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Optimization of Traction Power Supply System with Variation of Train Flow Sizes

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Abstract

Modern requirements for the operation of electrified railways are the efficient use of available technical means to ensure energy efficiency while increasing train traffic. The aim of the work is to substantiate the optimization of the structure of the DC traction power supply system with variation of train flows and traction loads. Such optimization should be performed after the reformatting of the train schedule and the subsequent impossibility of increasing the energy performance. The methodological basis for the optimization of the existing power supply system of the traction line is the use of a hybrid traction power supply system with an asymmetric arrangement of active generators.
KEY WORDS: *traction power system, train schedule, specific power, optimization of power supply of electric rolling stock*

1. Introduction

In modern conditions of railway transport operation it is important to increase the efficiency of the use of railway technical means and the quality of the organization of the transportation process. The choice of optimal train modes is one of the main tasks of railway transport. The problem of optimal train movement, first of all, is determined by the completeness of factors that characterize the section, the model of train movement, various factors and conditions of the process of train movement on a variable track profile, as well as the forces that arise [1].

Energy-efficient technologies for the implementation of the transport process primarily imply the introduction of rational forms of train schedules with optimal masses and intervals. Calculations show that optimizing the train schedule taking into account the existing tariff system can be found for the same freight flow option, in which electricity consumption will be lower, but in practice the actual change in train schedule may lead to different costs associated with increasing electric locomotive fleet, increasing the money spent on locomotive crews' salaries, etc. Increased traffic congestion on electrified railway sections leads to increased sensitivity of train schedules and to greater secondary delays that spread from train to train. The unevenness of the intensity of the train is explained by many factors. Objective reasons include track profile, differences in traction characteristics of different types of locomotives, distance between stations, etc. Subjective reasons are different qualifications of locomotive drivers, differences in the characteristics of locomotives of the same series, weather conditions.

The most significant external causes are fluctuations in the readiness interval for freight trains at stations, uneven timetables for passenger trains throughout the day, and "windows" for repair and track work. Changing the ratio of the proportion of trains of different types also affects the intensity of traffic, and therefore the interval between trains. All together the reasons for the unevenness of traffic intensity determine one of the properties of train movement - its uncertainty. Changing the position of trains while driving on a section is a stochastic process that is not the same in space and time.

Maintaining the optimal train density at the control station should be the primary task of managing the train operation and allow efficient use of the railway infrastructure and rolling stock capacity. It is necessary to take into account the real capacity of the electrified site.

The analysis of electricity consumption in recent years shows that the search for energy-saving technologies of the transport process on electrified lines should be conducted not only in the direction of the organization energy-efficient process of transportation but also by improving the electrical systems and their modes of operation. As a result of experimental studies, it was found that the voltage and power modes in the traction DC power supply system do not fully provide the necessary conditions for the introduction of high-speed or heavy traffic on existing lines, as packet trains have restrictions on voltage and specific power levels. Thus, there is a problem of optimizing the structure of the DC traction power supply system with variation of train flows and traction loads.

