Development of a system for electric power consumption control by electric rolling stock on traction tracks of locomotive depots

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Abstract. The paper deals with the problem of increasing the energy efficiency of train traction. The analysis of energy resources consumption of JSC “Russian Railways” is made and options for saving fuel and energy resources of the company are formulated by reducing unproductive losses of electricity by electric rolling stock of railways during their standstill on traction tracks and at points of turnover of locomotive crews. The analysis of existing methods of control of electric power consumption by electric rolling stock on traction tracks of locomotive depots is performed. The considered manual control method has the following disadvantages: the lack of completeness, timeliness and reliability of data on electricity consumption. The second method, which consists in installing measuring systems on the feeders of traction tracks, has the following disadvantages: it does not allow automated metering and rationing of electricity with details on the operations performed (shunting movements, heating of electric locomotives), drivers, series of electric rolling stock, as well as legitimately attributing unproductive electricity consumption and damage from it to the involved structures (Traction Directorate, Directorate for repair of rolling stock, LLC “STM-Service”, LLC “TMH-Service”, Directorate of motor car rolling stock). The third method, which consists in installing a low-voltage power supply device on traction tracks, is not applicable when operating electric locomotives at low temperatures, since in this case it is necessary to warm up powerful consumers, such as liquid pumps, oil pumps, motor-compressors, motor-fans, etc.; most of the electric rolling stock is not equipped with specialized sockets for connecting a low-voltage power supply device, which limits the serial implementation of this device. An alternative system of control of electricity consumption by electric rolling stock traction on the tracks of the locomotive depot was developed, which has the following advantages: implementation of automated metering and rationing of electricity with details on performed operations (shunting moving, heating of electric locomotives), drivers, series of electric rolling stock; improving the reliability of electricity metering; implementation of the possibility of attributing unproductive power consumption and damage from it to the involved structures (Traction Directorate, Directorate for repair of rolling stock, LLC “STM-Service”, LLC “TMH-Service”, Directorate of motor car rolling stock); elimination of the need for additional research for new series of electric rolling stock being put into operation; development of scientifically-based measures to reduce power consumption.

1. Introduction
One of the priority tasks of the Russian Railways holding is to improve energy efficiency indicators in all areas of the company’s activities (train traction, infrastructure, repair, production). One of the most
energy-intensive activities of the company is train traction, which accounts for about 85% of the total electricity consumption of JSC “Russian Railways”. Electricity costs for train traction account for 51.3% of all expenses in the structure of expenses of the Traction Directorate [1].

In the future, based on the data of the Energy strategy of JSC “Russian Railways” for the period up to 2020 and for the future up to 2030, the reduction in the specific electricity consumption for train traction to the level of 2015 should be from 2.5 to 4.4% by 2020, and from 8.0 to 9.0% by 2030 (figure 1).

It is possible to achieve the planned level of reducing the specific consumption of electricity for train traction, in particular, by reducing the unproductive consumption of electricity by electric rolling stock of railways during their standstill on traction tracks of locomotive depots and at the points of turnover of locomotive crews.

To solve this problem the following tasks are set in the paper:
1. To analyze the causes of unproductive power consumption by electric rolling stock on traction tracks and at points of turnover of locomotive crews.
2. To analyze the advantages and disadvantages of existing methods of control and management of electric power consumption by electric rolling stock within the boundaries of traction tracks of locomotive depots and points of turnover of locomotive crews.
3. To develop a new technology for control and management of electric power consumption by electric rolling stock of railways on the traction tracks of locomotive depots and at the points of turnover of locomotive crews, based on the use of data from automated electric power metering systems for traction rolling stock, equipped with a global positioning systems and wireless data transmission.

Figure 1. Forecast of changes in the specific electricity consumption for train traction in JSC “Russian Railways” for the period up to 2020 and for the future up to 2030.

