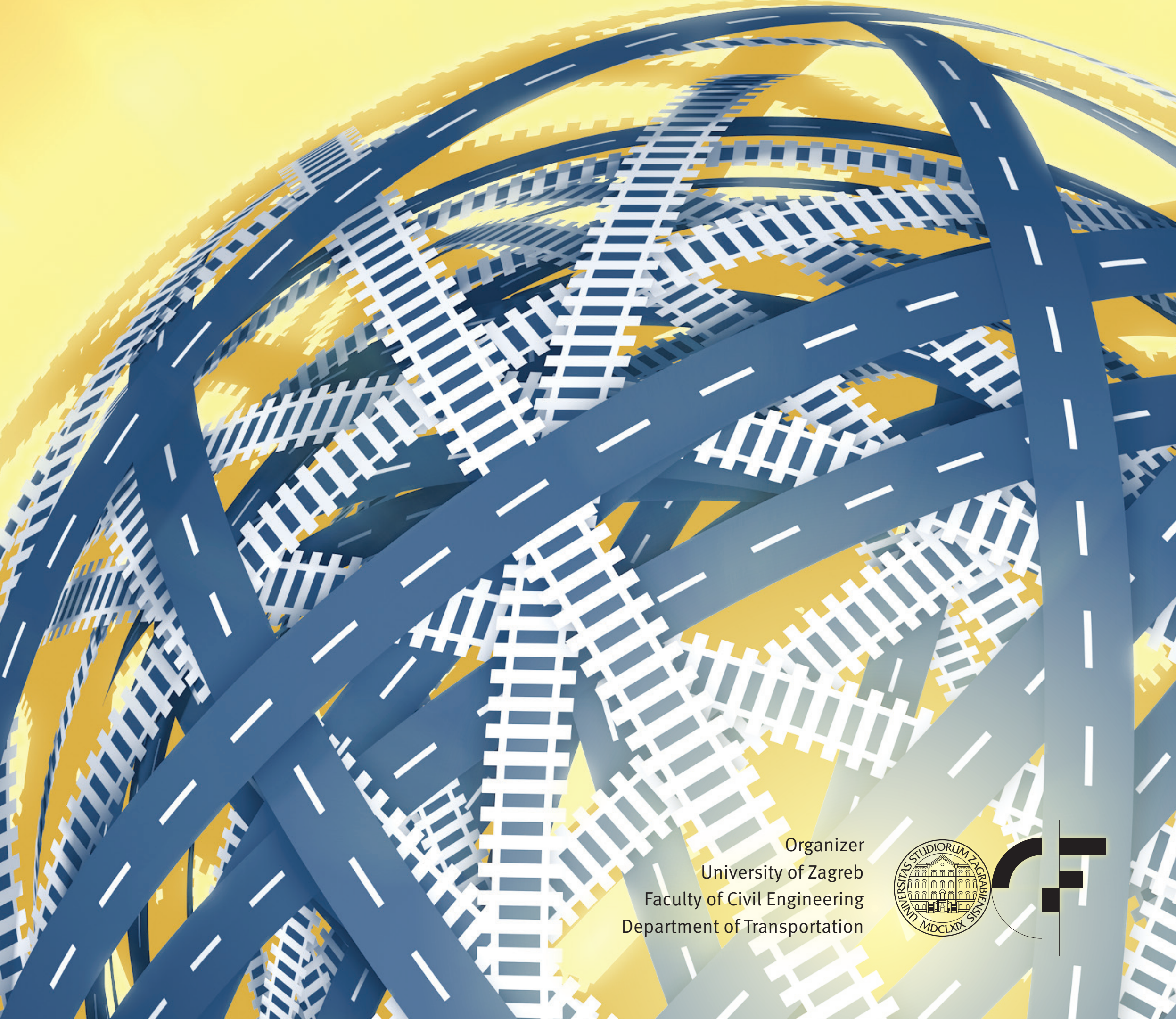
CETRA[2016]

