);

- the unbalance factor (the standard is no more than 4%):

K2 U% 11.46 (21.07.2022)

- the total harmonic distortion of the voltage (the standard is no more than KU(95%) = 5, KU(100%) = 8):

KU(A) = 17.60 (07.19.2022);

KU(AB) = 18.40 (07.19.2022);

- the harmonic factor of phase voltage of order n.

Excess by 3, 5, 6, 7, 9, 11, 13, 15, 17, 19, 21, 23, 27, 33 harmonic components of the voltage. The greatest distortion is caused by harmonics 9, 11, 13, and 15.

In some operating conditions, the value of these harmonics is more than 6 times higher than the standard value. The power supply scheme for the Mariinsk OPS is shown in Fig. 1.

During the period from 09.2007 to 08.2022, there were 26 shutdowns of main pump units at the Mariinsk pump station and 17 failures, which led to its stopping.

The deviation of the power quality indices causes the uninterruptible power supply (UPS) to freeze, with further transition of microprocessor-based automation system (MAS) of the automated production process control system to power supply directly from the network with low power

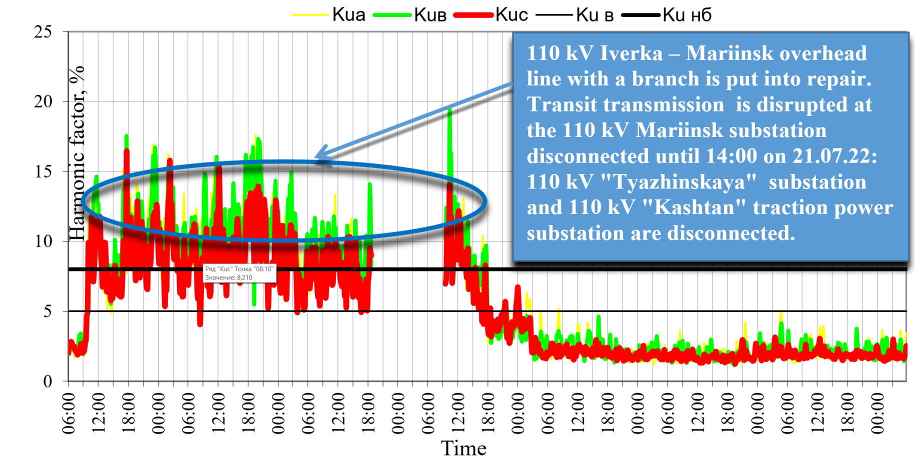

Fig. 2. Graphs of harmonic factors of phase voltages averaged over a time interval of 10 minutes for input No. 1 for the period from 07.18.2022 to 07.25.2022.

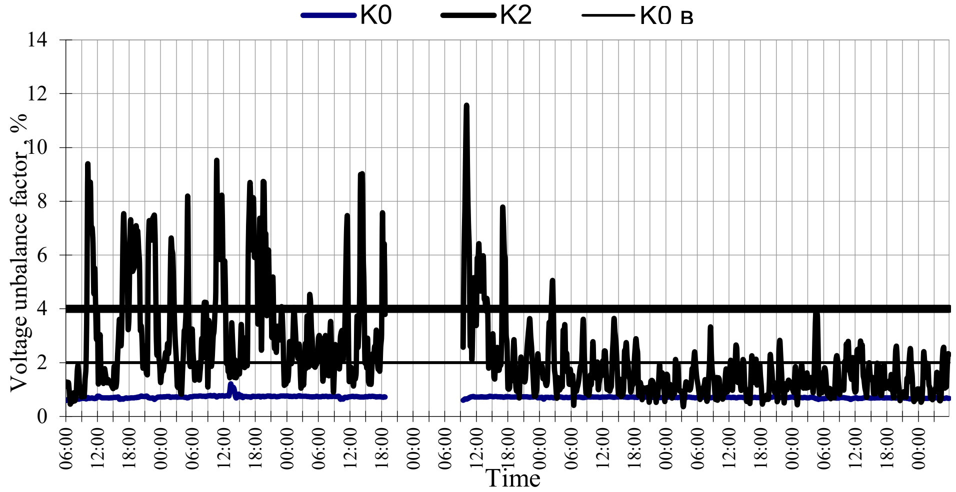

Fig. 3. Graphs of the unbalance factor for the zero sequence and negative sequence voltage averaged over a time interval of 10 minutes for input No. 1 for the period from 07.18.2022 to 07.25.2022.