Analysis of reported data on unproductive consumption of electricity by electric rolling stock of railways at their standstill (“hot” idle) on the traction tracks of locomotive depots and at the points of turnover of locomotive crews showed that in recent years there has been a systematic reduction in these losses of electricity. This fact indicates the effectiveness of measures taken by the Traction Directorate to reduce this type of loss, however, it is also worth noting that recently there has been a
decrease in the rate of loss reduction, which indicates the need to develop fundamentally new measures [10].

Data analysis (figure 2) showed that one of the main reasons for inefficient energy consumption of electric locomotives during their standstill on the traction tracks of locomotive depots and at the points of turnover of locomotive crews is the maintenance of an excess fleet of electric locomotives. Thus, according to figure 2, it can be concluded that freight locomotives are in operation only one third of the time of day, the remaining time is in standby mode.

Under the current budget figures of time of freight locomotives need extraordinary ability of the employees involved in the depot to execute the order of JSC “Russian Railways” dated 04.07.2012 No 1327p “About introduction in action of Provisions of the control organization of regime of working time and rest time of locomotive crews, ensuring accurate records of their work” [1, 3].

There is an increase in the time of unproductive standstill allocated for the acceptance and delivery of electric locomotives in accordance with the order of 19.12.2012 No 262p “On approval of the technological instructions for Maintenance of electric locomotives and locomotives”. In this regard, it is necessary to conduct additional technical training with locomotive crews [1, 4].

Taking into account the above, it should be noted that in general for JSC “Russian Railways” is a topical issue of developing a methodology for technical analysis that regulates the timely adjustment of the fleet, both on the quantitative basis of the size of the actual volume of transportation work, and on the qualitative basis of the deterioration of the energy efficiency of its electric locomotives.

In the conditions of increasing unproductive standstill of electric locomotives in operation, a significant way to increase their energy performance is to disconnect the current collector from the contact network of electric locomotives. A significant help in the implementation of this technology is the “Instructions for heating electric locomotives at standstill on the traction tracks of locomotive depots and turnover points”, introduced by the order of JSC “Russian Railways” from 05.03.2013 No CT-36/p [1, 5].

The reference point for improving the energy efficiency of electric locomotives is the “Norms of electric energy consumption for electric locomotives that are in standby mode, maintenance and repair” introduced by the decree of JSC “Russian Railways” dated 29.08.2014 No 2032/p [1, 6].

The experience of using the instructions for heating electric locomotives during their standstill on the traction tracks of locomotive depots and turnover points has shown that its regulations contain mainly recommendations aimed at ensuring the operability of electrical components and parts of electric locomotives [2]. In this regard, in order to reduce non-productive losses of electricity, the issue of developing mode maps for heating electric locomotives is relevant for JSC “Russian Railways”.

![Figure 2. The dynamics of the time budget of freight electric locomotives.](image-url)
However, it is impossible to solve these problems without creating a system of control and management of electric power consumption by electric rolling stock of railways on the traction tracks of locomotive depots and at the points of turnover of locomotive crews.

In order to formulate the concept of such a system, it is necessary to analyze the existing methods of control and management of electricity consumption.

2. Object and methods of research

Currently, the metering and control of electricity consumption during “hot” idle of locomotives in standby mode without locomotive crew is organized in accordance with regulatory documents of JSC “Russian Railways” [5, 6] mentioned earlier, as well as guidance on filling out registration forms THU-3 “Statements of metering of diesel fuel and electricity on the locomotives and on motor car rolling stock” (approved by order of JSC “Russian Railways” from 28.12.2012 No 2723p) [7] and regulation on the procedure of interaction of the locomotive depot repair and operational locomotive depot (approved by order of JSC “Russian Railways” from 29.12.2012 № 2763p) [8].

In accordance with these normative documents, metering and control of electric power during electric locomotives’ standstill on the traction tracks of locomotive depots and at points of turnover of locomotive crews is carried out by recording by driver-“heater” the corresponding readings of electric energy meters in the reports of THU-3 and transmitting it for further processing in the center of operational and technical accounting of JSC “Russian Railways” (figure 3).

