Intellectual monitoring and planning system of energy efficiency indices of the traction power supply system

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Abstract. The actuality of questions of energy saving in the traction power supply doesn’t give rise to doubts. At the same time in such complex composition as the traction power supply system, taking into account its cooperation with the electric rolling stock, questions solving of the energy efficiency increase must be accompanied by a complex efficiency assessment of the proposed activities. The technical and organizational arrangements implementing with this purpose in mind must not just secure the decline of the power intensity level of the vehicular process, but allow securing this vehicular process in the requisite volumes with excellent prospects at the moment and also be economically expedient. At present no such technologies and especially software tools exist which allow estimating and predicting the alteration of the energy efficiency indices of trains’ traction regarding the current values by change of the engineering parameters of the traction power supply system and the operating data of the railways’ areas. In this article a creation necessity of an intelligent monitoring system and an indices programming of the traction power supply system is justified, allowing determining the influence grade on the basic energy efficiency indices of the operational factors and the characteristics of the traction power supply system and to determine the optimal combination of these factors and characteristic for the justified changes planning of the traction power supply system characteristics and the improvement of the operational indices of trains’ traction in the view of the achievement of the maximal energy efficiency. The architecture of such a system is described. The tasks which solution allows practically realizing and implementing in maintenance the proposed elaborating are formed.

1. Introduction
Of 85.5 thousand km of general operational length of the railways in JSC «Russian Railways» the electrified lines amount 43.6 thousand km. It is the second index in the world after China. The maintenance costs in JSC «Russian Railways» are about 10 % of total company consumption; it is around 170 billion rubles per year. And in the general structure of power consumption, electric energy consumption on trains’ traction is around 58 %. That is why almost any actual working energy-saving production, which is realized in the company scales, can bring saving measuring by billions of rubles and that is why it can be actual and significant.

According to the Long-term development program of JSC «Russian Railways» in the field of foreground technologies which possess the highest integrated assessment of potential influence on the level of holding-company competitiveness, there are such technologies as:
– automated systems of administrative decisions support and planning of engineering infrastructure and rolling stock upkeep;
– intelligent systems using the «Internet of Things» in monitoring processes of infrastructure condition;
– simulation modeling technologies of the rolling stock and infrastructure interaction;
– systems of the digital simulation modeling which optimize the traffic processes of the rolling stock by means of using the algorithm of “Big Data” handling;
– intelligent-adaptive systems of planning, normalization, accountability, and promotion of fuel and energy resources consumption saving.

Priority of listed technologies is not random. In the modern world, information and skill to operate with it play a growing role. The processes monitoring of the power consumption in the traction power supply system, like any other monitoring, imply the permanent processes observations – acquisition, holding, and analysis of information, which organize the huge data sets in the course of time. Work with such data sets is compound by itself, and it is being extra complicated by the necessity of having the scientifically substantiated algorithms of their handling and receiving from them adequate for the interpretation of analytical information about the object condition [1]. For example, it isn’t enough to have an equipped by diagnostic transmitters electric train, in order to predict its conditions before rejection or level of the energy efficiency. It isn’t also enough to have a system of control and accounting of electric energy consumption even with the synchronous measurements on the traction substations and the rolling stock with minimal potential measurement resolution in order to conclude the level of the system energy efficiency.

The organized for today control and accounting of energy consumption on trains’ traction on the ways network of JSC «Russian Railways» including the most modern «Analytical assessment and control system of the level of the electric energy imbalance and the automated assessment of the electric energy specific consumption of the electric rolling stock on the Moscow central ring» can’t be considered as the full monitoring systems which are agreeable to the standards to intelligent systems. The active systems don’t have in itself the functions of the processes analysis giving the full picture of the energy flux-distribution in the traction power supply system and don’t answer the question about the energy efficiency level of an area work subject to the aggregate of active factors. So for such detailed processes analysis of energy consumption on the Moscow central ring with the purpose of the potential determination of the energy efficiency increase we had to do enough serious scientific researches on basis of the data mentioned in the analytical system [2]. At the same time, most of existent railways areas of JSC «Russian Railways» are not equipped with such systems of synchronous measurements on the traction substations and the rolling stock. The energy efficiency analysis in such areas is an even more complex and labor-consuming task.