4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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TIMETABLE OPTIMIZATION ON THE RAILWAY LINE ELECTRIFIED IN A DC POWER SYSTEM IN TERMS OF ENERGY CONSUMPTION USING THE PARTICLE SWARM OPTIMIZATION

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Abstract

The paper presents the results of the investigation of timetable influence on energy consumption and peak power demand on a DC electrified railway. The aim of the investigation is to optimize a timetable in terms of energy consumption and coasts. The original railway timetable was modified to insure the highest receptivity of the overhead catenary system (OCS) for the trains braking with recuperation. For this purpose the Particle Swarm Optimization has been used in connection with the program carrying out the parallel train performance calculations with the power flow calculation in the DC rail supply system with the recuperative braking. The optimization has been done taking into account the restrictions resulting from passenger waiting time.

1 Introduction

Energy saving is becoming more important for railway transport due to the growing prices of electric energy and environmental issues. Simultaneously it is known that traction energy is about 60-70% of the total energy consumption in railway [4]. Traction energy consumption could be decreased by improving the effectiveness of regenerating braking energy (RBE) utilization. Different methods are known to improve the effectiveness of regenerative braking energy recapturing, they could be divided into three groups [4]:

- Involving the energy storage devices (ESD). The different solutions belonging to this group enables storing regenerative energy and utilizing it when it is needed. The wide and general overview of the different storage systems has been presented in [14]. The solution gives independence from the power source receptivity [4].
- Optimisation of train braking effort and the speed trajectory for a single vehicle [4][5][6][13][21]. The subject has been investigated for last the two decades. In the number of papers different solutions in terms of methodology have been found. Various methods of artificial intelligence have been applied to find an optimal train speed trajectory.
- Improving the receptivity of the power source. This could be achieved via equipping a traction substation with an inverter to transfer energy to AC grid [9]. The second feasible method is timetable optimisation. The topic has been investigated for decades and much more intensively for the last few years [15][16][20]. The next chapter presents a literature review for this solution.

2 Literature review and aim of the research

The train timetable is a schedule of train traffic which is crucial to maintain the efficiency of transport service. Timetable influences many important economical, technical and environmental aspects. Since 1971 the timetable optimisation problems have been undertaken and a number of timetable optimisation models with different objectives have been applied. Many of different objectives of the timetable optimisation have been defined and a large number of optimisation models have been developed as well. Particularly the objectives: trip time [11], passenger waiting time [7], delay time [8], energy consumption [12].

Concomitantly the energy consumption has become more important factor in the last decade, thus more researches have been undertaken to solve the timetable optimisation problems in terms of energy consumption. The aim of the studies is to create the timetable which enables synchronizing of drive modes of different trains operating on the same supply section in order to improve source receptivity from the point of view of braking trains. In [12] the optimisation model based on a Genetic algorithm has been created. The pilot model of the railway system contains an electrified double track line with three power substations, six train stops and four trains operating. The timetable has been modified according to the Genetic algorithm result by shifting the reserve time. In [15] the timetable optimisation in terms of regenerative energy recovery has been done. The developed model enables modelling the transfer of regenerative energy not only between adjacent trains, but among all trains. The strategy of the timetable optimisation does not depend on the section length. The regenerative power could also be drawn not only by the accelerating trains but also by all trains on the supply section. However the model has the constant number of trains and all of the trains are the same type.

For last few years the timetable optimisation has been more often considered as a multi-objective problem. More than one aspect is being considered as the objective in optimisation models. For example in [1] two-objective optimisation is considered as a manner, to increase the efficiency of recuperation and to shorten the passenger waiting time. The aim of optimisation from the point of view of the first objective is the improvement of synchronisation between trains in up and down direction. In [20] the variation of passenger flow at stations is being considered, the concept of passenger waiting time is proposed and taken as the optimisation objective. The second objective is energy consumption and an iterative speed profile generation approach has been developed to find the energy-efficient speed profile.