In this case, the head of this center is responsible for the completeness, timeliness and reliability of entering data in the THU-3 statement [11].

Figure 3. “Manual” method of control and management of electric power consumption by electric rolling stock within the boundaries of traction tracks of locomotive depots and points of turnover of locomotive crews.

In such an organization of metering and control of electricity consumption on the traction tracks of locomotive depots and at points of turnover of locomotive crews, there is a lack of completeness, timeliness and reliability of data on electricity consumption, despite the responsibility assigned to the head of the center for operational and technical metering.
It should also be noted that the electric rolling stock of direct and alternating current of JSC “Russian Railways”, mainly old series, has electricity metering devices that have a low accuracy class and a high sensitivity threshold, which leads to an underestimation of electricity consumption when operating electric rolling stock in low-load mode when working on traction tracks of locomotive depots and at points of turnover of locomotive crews.

As shown by experimental studies performed on one of the railways JSC “Russian Railways” in 2015, the value of under-metering of electricity within the boundaries of traction tracks and points of turnover of locomotive crews reaches 2.8% of the total energy consumption for traction substations [11].

In 2012, specialists of the electrification service and the fuel and energy center of the Sverdlovsk road analyzed the use of traction tracks by operational and repair locomotive depots located within the borders of the road. The ways that are constantly used for standstill of electric locomotives, that are in standby mode, in repair and maintenance are identified. A survey of the identified areas of standstill was conducted and the technical possibility of partitioning the contact network for the installation of metering devices for electricity consumed by such electric locomotives was determined. Together with LLC “Horizont”, direct current power metering system was developed that allows its installation on contact network supports [9].

In the same year, for the first time on the Russian railway network, a sample of “Set of equipment for metering of electricity consumption on traction tracks” was installed and put into trial operation at Yekaterinburg-Sortirovochny station. It is intended for metering of the electric power consumed by electric locomotives and motor car rolling stock, which are in standby mode, during repair and maintenance, are in a standstill mode of “hot” condition (with raised current collectors) on traction (depot) tracks electrified at a direct current [9].

The set allows measuring the current parameters (current, voltage, power) of the contact network sections that feed the traction rolling stock located on the traction tracks, and transmitting the received information to a remote registration system via a GSM cellular communication channel directly to the fuel and energy center of the road [9].

The metering set includes cabinets for high-voltage and low-voltage equipment. For electricity metering, a DC meter of the SKVT-M type is used. The design of the set is convenient for installation: it can be attached both to the support of the contact network, and to cabinets intended for the equipment of heating points of cars. The set is connected to the contact network via two disconnectors of the RKS-3.3/4000 type (figure 4) [9].

![Figure 4. Set of equipment for metering of electricity consumption on the traction paths.](image)
However, this method does not allow automated metering and rationing of electricity with details on the operations performed (shunting, heating of electric locomotives), drivers, series of electric rolling stock, as well as legitimately attributing unproductive electricity consumption and damage from it to the involved structures (Traction Directorate, Directorate for repair of rolling stock, LLC “STM-Service”, LLC “TMH-Service”, Directorate of motor car rolling stock) [11].

Taking into account the appearance of a new generation of electric rolling stock, there are opportunities to reduce the consumption of electricity for hot standstill. Thus, the EP20 dual-power electric locomotive is equipped with sockets and the necessary switching and protective equipment to supply AC voltage of 3×380 V, 50 Hz to the low-voltage part of the system for its own needs, which is necessary to power the microclimate system, as well as heating devices for traction equipment and radio stations at air temperatures below 25°C. With this method of organizing the electric locomotive’s power supply during standstill in standby mode (in contrast to power from the contact network), the power consumption for the operation of sufficiently powerful consumers, such as liquid pumps, oil pumps, motor-compressors, motor-fans, etc. is excluded [12].