The planning of the power consumption level on trains’ traction in JSC «Russian Railways» is closely allied with the question of normalization of power inputs and regeneration. It is performed, as a rule, on basis of regression dependences of the power consumption unit quantities and the regeneration from the train weight and other factors determining as a result of statistical data manipulation of driver paths and other reporting. On this approach, a row of methods is based on applying in JSC «Russian Railways» An imperfection of such approach is apparent – the source data limitation which served for the creation of values calculating access (let’s look at this in detail by describing the object and methods of research). Another alternative of the analysis and planning of fuel and energy resources which is used in JSC «Russian Railways», is based on the equation differentiation of the trains traffic, as for example, it is realized in the method of consumption analysis and prediction of fuel and energy resources on trains’ traction, approved by JSC «Russian Railways» in 2014, and the methods generated from it. It is obvious that the train traffic equation and its derivatives describe the trains’ traffic, but not the operation of an electrified area together with the traction power supply system and that is why this method is applicable for the analysis of the fuel and energy resources consumption by the counters of the electric rolling stock and isn’t applicable for the assessment of the integrated indices by power supply of the area in whole.

The automated information system of energy-saving and the increase of energy efficiency of JSC «Russian Railways» (AIS «Energy efficiency») in the part of trains traction doesn’t solve the tasks neither automated monitoring nor automated planning of the trains traction energy efficiency it is
automated only in the part of the information exchange, the accounting and the assessment of the implementation of the tasks of the energy-saving by separate structural units. And the forming of energy-saving plans and the efficiency assessment of already implemented technologies are performed by users manually. This information is registered also manually in the accounting forms of the AIS «Energy efficiency».

At the same time in 2016 in Omsk state transport university, a method of the efficiency assessment of the regeneration energy was developed, and in JSC «Russian Railways» it was accepted and asserted. This method is based on application of the regression empirical equation, which is obtained by the results of the calculated accesses analysis, compiled on basis of the simulation modeling of work of the electrified railways’ areas with variant characteristics.

The fundamentals, calculated expressions, and algorithms of this method are assumed as a basis of the intelligent system concept of the regenerative braking control and the regeneration energy use [3]. These works can be a prototype of more difficult development, namely the intelligent monitoring system and the energy efficiency planning of the traction power supply work.

The purpose of this article is the substantiation of the creation relevance of a system exactly like this (intelligent) and the formation of the tasks which are necessary for its creation. The intelligent system becomes indispensable, taking into account the requirements and outlooks of the Long-term holding company development program as well as taking into account:

– considering object structure difficulties (the traction power supply systems in interaction with the electric rolling stock);
– imminences of the work with the big data arrays;
– realization necessities of the optimal solutions search algorithms.

Creation of such intelligent system which is based on the analysis of the big calculated data arrays of simulation modeling and the accounting statistical data allows receiving an implement for automated monitoring and planning if the energy efficiency indices of the traction power supply system for increase of trains’ traction energy efficiency [4 – 7]. Such a system for its own users becomes inherently an automated system of the management decision-making and the parameters planning of the vehicular process, the technical content of the traction power supply system, and the rolling stock.

2. Object and methods of research

It is necessary to understand that the energy efficiency increase of trains’ traction is a complex and multilevel task. In trains’ traction production process the different engineering devices, the technological processes, organizational arrangements, and external factors are enabled and influence its efficiency. All that is the closely coupled and interacted elements of a complex structure which provides the vehicular process with the traction vehicle. The final energy efficiency of trains’ traction forms from the energy efficiency of the separate supplying it and the closely coupled composite elements:

– traction substations;
– traction network;
– electric rolling stock and its modes of operation;
– non-traction rolling stock;
– track profile;
– organization of trains traffic;
– weather conditions in the area.