2. Methodology

The choice of optimal train modes is one of the main tasks of railway transport. The task of optimal train movement, first of all, is determined by the completeness of the set of factors that characterize the section, train model, various factors and conditions of the process of train movement on the variable track profile, as well as the forces that arise, etc. At some point, the increase in maximum capacity is achieved when the marginal increase in the operation of one additional train is lower than the cost of a longer trip time and increased sensitivity to delays. There is a conflict of interest between adding new routes to the train schedule to meet higher demand and maintain the quality of trains already scheduled. The need to resolve this conflict increases when the railway market is deregulated and service operators cannot abandon train slots due to capacity constraints [2]. Many rail lines already use the maximum capacity, and various measures are taken to meet new demand. Such actions include the construction of new railway infrastructure, the modernization of existing infrastructure or the more efficient use of existing infrastructure. Building new railway infrastructure is expensive, and it is therefore important that the right actions are taken at the right time. Coverage of the understanding of practical capacity in the documents of the International Organization of National Railway Companies in order to jointly address the challenges of railway transport development is presented in the standard that examines the capacity of UIC406-R [3]. This document uses a market-oriented approach to bandwidth determination. Studies show that in some cases, individual railway sections can be overloaded, even with a small number of trains. This standard is based on the compression of the train schedule, but to begin with, the section should be divided into smaller sections, which will be compressed separately. The schedule should be firmly adjacent to each other without breaking safety intervals. In other words, the train schedule should be "compressed" so that there is as little time as possible between the threads of the schedule. As a rule, spare time is introduced in order to reduce delays between trains in an emergency. Thus, the capacity depends on the location of trains in time, the number of trains of different speed categories, the length of the section, the accepted level of punctuality (accuracy of compliance with the schedule), the number of delays and stops, the required commercial speed and the specified interval of their departure. As a consequence, capacity can only be estimated after the establishment of a transportation plan, which is formed on the basis of traffic schedule requirements. Increasing the capacity of railway sections can be achieved by technical measures and by reconstruction [4]. Organizational and technical measures include the reduction of intervals between trains, the use of more efficient types of schedules, doubling and connection of trains, increasing the number of rolling stock, increasing the total mass of rolling stock. These measures are the most efficient and cheapest way to solve the problem, but allow to improve the situation to certain limits and do not exclude the possibility of further reconstruction (replacement of interlocking devices, development of track devices, reconstruction of rolling stock and traction). Therefore, with a sharp increase in traffic, when capacity is limited, the sites need to take the necessary measures to comprehensively organize the operation of railway transport on the basis of energy-efficient schedules and train formation.

The energy-optimal train schedule is a schedule that provides for the transportation of scheduled passenger volumes and cargoes with minimal electricity losses associated with the costs of traction for locomotives and unconditional safety of transportation [5]. With energy-optimal train schedules, we can also avoid reducing rolling stock downtime, reducing the amount of shunting work, increasing the speed of delivery of goods and passengers, and so on. The implementation of energy-optimal traffic schedules for passenger trains shows the possibility of reducing electricity costs for traction by 5-6%. Currently, energy-optimized traffic schedules are introduced into the traffic schedule for freight trains [6]. The principle of reducing power losses is formed in the way, when there is a choice of many possible values of the intervals between trains and from them are selected those that correspond to minimal power losses.

First of all, to solve this problem, "hard train-path" are used - the technology of train movement on a strict schedule, which is not subject to change. The use of this technology will reduce the downtime between cars and trains at line and sorting stations by accelerating the turnover of traction rolling stock at technical stations, as well as by stabilizing the work of locomotive crews. This leads to improved use of rolling stock both in terms of power and time. When using "hard" paths, the acceleration of the production cycle is achieved due to following factors:

- reduction of failures in the operation of technical devices, allows up to 10% to increase the available capacity of railway sections;
- shortening of downtime of structures at service stations;
- the use of free path of the schedule to accelerate the movement of trains [7].

When performing transportation by rail on hard paths, it is possible to optimize both the direct transportation process (taking into account information on current speed limits, providing "windows" for repairing the upper structure of the track, information on force majeure) and related operations (supply planning of locomotives for train) [7]. It can be hypothesized that the most perfect will be the schedule of trains with a stable part of the train flow, and free paths can be used to vary its parameters and performance indicators.

To confirm this, we conducted studies on a real electrified section (Fig. 1) with a real trains schedule of (Fig. 2).

The tested section has two tracks, is 128 km long, has 8 section between substations and receives power from 9 traction substations according to the scheme (Fig. 1). The non-load voltages and the internal resistances of the traction substations are determined based on their passport data.

To illustrate the provisions of the proposed hypothesis, consider the movement of the train N7 (Table 1).