The proposed timetable optimisation model is two objective optimisation. The first objective is the minimum energy consumed by power substations. The second is maintaining the condition of the passenger flow alleviation without increasing the maximum passengers waiting and travel time. The result of the investigation is the timetable optimisation in terms of maximisation of regenerative energy flow among trains operating in the considered railway line and simultaneously maintaining passenger waiting time that is not longer than the original timetable. The timetable is modified by changing departure and arrival times at the stations as it is shown in Figure 1. The simulation model includes occurrence of random variations in railway traffic, especially the station dwell time and occurrence of unplanned train stops and speed reductions which are described by a random variation. The parameters of the random variations are prepared based on the statistic data from the railway operator. The random variations have been introduced to the model in order to improve the accuracy of the model. The Particle Swarm Optimisation is applied as an optimisation tool. The investigation considers a case study with a double track railway line electrified in a 3 kV DC system with different types of train operation. The case study is based on the original timetable taken from a Polish railway operator. The timetable has been modified according to the optimisation algorithm operation result.

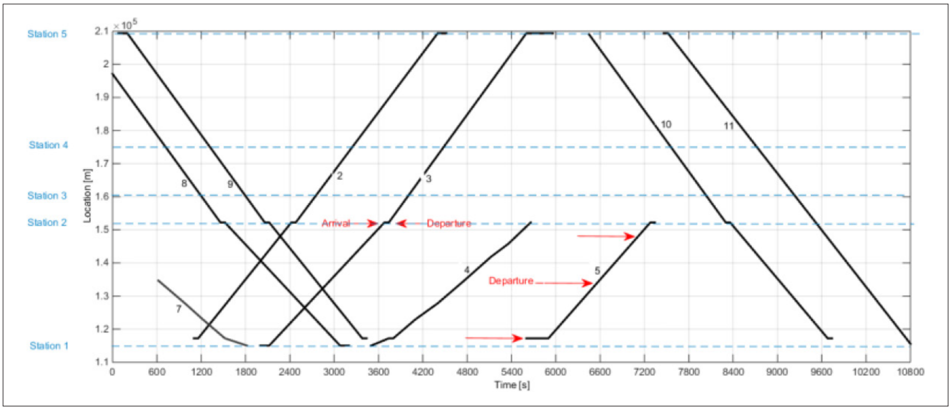

Figure 1 Graphic timetable with modified variations

3 Simulation model description

The tool applied for the purpose of the research is a complex simulation model of an electrified railway line. The general scheme of the model is presented in Figure 2. The program enables simulation of regenerative braking of trains. In the program there are no limitations in terms of a number of trains, substations and train stops as well as track length. The simulation program consists of the layer of parallel train performance calculation (1) which gives the location and the power value of each train operating on the modelled line. The algorithm is based on the set of equations 1:

$$\begin{cases} \dfrac{dv(t)}{dt} = \dfrac{F(v(t),U(t)) - W(v(t),s(t))}{m(1+\eta)} \\ \\ P(t) = F(t) \cdot v(t) \end{cases} \tag{1}$$

These values are necessary as input data to the algorithm of the power flow and pantograph voltage calculations (2). Due to the nonlinearity of the loads as electrical elements there is need for using the iterative method to solve the circuit. Therefore a simple iterative method is used in connection with a superposition method [17][18][19]. In case when the overhead catenary system OCS is not fully receptive from the point of view of braking trains the algorithm of the iterative subtraction of the regenerative current is being operated. Pantograph voltages cannot exceed the maximum permissible value given in standard EN 50163, in case of a 3 kV DC system – 3900 V.
On Figure 2 the input data necessary into insert to the program is shown. The input data includes the vertical profile of the track, which influences on the regenerative braking profiles of trains.

