Current Issues to Diagnose Electric Connections of the Traction Energy System

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Abstract. Currently, the task is to increase the capacity of the Russian Far Eastern Railway in the direction of ports on the Pacific Coast. This causes a significant increase in loads in the traction energy system, and under such conditions, the serviceability of the electric power infrastructure is crucial to ensure. In this regard, the stability of operation can be increased by improving the monitoring and diagnostics systems of the traction network elements. One of these elements is the electrical connection which has always been the most sensitive in the power grid. Therefore, the identification of factors that affect its failure, as well as the logic in maintenance and repair are relevant and significant not only for railway networks but for the electric power industry as a whole.

1. Introduction
Over 50% of railways in the Russian Federation, are electrified with direct and alternating current and used to carry more than 80% of cargo. For the recent 10-15 years, heavy and long-distance train traffic has increased on the Russian railways. Moreover, new rolling stock has been put into operation; the speed of passenger trains and the load on electrified lines have been increased. As part of the railway transport reform, requirements for the quality and reliability of traction energy equipment are increasing, including the overhead network.

The entire electric rolling stock on electrified railways is powered by the power supply system. In particular, the electric power is transmitted to ERS through traction substations and special overhead power lines. The traction substation converts the power to the required voltage level (3.3 or 27.5 kV systems) and then feeds it through the overhead network to the pantograph.

Current clamps play an important role to ensure that the wires of the catenary suspension are connected to each other without loss of electricity at current collection and safety compromises [1]. The contact wire is the most important part of the overhead network and the main channel to collect the current. The contact wire is usually a cylinder with grooves on both sides and a conductive body that slides directly over the pantograph, so it should have a higher conductivity and greater tensile strength. The grooves are intended to ease the installation of clamps and non-removable contact wires of the suspension, while they should not affect the slip-page of the pantograph. The contact wire transmits the current directly to the loco-motive by the pantograph sliding on its lower surface, and its condition directly affects the quality of current collection and safe operation of the locomotive.
2. Problem definition
In order to meet the mechanical and electrical requirements in terms of power transmission to the rolling stock, various types of electrical connectors with different functional purposes are required [2]. Standard designs of connections that are usually used include the bolted, crimped, wedge, collet, swaged or twisted, with crimping, thermal affected (figure 1). Due to the variety of designs, electrical connections are used to mount the traction network wires.

Figure 1. Identification of electromechanical connection sites.

The basic elements of the catenary system and overhead power lines: 1 — contact wire; 2 — suspension strand; 3 — earth conductor of support; 4 — contact line support; 5 console; 6 — console linkage; 7 — string of insulators; 8 — overhead lines (OHL); 9 — bracket; 10 — clasping insulator; 11 — main stem of reverse retainer; 12 — section string; 13 — stitch wire; 14 — secondary retainer bar; 15 — main stem of direct retainer; 16 — axis of track; 17 — rail; G — dimension of support; N — height of the contact wire from the elevation mark.

The contact suspension wires are connected to each other, as well as to supporting devices and supports, using special fittings of various designs depending on the purpose. The component elements of the reinforcement can be made of various materials as per their function.

More than 20 types of overhead network bolt clamps are used in the chain suspensions of overhead networks of electrified railways.

The state of the electrical connection is affected by various conditions, which results in the weakening of the pressing force, heating of the connection joint, changing the places of contact.

Requirements applied to the feed clamps include minimum weight, corrosion resistance, minimum electrical resistance, and tensile strength.

However, these requirements are difficult to implement due to a range of factors. Breaks in the suspension strands, contact wires, feeding or strengthening feeders - all these states are usually due to overheating of the current-conducting clamps installed thereon [3-4]. Clamps may be overheated due to changes in the contact properties, namely, an increase in the contact resistance due to deformation of the clamps, oxidation, corrosion; loosening of the fasteners; installing the clamps without special cleaning of the contact surfaces; reducing the area of the contact surfaces.

The clamps on feeders and suction feeders, as well as in other sites may be subjected to the increased load [5]. A change in temperature would cause residual deformation therein which leads to
an increase in the transient resistance. In other sites, dangerous overheating of the wires may occur under heavy loads (figure 2).

**Figure 2.** Statistics of damage of the overhead network devices: 1 - damage to the overhead network devices out of the total number of failures, 2 - failure of electrical connections out of the total number of damage to the overhead network.

Reliable operation of contact connections requires solving several problems: 1) reducing the resistance of the contact surface, 2) extending the service life while maintaining the required properties, 3) preventing oxidative processes.

### 3. Solution

Figure 3 shows the causes of damage to bolted electrical connections that lead to a break in power supply.

**Figure 3.** Causes of damage to bolted electrical connections to cause the power interruption.

More than 20 different types of contact screw clamps are used in DC and AC overhead networks, 12 of them made of non-ferrous metals.

Different types of contacts have different requirements for their parameters and reliability, but since any contact functions to transmit current with the least losses, the formation of the actual contact area and the area of the conducting contact greatly affects their performance and reliability [6-7].
These processes depend on lots of independent and interrelated factors. The variety of these factors can be divided into operational characteristics as specified by operating conditions, as well as structural and technological factors determined by the design and manufacturing conditions of the contact device [8].