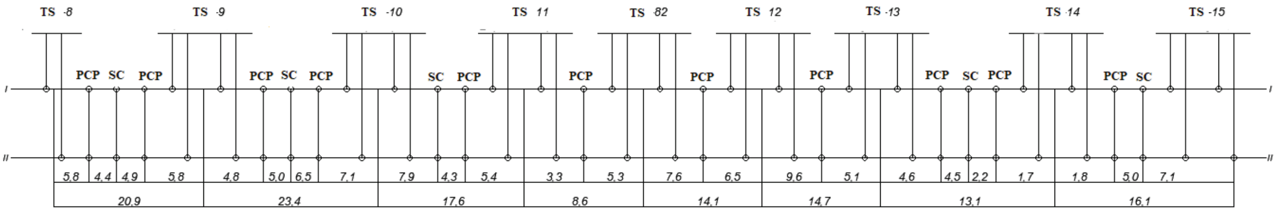

Fig. 1 Power supply of electrified section P – ND

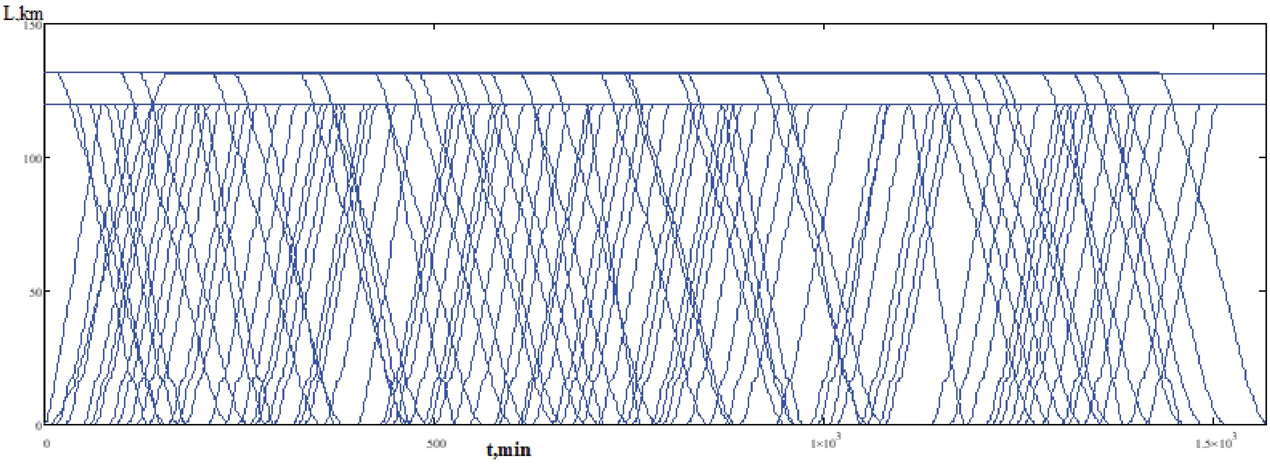

Fig. 2 Train schedule on the section P – ND

Table 1

The movement of the train N7 on the section

No.	Block post	Journey time, min	Distance between stations, km	The distance, km	Note
1	ND	0		0	
2	N	12	4.7	4.7	
3	P	16	3.1	7.7	
4	DN	26	2.3	10	
5	G	33	2.4	12.4	
6	D	42	5.7	18.1	
7	C	55	9.6	27.7	
8	ZK	68	13.7.	41.3	
9	KP	72	3.9	45.2	
10	V	85	12.6	56.7	
11	VD	94	8.2	66.9	
12	RE	109	15	81.9	
13	VG	129	17.3	99.2	
14	E	137	8.9	108.1	Overtaking
	E	152	0	108.1	
15	P	175	17.9	126	
16	PS	188	4.6	130.6	

Calculations of energy parameters were performed using the spatio-temporal representation of the electric traction load. The space-time model of the traction supply system [8] is based on the analytical description of the basic electrical processes by the functions of two variables, the relationship between which is determined by the train schedule, which in turn determines the graphical coordinate of each individual train with the number n in any moment of time t. Using other initial data in the form of electric locomotive power profile, parameters of external and traction power supply system, piecewise-defined functions of two variables are determined, which are the dependences of current distribution and voltage losses in the catenary in time and space.

According to the timetable, the moment of arrival of the first train to the destination is 120 minutes, which also means that there are some trains that have not completed the route. For this purpose, was selected data about voltage and power (Table 2).