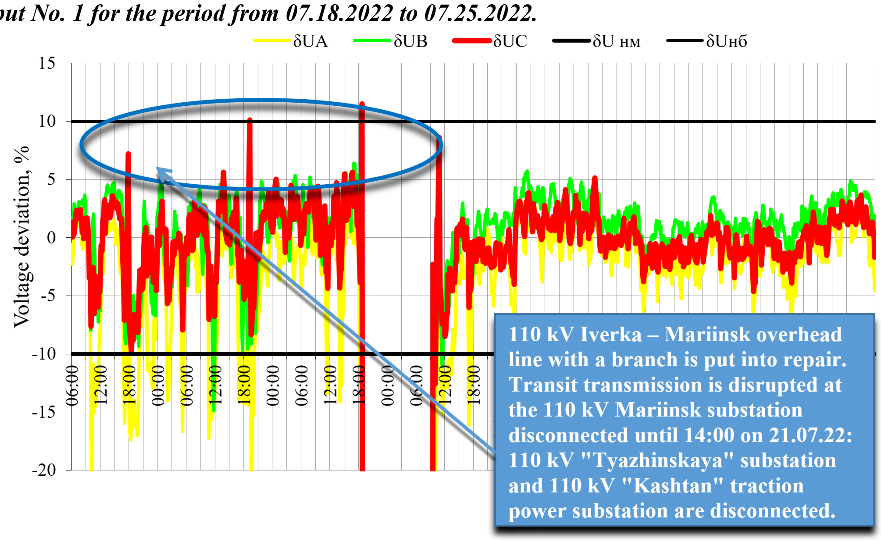

Fig. 4. Graphs of phase voltage deviations averaged over the time interval of 10 minutes for input No. 1 for the period from 07.18.2022 to 07.25.2022.

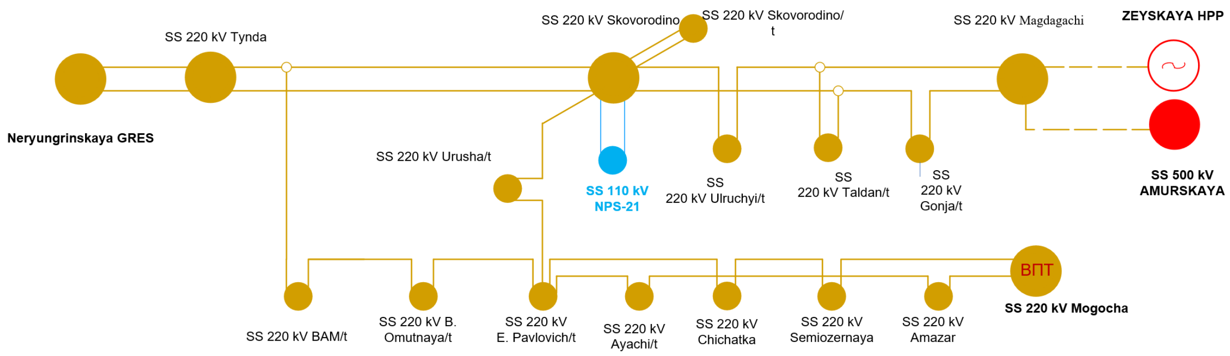

Fig. 5. Power supply scheme of the Skovorodino OPS-21 of the Transneft–East LLC.

Fig. 6. A general view of two static var compensators at the Skovorodino OPS-21 of the Transneft–East LLC.