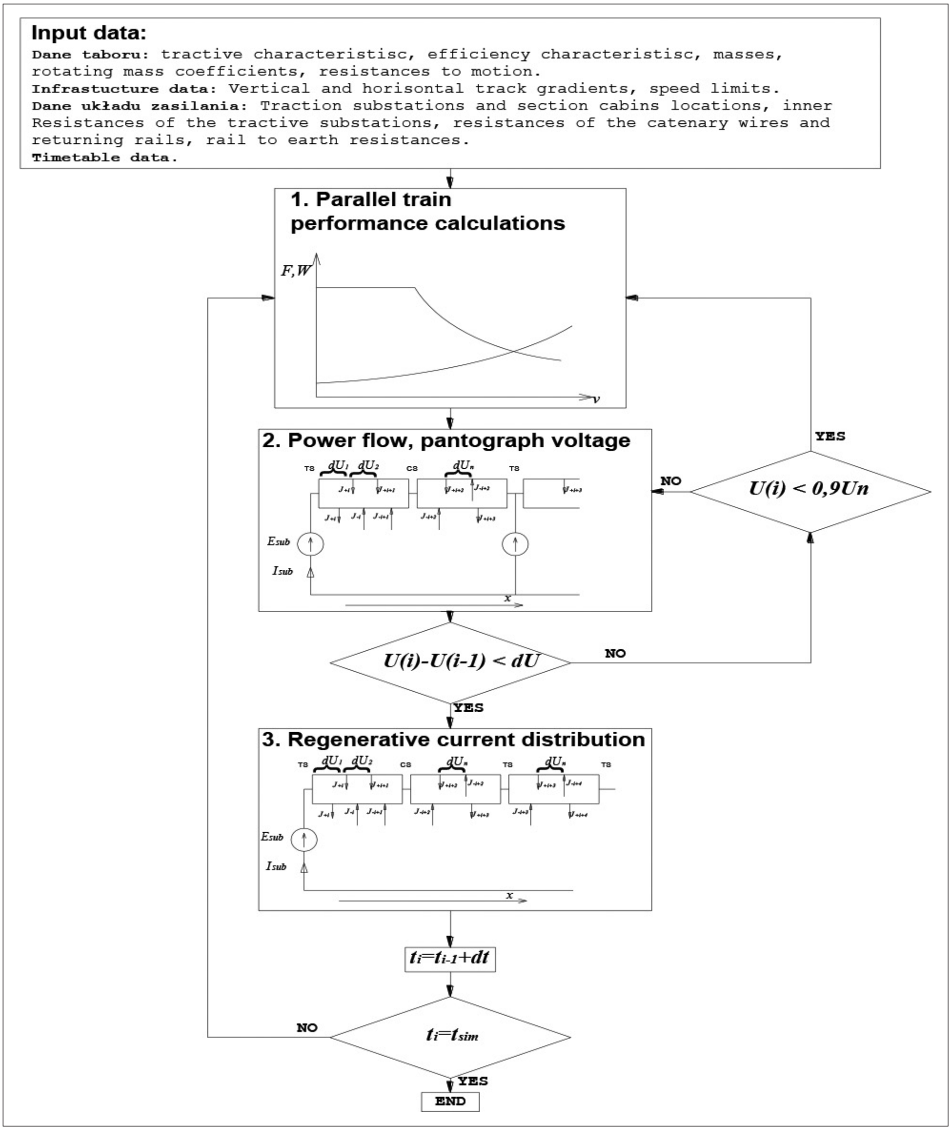

Figure 2 General scheme of the optimisation program

4 Particle Swarm Optimisation algorithm (PSO)

The general scheme of the Particle Swarm Optimisation is shown in Figure 3. [3] In the first step the initial positions and velocities of the established number of particles are being found. During the second step the objective functions are being calculated for each particle position in a multidimensional space of variables. During this step the energy consumption is being calculated by the program described in Chapter 3 for each particle, where the variables are the parameters of a timetable – departure and arrival times. In the next step the best solution for each particle and for all particles, for all previous PSO algorithm iterations are being recorded.