At the same time, the energy efficiency assessment of trains’ traction must be complex and directed the integrated indices. For the electric rolling stock the electric energy specific consumption is such index after deduction of the specific regeneration. For the energy efficiency of trains’ traction characteristic on the area in whole, the optimal index is the electric energy specific consumption releasing on trains’ traction by traction substations counters which characterizes the vehicle process power intensity taking into account all the engineering and commercial components of the energy balance. However, the given index calculated on basis of the accounting information doesn’t give the answer about the energy efficiency level and the potential of its improvement.
At the same time, the above mentioned Long-term development program of JSC «Russian Railways» demands the annual reduction of the production process power intensity level of trains' traction, namely the reduction of the specific energy consumption on trains’ traction. Besides the plans of traffic volume increase are also clearly defined at the expense of the vehicle process main indices improvement, such as the areas bandwidth [8], the number of heavy and double trains, and the implementation of high-speed traffic and other. The achievement ways of these improvements are numerous and reduce to the traction power supply amplification [9], the renovation of the electric rolling stock fleet, the alteration of the trains’ traffic organization, and the trains driving modes. However, for the implementation of the plan of the traffic volumes increase with the parallel power intensity reduction of trains’ traction energy supply process it is necessary that every step on the way to these volumes increase is accompanied with the change assessment in the level of energy efficiency and the searching of the optimal solutions in the view of achievement of the maximum possible value of its indices. That means that by making a decision about the increase of one of the planned indices it is necessary to orientate also on its interaction with the other indices and project parallel the change of the other so that on the output to get the highest efficiency by the integral indices including the energy efficiency criterion.

For this realization we need:
– first, to organize the qualitative monitoring of the power consumption processes in the traction power supply system;
– second, to organize the automated intelligent analysis of the monitoring results;
– third, to organize the system of the energy efficiency intelligent planning which could help to make justified changes in the characteristics and work parameters of separate railways areas and the specific locomotive sheds for the purpose of the planned achievement of the placed landmarks [10].

The organization methods of the research work for the purpose of the creation of such a complex system are the following:
– «global» monitoring of the power consumption of an area with the equipping of all attachments of the traction power supply system of the area of the unified automated system of the electric energy accounting [11] and the equipment of the all-electric rolling stock, working on the area, with salaried high-precision automated systems of the electric energy accounting and the systems of global positioning GPS/GLONASS, connecting to the unified server;
– «local» experiment, by which a railway area is equipped by systems of the electric energy accounting on the contact network feeders of the traction substations and some electric locomotives are equipped by specific fixation system of the electric energy consumption and the location with the information transfer to the unified server, a special trains traffic schedule and special traction network power circuits are organized. This method allows gathering the necessary amount of information about the power consumption processes on the area and creating on its base the mathematical models for further modeling and power consumption analysis;
– statistical methods of the regression dependences patterning by the railways accounting data [12 – 14];
– methods of the simulation modeling of the trains traction energy supply processes for the purpose of the creation of calculated accesses of maximal sizes including all possible combination variants of all necessary for the accounting factors.

Any the largest bank of statistical accounting information from the systems of control, accounting, and monitoring on the area doesn’t allow organizing an accesses on which base it would be possible to create the empirical expressions fully describing the values interactions of different factors and the values of the energy efficiency indices. As any such access and the received with its help expressions will be limited by that range of factors and parameter values which we could observe during the controlled period. This makes difficulties by the system efficiency assessment in case of alteration in it exceeding the limits of values analyzed previously. For example, if on any railways the trains with the weight of 9000 t have never exploiting area and the average technical speed have never had the values of km/h and more than it will be problematically to predict the energy efficiency level by these serious changes on basis of the expressions which are received with the help of parameters values access for the
previous periods. Thereupon the methods of simulation modeling give a wide space for the detailed energy consumption systems analysis on the calculated areas.

As the statistical and mathematical manipulations for the comprehensive analysis of the object of research (interaction systems of the traction power supply system and the electric rolling stock) and the data abstract for the purpose of the solving of marked problems it is assumed to use the following: the simulation modeling, the correlation analysis, the synthetic neural networks, the graphs’ theory, the methods and means of work with «Big Data», the artificial intelligence and other.

3. Results

As it was justified above the offering intelligent system must be based on the maximal use of the simulation modeling methods of the energy supply processes accompanying them the mathematical manipulations and solve the two main tasks:

first, the qualitative monitoring of the power consumption processes including the control, the accounting, the analysis of the power consumption processes and the energy efficiency level;

second, the planning on basis of the deep analysis by results of performed monitoring.

In figure 1 a fundamental architecture configuration of the intelligent monitoring and planning system of the energy efficiency indices of the traction power supply system is shown (IMPS TPSS).

In the left part of the configuration in figure 1 a simplified interface structure of the automated workplace (AW) of the IMPS of the TPSS is shown, interacting with whom the user can solve the two tasks given above.