Table 2

No. of train	Coordinate, km	Current, A	Voltage,V	Power, kW
N7	100,559	0	3296,1	0
N8	119,207	108,636	3285.1	356,874
N9	89,713	0	3288,1	0
N10	73,931	0	3261.9	0
N11	68,269	0	3267,8	0
N12	39,294	2102,44	2669,1	5611,612
N13	24,339	2477,24	2589.3	6414.324
N14	10,804	2360	2652,3	6259.352
N15	0	736,765	3079,7	2268,99
N16	28,238	1080,08	2563.4	2768,683
N17	12,114	0	2734,5	0
N18	30,835	0	2632,3	0
N19	62.08	0	3262	0
N20	75,295	458,648	3218.1	1475,96
N21	113,962	0	3292.6	0

As can be seen from the results of the analysis, some trains were in traction mode, and some were in idle mode. The maximum current consumption of train N13 is 2477,238 A in the odd direction. The voltage on the pantograph of the rolling stock is outside the permissible values (Fig. 3). If we look to the N17 and N18 passenger trains running in a pairwise direction, one can notice that these two trains are in idle mode, but the voltage on pantograph is beyond the permissible values. This can be caused by the consumption of significant traction current by trains located near these trains N17 and N18. Fig. 4, in turn, shows the power consumption of trains on the tested section.

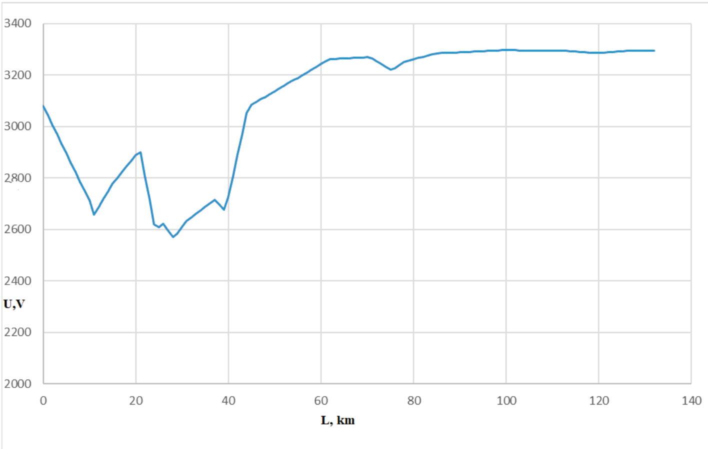

Fig. 3. Voltage distribution on the 1st track

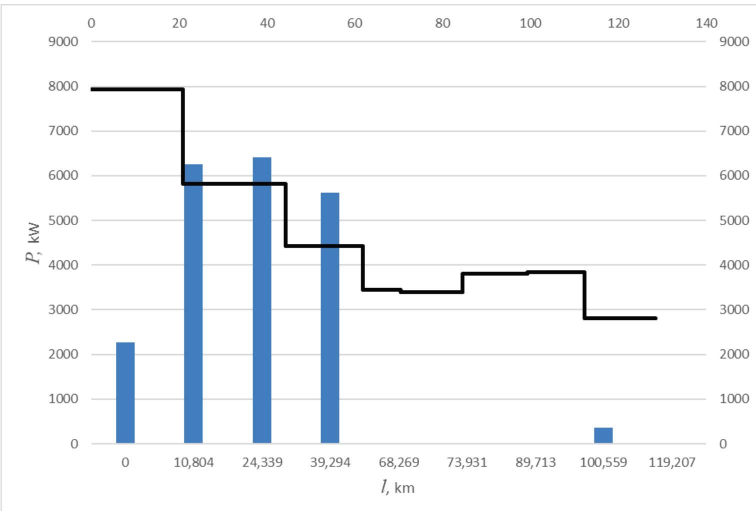

Fig. 4 Power consumption per kilometer while running on the 1st track: solid straight line - specific power of the traction line, columns - power consumed by electric locomotives

The results of the calculation for the maximum mode (in this timetable - 125 minutes) are shown at Fig. 5.