The sequence of actions when carrying hot standstill EP20 electric locomotive powered from a low voltage source (figure 5) is defined by the “Instruction on transfer of the EP20 electric locomotive in the mode of warming up of equipment and control of equipment in heating mode”. Voltage supply is performed when the main and high-speed switches are switched off, current collectors are lowered, panels and doors of cabinets with high-voltage equipment are blocked [12].

In September 2016, measurements were made at the Moscow-Sortirovchnaya-Ryazan operational locomotive depot of electric power consumption when feeding the EP20 electric locomotive in hot standstill mode from the 3 kV DC contact network and from the low-voltage AC network. When connected to the contact network, electricity consumption is recorded according to the data of the on-board system of the locomotive (RPDA); when connected to a low-voltage source-using the “Micron” power meter PSCH-3TM.05b.01. The operating time when powered from the contact network and from a low-voltage source was one hour, the outdoor temperature was 16.8°C. When connecting the contact network, the power consumption for one hour of hot standstill was 61 kW·h, and when connecting to a low-voltage source - 3.17 kW·h. Thus, it is possible to reduce the power consumption for the hot standstill of the EP20 electric locomotive by 19 times. Such savings are possible at outdoor temperatures of at least -25°C [12].

![Low-voltage power supply device on traction tracks.](image)

However, this method of metering and control of electricity consumption at all its advantages has a number of disadvantages: not applicable when operating EP20 at low temperatures, as in this case,
heating of powerful consumers, such as liquid pumps, oil pumps, motor-compressors, motor fans, etc. is needed; a large part of the electric rolling stock is not equipped with specialized sockets for connecting devices low-voltage power supply, which limits the serial implementation of this device.

In this regard, the issue of developing a new technology for control and management of electric power consumption by electric rolling stock of railways on the traction tracks of locomotive depots and at the points of turnover of locomotive crews, in which the above disadvantages are completely absent, is relevant. This technology should be based on the use of automated power metering systems for traction rolling stock, equipped with a global positioning system and wireless data transmission.

3. Results

The system for control and management of electric power consumption by electric rolling stock within the boundaries of traction tracks of locomotive depots and points of turnover of locomotive crews includes an automated measuring system on the electric rolling stock, as well as a stationary part consisting of data reception points from the electric rolling stock and a single data processing server (figure 6) [13, 14].

Information from automated metering systems of electric rolling stock is sent to a single data processing server via data reception points via wireless communication. The accumulated data is transmitted from the board of an electric rolling stock when the rolling stock enters the coverage area of the receiving point. The point of reception of data may be located in the maintenance and repair locomotive depot or at the stations. The metering system on an electric rolling stock includes modules for metering electrical quantities, a satellite navigation module (GPS/GLONASS), a hub, and a wireless communication module [13].

Automated metering system for electric rolling forms a data array in which each moment of time $t_i$, recorded with some constant interval $\Delta t$, corresponds to the value of the consumption $E_{ri}$ and return $E_{p_i}$ electricity by electric rolling stock, instantaneous value of the voltage $U_{ri}$ on the current collector and the electric locomotive current $I_{ri}$, and its geographic coordinates: latitude $\phi_i$ and longitude $\lambda_i$, where $i$ - is the interval number [13]. The resulting array can be represented as table 1.

| Point for receiving data from the ERS board | Single data processing server | Point for receiving data from the ERS board |
|-------------------------------------------|---------------------------------|-------------------------------------------|
| Coverage area of the receiving point | ERS 1 ERS 2 | Coverage area of the receiving point |
| ERS 3 ERS 4 | ERS 5 | ERS outside the coverage area of the data receiving point |

![Figure 6. Simplified concept of a system for control and management electric power consumption by electric rolling stock within the boundaries of traction tracks of locomotive depots and points of turnover of locomotive crews.](image-url)
Table 1. Array of data recorded by the metering system on an electric rolling stock.