![Figure 1. The fundamental architecture configuration of the intelligent monitoring and planning system of the energy efficiency indices of the traction power supply system.](image)

The first task (the energy efficiency monitoring) is solved by the overhead circuit (see figure 1) in several steps:

1) the user of the AW of the IMPS of the TPSS chooses the necessary area and the calculation period for the analysis;

2) the IMPS of the TPSS forms a request of the necessary accounting data of the calculation period for the calculation on servers of the informational calculating centers (ICC) of JSC «Russian Railways»;

3) the necessary data of the calculation period for the calculation from the corresponding electronic accounting forms holding in the DPC, are downloaded in the IMPS of the TPSS;
4) the IMPS of the TPSS performs the calculation of the actual indices values of the chosen period, estimates the energy efficiency level about the potential by the actual conditions;
5) the IMPS of the TPSS determines the changes list to the parameters and characteristics for the indices improvement and the achievement of the energy efficiency accounting level;
6) in the AW of the IMPS of the TPSS the information about the actual energy efficiency level, the potential of its increase and also recommendation and proposals for the potential achievement with the assessment of the prognosis changes of the energy efficiency indices is derived;
7) the user of the AW of the IMPS of the TPSS makes a decision of the energy supply optimization of trains’ traction on the area by the existing vehicle process indices level (traffic sizes, weight norms, trains traffic speeds and other).

The second task is the energy efficiency planning of the chosen area for the perspective taking into account the plans of indices improvement of the vehicular processes and the rated (intelligent) changes in the area parameters and also with the list determination of the inviolable or undesirable to the change area parameters. This task is solving by the lower circuit (see figure 1) in the following sequence:
1) the user of the AW of the IMPS of the TPSS chooses the necessary for the analysis area, the calculation period and the perspective, specifies the planned indices of the vehicular process, denotes the project changes in the area parameters (in the presence of them) and the inviolable (or undesirable to the change) area parameters;
2) the IMPS of the TPSS forms a request of the necessary for the calculations accounting data for the previous period which is similar to the perspective on servers of the informational calculating centers (ICC) of JSC «Russian Railways»;
3) the necessity for the data of the calculation for the previous period from the corresponding electronic account forms keeping in the ICC, are download in the IMPS of the TPSS;
4) the IMPS of the TPSS does the compatibility checking of the planned parameters (specified by user) and the indices with the other (unspecified) active areas parameters;
5) the IMPS of the TPSS performs a calculation of the planned energy efficiency indices by saving or the minimal changes of the unspecified by user area parameters;
6) the IMPS of the TPSS performs the selection of the optimal parameters combination and forming the variants of the alterations in the unspecified by user parameters and area characteristics;
7) in the AW of the IMPS of the TPSS the information about the prognostic level of the energy efficiency and the recommendation of its increase is derived;
8) the user of the AW of the IMPS of the TPSS makes a decision on the energy supply optimization of trains’ traction on the area for the prospective level of the vehicle process indices.

It is worth noting that in both variants of tasks choice the user of the AW of the IMPS of the TPSS makes a decision of the energy supply optimization of trains’ traction on the area by itself by the active or perspective vehicle process indices level orientating at the intelligent system recommendations inherently giving it support.

4. Discussion
As you can see from the above described the suggested system of the IMPS of the TPSS allows improving qualitatively the monitoring level of the power consumption processes in the traction power supply system. As the systems like analytical system using ob the Moscow central ring are extremely expensive and don’t have a widespread occurrence on the railways’ network, the suggesting development orienting at the work with the active accounting of JSC «Russian Railways» is actual and competitive.

The offering architecture of the IMPS of the TPSS on the condition of its qualitative realization allows performing the monitoring and the work planning of such complex structure which is the traction power supply system in the interaction with the electric rolling stock basing on the having available information without the areas equipping with the special accounting and the power consumption control systems.
This approach subject to the all analytical and mathematical developments which are necessary for its realization will be an innovative decision of trains’ traction energy efficiency increase as for the practical realization of such complex system lots of science-intensive works original approaches, courageous decisions which are tested and confirmed in practice will be necessary.

The creation purpose of the IMPS of the TPSS is the exploiting efficiency increase of railways’ traction power supply system at the expense of the intellectualization of the determination processes of the influence level of the exploiting factors, parameters and characteristics of the traction power supply system on the main energy efficiency indices and at the expense of these factors technologies creation of the optimal combination determination, the parameters and the characteristics for the justified changes planning of the traction power supply system characteristics and the improvement of trains’ traction energy efficiency indices.