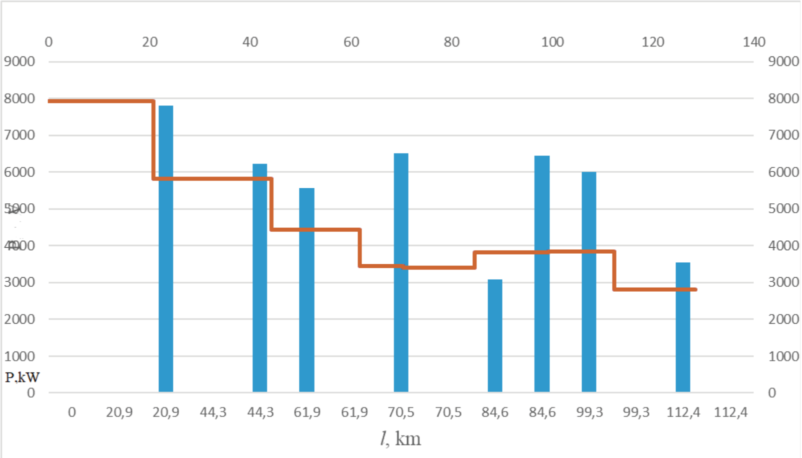

Fig. 5 Power consumption per kilometer during running (maximum number of trains in traction mode)

The analysis of the obtained results shows that in some substation zones the instantaneous power consumed by the traction load exceeds the power generated by the traction substations, which, in turn, decrease the voltage at the rolling stock pantograph below the normative value. Thus, the results of the studies revealed two problems:

- analysis of train timetables shows that in cases of increased power consumption the voltage level decreases;
- in the traction lines there are zones of limited power consumption, ie, zones where the power consumption of the rolling stock exceeds the energy consumption of the traction power supply system, which reduces the speed.

To eliminate these problems, we have changed not only the order of alternation of trains on the section, but also the intervals between these trains. The results of the calculation for the updated train timetable are presented at Fig. 6.

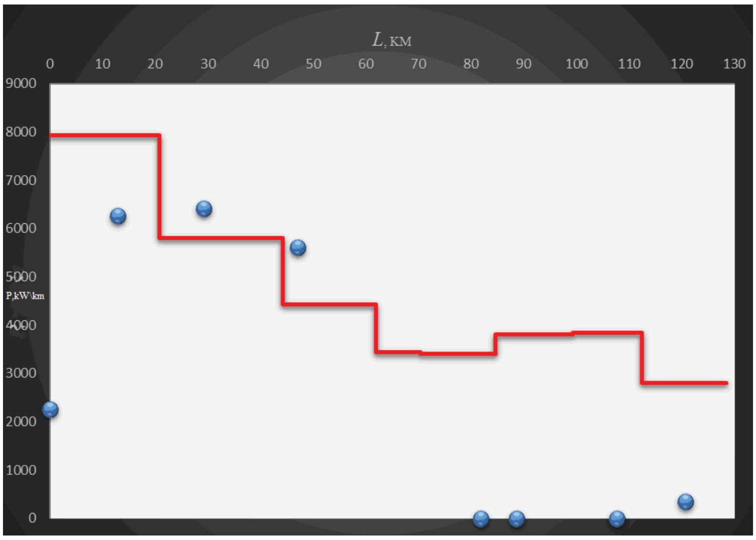

Fig. 6 Power consumption per kilometer while running on the 1st track when the train schedule varies

The analysis of the obtained data shows that the optimization of train timetable can decrease the power consumption of the rolling stock, but in some cases there power supply is limited. For this reason, there is a need for optimization of the traction power supply system. For this purpose it is necessary to install additional generating capacities at points with following coordinates: 40 km and 50 km. Taking into account the current trends in power supply system development, the task of location of additional generators can be performed by using a hybrid, asymmetric traction system [9].

3. Conclusions

To eliminate the limitations in the operation of the electrified section, the approach of optimizing the intervals between trains and reformatting the train timetable was applied in the work. When constructing an optimized train timetable, the train intervals were determined for cases with minimal energy losses in the traction line, taking into account the actual specific power of the traction network while providing the required voltage mode. At the same time, the average voltage level on the limiting sections increases by 7% and the length of the electrified sections limiting in terms of specific power decreases significantly.

At the same time, in order to eliminate the possibility of the emerging of power supply sections limiting the required train flow and to ensure the necessary stability in terms of voltage and specific power, it is necessary to optimize the power supply circuits of the traction line. It can be performed using a new power supply circuitry of electric rolling stock with the use of active means of strengthening the traction line with electricity generators and their asymmetric location in places of localization of voltage instability during the intensification of trains.

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