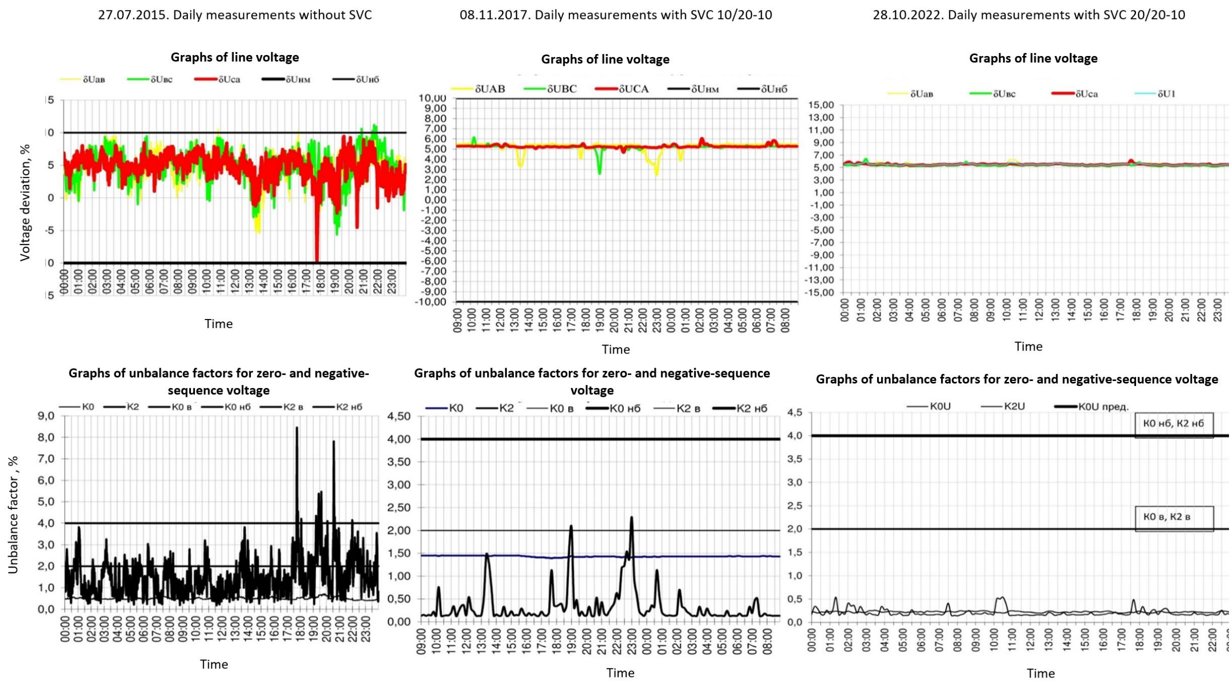

Fig. 7. Dynamics of bringing the PQI of the Skovorodino OPS-21 of Transneft–East LLC to the standard values with SVC on the first section of 10 kV buses.