For the achievement of the denoted purpose the solution of a group of tasks is necessary, to the main of them we can relate:

1) The creation of the simulation models of the railways electrified areas for the work modeling of the traction power supply system and the indices calculations of trains’ traction energy efficiency.

2) The implementation of the multivariate simulation modeling on basis of the created simulation models for the purpose of the receiving of the calculating data accesses about the dependences of trains’ traction energy efficiency indices from the combination of the influencing factors on the different-type railways areas (receiving of the calculating «basic» accesses of the big data – «Big Data»).

3) The analysis of the data «Big Data» of the calculating «basic» access by a method of the artificial neural networks or the regression analysis.

4) The determination of the empirical coefficients and the receiving of the mathematical expressions which are necessary for the calculation of trains’ traction energy efficiency indices depending on the values of the operational factors and the railways’ areas characteristics.

5) The method development of the automated determination and the analysis of trains’ traction energy efficiency indices on basis of the actual accounting values of the operating factors and the characteristics of the calculating areas which are received from the information-analytical systems of JSC «Russian Railways» by the empirical and mathematical expressions developed by the solving of task 4.

6) The algorithm development of the enhancement of the mathematical expression for the calculations of trains’ traction energy efficiency indices on basis of the calculating accesses actualization at the expense of their synthesis with the accounting information accesses receiving during the operation process of the considering area. Here an implication is that:
   - formation of the «working» access from the accounting operating data and its processing;
   - checking of the adequacy of the empirical coefficients and the mathematical expressions which are received by the processing of the calculating «basic» access;
   - checking of the uniformity and combining calculating «basic» access and «working» accounting access;
   - receiving of the final empirical coefficients and the mathematical expressions for the calculation of trains’ traction energy efficiency indices.

Something similar is described in the article [15]. Only in this case, it is supposed that the «working» access in the operation process of the IMPS of the TPSS on the area will be constantly complemented with the new data and the enumerated above points in the automated mode must repeat for the purpose of the constant generalized access actualization.

7) The development of the general operation algorithm of the intelligent monitoring system, the analysis, and the planning of the energy efficiency indices of railways’ traction power supply system.

After solving of the denoting tasks first directed at the organization of the energy efficiency indices monitoring at the expense of the operation realization of the principal circuit upper contour (see figure 1) for the capabilities realization estimating by the lower contour of the same circuit, the algorithm development of the optimal selection of the combination of the values of the separate elements of such
structure – the operating factors and the characteristics of the area for the further justified planning of their changes.

For these purposes, an adaptation of the «graphs theory» is supposed. So the all values of the operating factors and the characteristics of the area with the specified discontinuity can be represented as the peaks of the graphs array which arcs make the factors and the characteristics bonds realizing for the specified calculating conditions and the graphs show the all possible variants of the factors and the combination of the characteristics on the calculating area, their number is N, and correspond to the number of the possible variants of the operating factors and the combination of the characteristics. The search task of the optimal solution will be reduced to the performance of the automated calculations combination by the number N and the research among the received values the optimal values of the energy efficiency indices.

5. Conclusions

To sum the foregoing it is worth noting that the main results of this work are:

– formulated and justified purpose of the scientific researches and the creations directing at the increase of the traction power supply system efficiency at the expense of the creation and the implementation of the intelligent system of trains’ traction energy efficiency monitoring and planning;
– created principal architecture circuit of the future intelligent system which will fill with the content during the solution of the given tasks;
– formed list of the necessary for the solution tasks and subtasks.

The further researches add up to the performance of the sequence of the works which allows realizing the types of machinery which are laid in the architecture. That means that at the output it is necessary to get the finished conceptual and the functional platform for the soft realization of the IMPS of the TPSS. Within the framework of the work performance the all necessary algorithms, methods, empirical expressions, and the necessary coefficients for the soft realization of the proposed intelligent system must be developed and scientifically based. In conclusion, it is necessary to perform the assessment of the economic efficiency of the IMPS of the TPSS for JSC «Russian Railways» and the national economy in whole and to start the creation of the software embodying this idea in the practically available innovative technology which is convenient for users and contributes the improvement of trains’ traction energy efficiency indices.

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