| Moment of time, t | Readings of electricity consumption meters, $E_T$ | Readings of metering devices of electricity return, $E_{\text{P}}$ | Instantaneous value of the current collector voltage, $U$ | Electric locomotive current, $I$ | Geographic coordinates of the track’s point (latitude – $\phi$, longitude – $\lambda$) |
|------------------|---------------------------------|-----------------------------|---------------------------------|-----------------------------|---------------------------------|
| $t_0$            | $E_{T0}$                         | $E_{P0}$                     | $U_0$                           | $I_0$                       | $\phi_0$; $\lambda_0$          |
| $t_1$            | $E_{T1}$                         | $E_{P1}$                     | $U_1$                           | $I_1$                       | $\phi_1$; $\lambda_1$          |
| $t_2$            | $E_{T2}$                         | $E_{P2}$                     | $U_2$                           | $I_2$                       | $\phi_2$; $\lambda_2$          |
| $t_3$            | $E_{T3}$                         | $E_{P3}$                     | $U_3$                           | $I_3$                       | $\phi_3$; $\lambda_3$          |
| $t_4$            | $E_{T4}$                         | $E_{P4}$                     | $U_4$                           | $I_4$                       | $\phi_4$; $\lambda_4$          |
| $t_5$            | $E_{T5}$                         | $E_{P5}$                     | $U_5$                           | $I_5$                       | $\phi_5$; $\lambda_5$          |
| $t_6$            | $E_{T6}$                         | $E_{P6}$                     | $U_6$                           | $I_6$                       | $\phi_6$; $\lambda_6$          |
| $t_7$            | $E_{T7}$                         | $E_{P7}$                     | $U_7$                           | $I_7$                       | $\phi_7$; $\lambda_7$          |
| $t_8$            | $E_{T8}$                         | $E_{P8}$                     | $U_8$                           | $I_8$                       | $\phi_8$; $\lambda_8$          |
| $t_9$            | $E_{T9}$                         | $E_{P9}$                     | $U_9$                           | $I_9$                       | $\phi_9$; $\lambda_9$          |
| $t_{10}$         | $E_{T10}$                        | $E_{P10}$                    | $U_{10}$                        | $I_{10}$                    | $\phi_{10}$; $\lambda_{10}$    |
| …               | …                               | …                            | …                               | …                           | …                               |
| $t_i$            | $E_{T_i}$                        | $E_{P_i}$                    | $U_i$                           | $I_i$                       | $\phi_i$; $\lambda_i$          |
| …               | …                               | …                            | …                               | …                           | …                               |
| $t_K$            | $E_{TK}$                         | $E_{PK}$                     | $U_K$                           | $I_K$                       | $\phi_K$; $\lambda_K$          |

The recorded data is stored in the memory of the metering system and automatically transmitted over the radio channel to the server for collecting and processing information every time a radio transmitter installed on an electric rolling stock enters the coverage area of a special radio point [13].

On the server for collecting and processing information using a single software package, the calculation of electric energy consumption within the boundaries of traction tracks of locomotive depots and points of turnover of locomotive crews is performed using the algorithm shown below (figure 7).

The algorithm for data processing in order to identify the moments of entry and exit to the traction tracks of the depot and calculate unproductive losses during “hot” standstill is shown in figure 7.

The algorithm body can be nominally divided into three functional blocks.

In block 1, input data is entered (measurement interval $\Delta t$, ERS series, ERS number, date, coordinates of traction tracks and set the start time of the trip ($t_0$), the initial values of the actual flow rate in traction mode ($W_{\text{at}}$), return in recovery mode ($W_{\text{ap}}$) and the initial value of the location of the electric rolling stock ($\phi_0$; $\lambda_0$), which corresponds to the coordinate of the control post [13].

Block 2 defines the moments when electric rolling stock is located on the tracks of operational and repair locomotive depots or turnover points.

The actual coordinate is analyzed at every $i$-th moment of time. In this case, the moments when it corresponds to the values of coordinates, tracks of operational and repair locomotive depots or turnover points are considered to be the moments when the electric rolling stock is located in these metering zones. When the values of the actual coordinate do not match the values of the coordinates of these metering zones, the total unproductive expenditure is calculated for the same type of operations, as well as checking that the electricity consumption norms are met.
In block 3, the status code change is checked. If the status code does not change, it returns to block 1. Otherwise, the actual expense and standstill for performing an operation that corresponds to a specific status code is calculated. Next, the transition to the next status code is performed, and the above process is repeated.