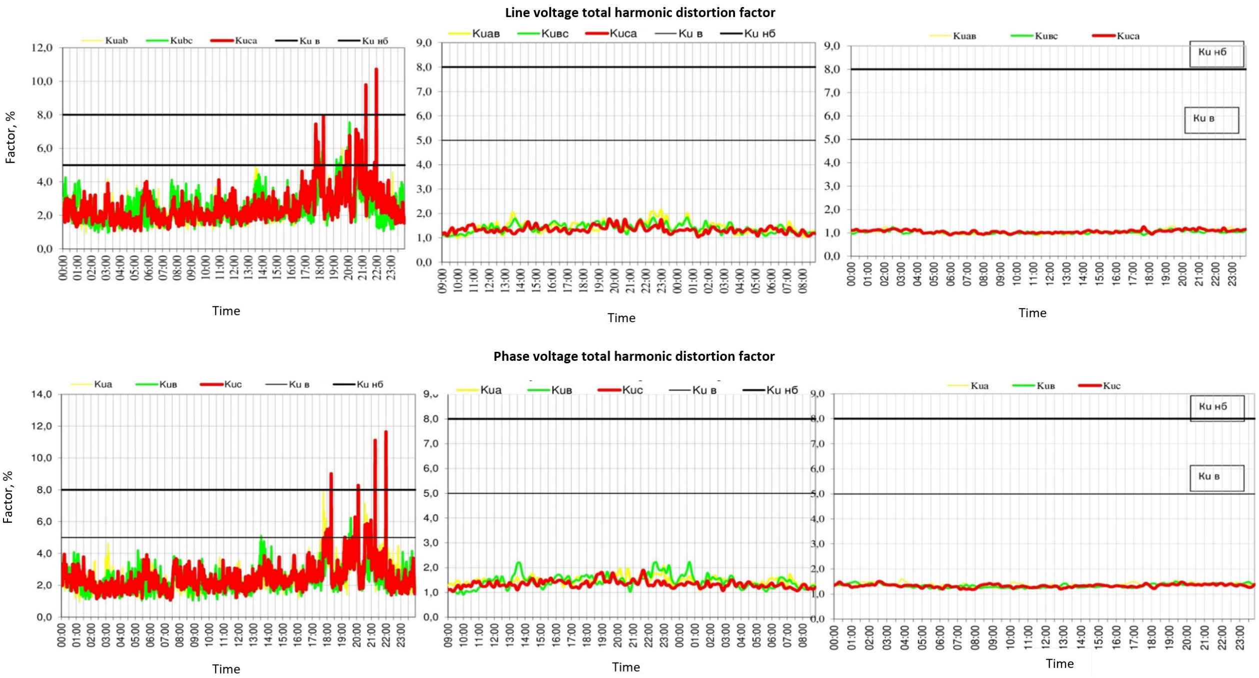

Fig. 8. Dynamics of bringing the PQI of the Skovorodino OPS-21 of Transneft–East LLC to the standard values with SVC on the first section of 10 kV buses.

quality indices, which results in generation of the false signal “Malfunction of vibration monitoring devices” and the subsequent shutdown of the main pump unit (MPU) No. 2 and MPU No. 4 with the restart of the UPS MAS.

Mariinsk station is located on the Trans-Siberian Railway and is the gate of the Eastern Section of the Russian Railways JSC. It is unique in that there is a change in the type of traction from DC (3 kV), on which the railways of the western part of the Russian Federation operate, to AC (25 kV), used in its eastern part of the Russian Federation. This requires changing the locomotives of all transit trains passing through the station.

Currently, the Mariinsk station handles up to 128 freight trains daily, including up to 32 combined container trains. After the reconstruction, the capacity of the station will increase to 140 freight trains per day in total for the eastern and western directions. Accordingly, the inter-train interval of electric rolling trains will be reduced and the load on traction substations, and hence on the 110 kV transit overhead lines feeding the 110 kV Mariinsk substation will increase. A similar situation will occur at all traction substations.

Due to the terrain features, loaded trains can go up (phase “A”) and down with electricity recovery (phase “C”), therefore, both negative and positive voltage deviations are observed.

Since VL80R electric locomotives (25 kV AC) are equipped with collector electric motors NB-418Kb with a thyristor inverter driven by the network, the electricity recovered by electric locomotives in braking mode distorts PQI in terms of harmonic composition.

The most promising option is to reconnect the 6 kV indoor switchgear (IS-6 kV) of the Mariinsk substation to the 110–500 kV substation, which does not directly supply traction substations of Russian Railways JSC.

The paper presents graphs of PQI deviations for the other facilities of Transneft – Western Siberia JSC.

It is worth noting that to normalize the PQI at the oil pumping station (OPS), Transneft–East LLC introduced static var compensator STK-10/20-10 at the Skovorodino OPS-21 in 2017, which was followed by the modernization of the equipment (installation of STK-20/20-10) in 2020. The power supply scheme of the Skovorodino OPS-21 of the Transneft–East LLC is shown in Fig. 5.