Failure of the contact is defined as the moment when it can no longer function. This moment occurs when the contact temperature increases sharply due to a significant increase in its resistance as a result of various real processes in the physical contact. The interaction of such processes can be shown in the hierarchy (figure 4).

![Figure 4. Block diagram featuring causes of failures in the power supply system due to the unsatisfactory state of the electrical connection.](image)

For a reliable connection, the contact area must be large enough to remain even after a lasting failure. In order to track the state of the contact, a control block is proposed (in figure 3, the block is marked with a dotted line) in the block diagram of the algorithm, which shows the influence of various factors on the appearance of overheating and failure of the electrical connection. The performance of the entire system depends on the search and prevention of such adverse effect occurrence [9].

The rate of degradation of the junction is defined by the nature of various processes in the contact zone. This initial stage takes a long time without any visible changes, since the properties of the touch point groups and their total resistance change slightly. However, if the contact resistance changes, the large local overheating occurs followed by the rapid degradation of the contact due to thermal, chemical, mechanical and electrical processes.

In the overhead network, bolted clamps are mainly used that provide the mechanical and electrical connection of the conductors. The quality of the obtained connection points is identified as per the requirements of [6] by the coefficients of electrical contact defects.

In order to figure out the mechanisms of potential damage, design criteria, fault-tolerant functions and methods of structural maintenance, it is important to evaluate the effectiveness of sensor-based systems to monitor the feed clamps in terms of deterioration of their life cycle [10].

Therefore, monitoring and diagnostic methods should be aimed:

- to detect the wear or damage that affects the structural integrity of the equipment or electrical system;
- to determine the wear parameters characterizing its extent;
- to assess the harmful effect of degradation on the power equipment characteristics;
- to initiate the mitigating or corrective actions to restore the operational capabilities of power equipment.

Contact degradation is assessed by continuous or regular inspection, measurement, recording, and interpretation of physical parameters related to the operation of the equipment. The data obtained relate either to the degree of degradation or to the remaining service life of the equipment. The deterioration can be assessed in terms of physical, electrical, or performance changes (deviations of the operating parameters from the expected values) [11].

In the case of power connections and power equipment in general, reducing the number of failures increases the reliability of the network. This task can be achieved through preventive maintenance using the advanced monitoring and diagnostics methods, in particular, through more accurate online monitoring. The final result of these measures is the improved reliability of the power system and prevented power outages [12]. This, in turn, provides the economic benefit in terms of cost savings, since extending the life of power equipment beyond its design life reduces the capital cost to replace the outdated equipment.

State monitoring is the continuous or regular check and evaluation of the functionality and operational readiness of an electrical connection or system as a whole. It provides information on measurements, regular tests or inspections designed to produce consistent, repeatable results, based on which a conclusion is made about the current characteristics or the state of operational readiness of the electrical connection.

Figure 5 shows the block diagram to service the bolted electrical connections.

![Block diagram of the bolted electrical connection maintenance algorithm](image)

**Figure 5.** Block diagram of the bolted electrical connection maintenance algorithm.

Effective monitoring of electrical connection degradation requires the knowledge of one or more indicators of the current state, which provide information about the physical state during observation [56]. It can identify aging mechanisms that have not been probably considered thoroughly during the initial inspection, and define the emerging defects. An acceptable indicator for state monitoring should provide early warning of impending functional degradation, which may not yet be obvious, but already has a change detectable before failure [13].

Ideally, monitoring of the single status indicator should reveal the functionality of the electrical connection within the existing criteria, allowing the user to make a choice: whether to continue working without changes, perform maintenance, repair, or replace it [14]. From the practical point of view, monitoring methods should be non-destructive, assessing the state without dismantling the electrical connection.

Online monitoring of the equipment state is becoming more attractive, as accurate condition assessment and subsequent operation management make the network more economically viable and
reliable. It should be noted, however, that the broader development of the state monitoring plan is generally weakened by the lack of adequate understanding of degradation mechanisms, which in turn makes it difficult to identify and develop appropriate state indicators and monitoring methods.

In any electrical system, electrical contacts are the weakest links, and they present the most common problems. Therefore, in order to monitor the condition of various power plants, many sensors and monitoring systems are being developed, their main function being to determine the location, type and magnitude of deterioration.

However, only a small part of the accident causes can be detected using the senses, such as visual and acoustic inspection. In this case, the human factor is of great importance. The inspection result depends on the skill of the inspector. Therefore, a complete check of the device's functioning is required.

4. Conclusions
The reliability of the traction power system depends on the reliable operation of its elements. According to the statistical data on the fault rate of the traction energy system, electrical connectors are important elements that determine the reliability of the entire system.

The increased transient resistance $R_T$ causes the large overheats and subsequent failure of the electrical connection. The transient resistance $R_T$ increases during operation due to the formation of oxide films and loosened bolts of the electrical connection. All this results in the decreased contact surface and, as a result, the increased transition resistance.

The regular control of the electrical connection and timely maintenance during operation is an important task to maintain the operability of the traction energy system [15].

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