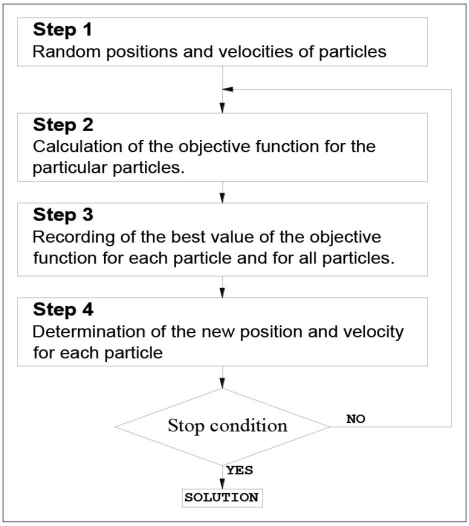

Figure 3 General scheme of a PSO algorithm

In step 4 the new velocities and locations are being calculated according to the Eq. 2 and 3 [3]:

$$v_k^{t+1} = c_0 r_0^t v_k^t + c_1 r_1^t \left(y_k^t - x_k^t\right) + c_2 r_2^t \left(y_k^{p*t} - x_k^t\right) \tag{2}$$

$$x_k^{t+1} = x_k^t + v_k^{t+1} \tag{3}$$

Where:

r_0^t, r_1^t, r_2^t – random figures from the interval (0,1),
v_k^t – particle velocity in the previous step and in k-dimension,
x_k^t – particle coordinate in the previous step and in k-dimension,
y_k^t – particle coordinate in the location where the value of the objective function is the best till current step,
y_k^{t*t} – coordinate in the location where the value of the objective function is the best for all particles till current step,
c_0 – coefficient determining the influence of the particle velociety on its own velocity in the next step
c_1 – coefficient determining the influence of the best particle location on its velociety in the next step
c_2 – coefficient determining the influence of the best location found till current step among all particles on the particular particle velocity in the next step.

The optimisation algorithm includes two objectives. The first one is the minimum energy consumption. The second is maintaining the pasenger waiting time, so it is not longer than before the timetable modification.

5 Timetable influence on the energy consumption.

The current chapter presents the results of simulations carried out on the program presented in Chapter 3. The operation of a 5 car electric multiple unit with regenerative braking is implemented. Two variants of simulations in terms of a section length have been done:

1) The double track line of 50 km length has been modelled with 12 train stops. Section busbar short circuit brakes are closed. Infrastructure data shown in Table 1. (Option 1)

2) The double track line of 12,5 km length has been modelled with 4 train stops. Section busbar short circuit brakes are opened, with train stops shown in Table 1. (Option 2)

In the first case the data of infrastructure implemented into the program is presented in Table 1. The line is electrified in a 3 kV DC system with 5 power substations and 4 section cabins. Figure 4 shows the instant values of substation power against time for the first option. Figure 5 shows the timetable of the trains implemented into the program with shift time between directions.

Table 1 The infrastructure data

Train stops locations [m]	Power substations locations [m]	Section cabins locations [m]
1200, 4000, 8000, 12000, 15243, 21000, 24003, 29879, 35923, 43043, 45092	0, 12500, 25000, 37500, 50000	7000, 21000, 32000 43000

The train operation with headway time of 400 s in both directions has been modelled. Train stops have been modelled with different dwell times. The number of simulations has been made with different shift times between directions.