The 110 kV OPS-21 of Transneft-East LLC is powered by two 110 kV overhead lines from the 220 kV Skovorodino SS of the power system of the East - a branch of FGC UES PJSC. The length of the 110 kV supply lines is 23 km. The 220 kV Skovorodino TPSS of the Trans–Baikal Railway branch of the Russian Railways JSC is powered from the 220 kV Skovorodino SS by two 220 kV overhead lines, the length of the 220 kV supply line is 5.2 km. The nearest power source for the 220 kV Skovorodino SS is power system of the East – a branch of FGC UES JSC (155.2 km), for 220 kV Tynda SS, the power source is Neryungri GRES. In addition, the 220 kV Skovorodino SS provides power to the nearby 220 kV traction substations (BAM TPSS, Urusha TPSS, Ulruchyi TPSS, and Gonzha TPSS) via 220 kV overhead line. Thus, the 110 kV OPS-21 substation is connected according to a radial dead-end scheme, in which the quality of electrical energy depends on the distance between the supply center and the consumer.

At the 220 kV Skovorodino SS, single-phase loads of varying magnitude with heterogeneous harmonic composition prevail, which is caused by the operation of five traction substations. The 220 kV Skovorodino TPSS, located at a distance of 5.2 km from the 220 kV Skovorodino SS, has the most significant impact on the quality of electrical energy.

A general view of the two static var compensators at the OPS-21 is shown in Fig. 6.

The dynamics of bringing the PQI at the OPS-21 to the normalized indices of State Standard (GOST 32144-2013) is shown in Fig. 7 and 8.

Thus, the SVC 20/20-10 when used at the OPS-21:

- improves the harmonic composition of the 10 kV bus voltage;
- compensates for slow and fast voltage changes (dips) up to 13% of the rated voltage of 10 kV, with a three-phase balanced voltage reduction of 10 kV and a short-circuit power of 152.69 MVA;
- ensures reliable operation of the equipment under the voltage unbalance in the network.

III. Conclusion

In order to enhance the reliability of the electrical equipment of the Transneft facilities along the Trans–Siberian railway and Baikal–Amur mainline, it is crucial to take measures to improve the PQI in the transmission and distribution networks of the power system of Siberia and the East by ensuring electromagnetic compatibility of the traction load with the supply network. This process involves converting an unbalanced non-sinusoidal load current with a significant proportion of reactive component into a balanced sinusoidal current that ensures such electromagnetic compatibility. Power factor correction units (SVC and STATCOM) can provide this.

The issues addressed in the paper were thoroughly discussed at the Round Table "Low quality of electricity in 35-220 kV electrical networks feeding electrified railways and public consumers. Technologies of its normalization" within the framework of the International Forum "Electrical Networks," Moscow, November 22–25, 2022.

The following points are important to highlight:

1. The most effective solution to the problem of low power quality in the transmission networks adjacent to the Transsib and BAM is the installation of three-phase compensators with phase-by-phase control of the SVC and STATKOM type at traction substations of Russian Railways JSC. In order to stimulate their application, the contracts for the connection of traction substations to the electric grid must not only specify the requirement for their installation, but also provide a system of discounts and surcharges for the use of electricity for the execution of this paragraph in an amount that ensures the regulatory payback period of the power factor correction unit. This can be helped by rationing in terms of encumbrance of technical conditions for connecting distorting loads in the network, depending on the ratio of the short-circuit power at the point of connection to the installed load capacity, as is done in electric companies abroad.

2. In order to carry out the Federal Project "Development of the railway infrastructure of the Eastern Section of Railways," to achieve its goals and accomplish the objectives set, it is crucial to develop and implement the program for installing reactive power compensators and other necessary equipment at the traction substations of the Russian Railways JSC. This program plays a vital role in future ensuring reliable supply of electric power in Transbaikalia, Eastern Siberia, and the Far East.

3. High quality of electricity in the unified power system networks can be ensured only if the use of advanced reactive power compensators by consumers is stimulated at the state level, which requires the adoption of appropriate laws that underlie the tariff policy of the Russian Federation in this area.

According to the solutions proposed at the Round Table, on 10.02.2023, a joint meeting of the Scientific and Technical Council of the ROSSETI FGC UES and the section “Electrical Equipment” of NP STC UES was held at the Rosseti Science and Technology Center. Based on the results of the meeting, some measures were recommended to formulate a regulatory act and make changes to the existing regulatory documentation, and conduct a separate in-depth study to address the power quality challenges.

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