The developed method takes into account the provisions of the current instructions of JSC “Russian Railways” [5], which regulate the heating of electric locomotives during standstill on the traction tracks of locomotive depots and turnover points.

Advantages of the proposed system of control and management of electricity consumption within the boundaries of traction tracks of locomotive depots and turnover points:

- implementation of automated metering and rationing of electricity with details on the operations performed (shunting, heating of electric locomotives), drivers, series of electric rolling stock;
- improving the reliability of electricity metering;

**Figure 7.** Algorithm for control and management of electric power consumption by electric rolling stock within the boundaries of traction tracks of locomotive depots and turnover points, with a division by operations performed by different drivers.
4. Conclusions

1. Data analysis time budget of freight locomotives showed that one of the main reasons of inefficient energy consumption of the electric rolling stock during standstill on the traction tracks of locomotive depots and at points of turnover of locomotive crews is content in excess of operation of electric locomotives fleet, so in general for JSC “Russian Railways” is a topical issue of development of methods of technical analysis governing the timely adjustment of the fleet, as on the quantity of matching size to the actual volume of transportation work, so and on a qualitative basis of deterioration of energy efficiency of its electric locomotives;

2. Experience of the applying the manual of heating of electric locomotives during standstill on the traction tracks of locomotive depot and turnover points showed that its regulations contain mostly recommendations aimed to ensure the operability of the conductive components and parts of locomotives, so with the aim of reducing unproductive losses of electricity, the issue of developing mode maps for heating electric locomotives is relevant for JSC “Russian Railways”;

3. In the case of manual control and management of electricity consumption on the traction tracks of locomotive depots and at the points of turnover of locomotive crews, there is a lack of completeness, timeliness and reliability of data on electricity consumption, despite the responsibility assigned to the head of the operational and technical metering center.

4. Method of control and management based on data from a set of equipment for metering of the electricity consumption on traction tracks of the Sverdlovsk railway and LLC “Horizont” does not allow automated metering and rationing of electricity with details on the operations performed (shunting, heating of electric locomotives), drivers, series of electric locomotives, as well as legally attributing unproductive electricity consumption and damage from it to the involved structures (Traction Directorate, Directorate for repair of rolling stock, LLC “STM-Service”, LLC “TMH-Service”, Directorate of motor car rolling stock).

5. Method of control based on device data of the low-voltage power supply for metering of electricity for traction tracks of the Moscow railway has a number of disadvantages: not applicable when operating EP20 at low temperatures, as in this case, the necessary heating of powerful consumers, such as liquid pumps, oil pumps, motor-compressors, motor fans etc.; most of the electric rolling stock is not equipped with specialized sockets for connecting a low-voltage power supply device, which limits the serial implementation of this device.

6. Developed technology has a number of advantages over existing ones:

- implementation of automated metering and rationing of electricity with details on the operations performed (shunting, heating of electric locomotives), drivers, series of electric rolling stock;
- improving the reliability of electricity metering;
- implementation of the possibility of attributing unproductive power consumption and damage from it to the involved structures (Traction Directorate, Directorate for repair of rolling stock, LLC “STM-Service”, LLC “TMH-Service”, Directorate of motor car rolling stock);
- eliminating the need for additional research for new series of electric rolling stock being put into operation;
- development of science-based measures to reduce energy consumption.
7. Developed technology is proposed to be implemented on the entire railway network of JSC “Russian Railways”. It is proposed to test this technology on the traction tracks of the “Moskovka” service locomotive depot in Omsk.

In conclusion, it should be noted that the implementation of these tasks in practice will reduce the unproductive power consumption of electric rolling stock of railways during standstill on traction tracks and at points of turnover of locomotive crews, which is essential for the development of the Russian Federation.

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