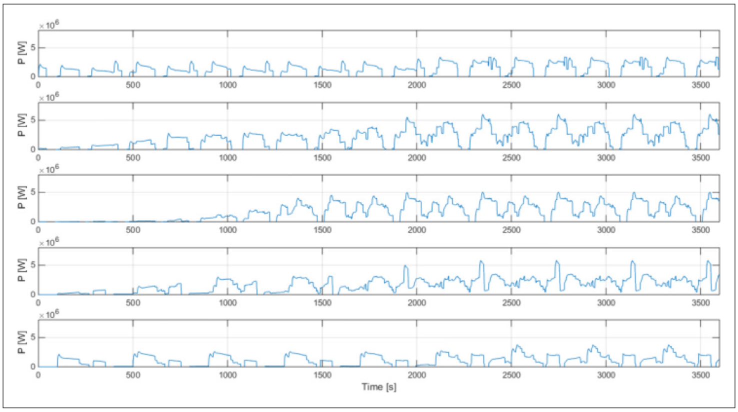

Figure 4 Instant power of substations against time

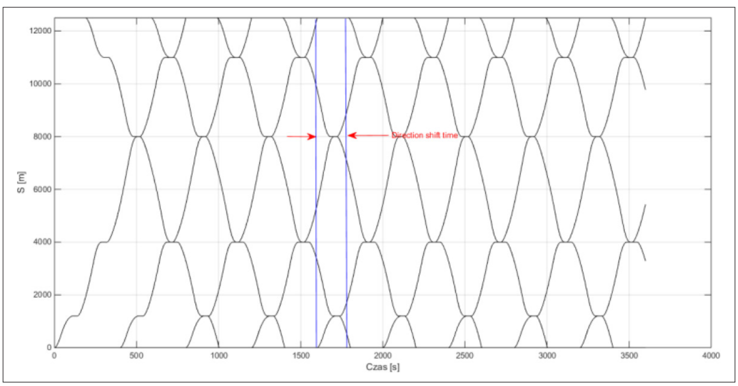

Figure 5 Implemented timetable of multiple units operation

Figures 6 and 7 show total energy consumed by power substations as a function of shift time between directions of traffic.

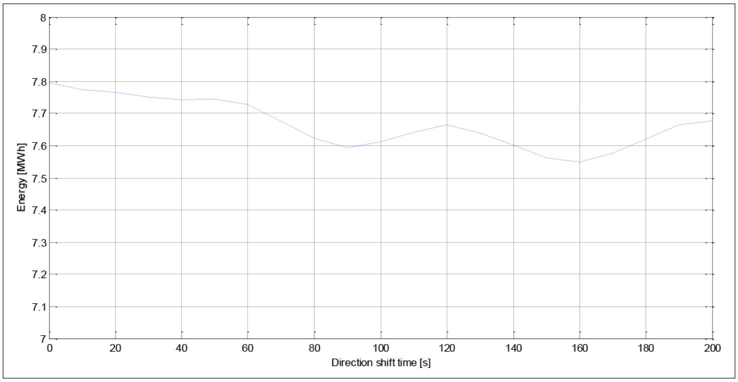

Figure 6 Energy consumption as a function of shift time between directions for option 1

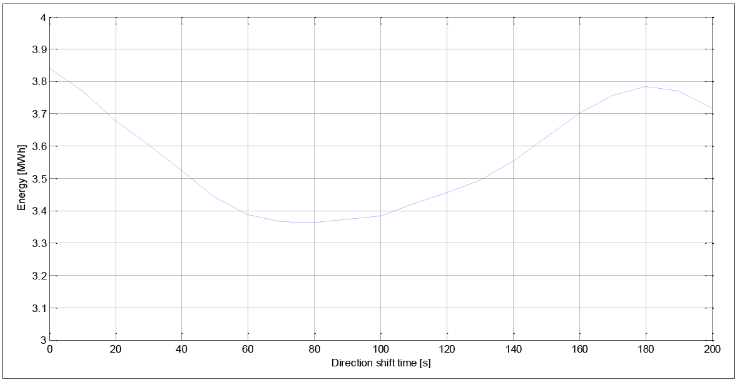

Figure 7 Energy consumption as a function of shift time between directions for option 2

6 Conclusions

The proposed timetable optimisation method provides the possibility of achieving more effective and accurate solution than the current solutions due to elimination of the train number limitations, stops and power substations as well as the implementation of random factors in trains operation. The model involves different types of trains including passenger, suburban and freight trains. Initial simulation results show that total energy consumption differs on the shift time between directions more in case with a short supply section than with a long one. It proves that timetable optimisation is more effective in case with shorter supply sections and longer average headway times. Figure 7 shows that by the modification of shift time, the total energy consumption may be decreased by 12,4 %.
It should be noticed that energy consumption is the result of random varieties influence. Precisely for this reason the effect in terms of energy saving in a traction system should be estimated in a long term perspective, and considered with support of the statistics tools. The drawback of the presented solution is significant computation time, which takes several hours. The proposed process of the optimisation is based on the multiple operation of the program described in chapter 4 .

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