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Efficiency analysis of the 25 kV/50 Hz traction network with static frequency converters

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Abstract— Based on computer simulations, the article shows possible energy savings when is railway line 25kV/50Hz powered from indirect static frequency converters instead of the conventional power supply only by transformers. One operational situation including 37 trains is sequentially powered by seven different combinations of conventional and converter power stations. Simulations based on the compiled mathematical equations show the changing energy at the input to the power stations depending on their types and the setting of the output control characteristics.

1. INTRODUCTION

The new technologies of the traction network 25kV/50Hz are based on the usage of static frequency converters (3 phase controlled pulse rectifier, DC link, 1 phase inverter) according to Fig.1. For more information on the concept of converter-based power supplies and converter equipment for traction power stations, see References [1], [4], [9], [10], [12], [14].

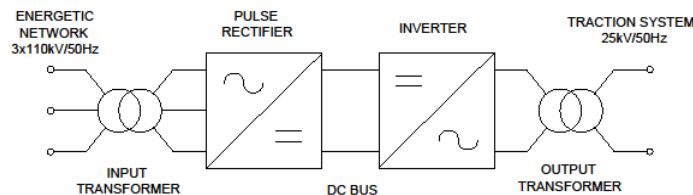


Figure 1 Block diagram of the 25 kV 50 Hz converter-based power station

Simulation analysis was focused on the comparison of energy and voltage ratios in the realistic section of a railway network with a simulation of real train operation. Several railways in the north-east of Bohemia had been selected for the analysis. The railways are single-track and, while currently not electrified, their electrification would be appropriate due to intense cargo transport activity in certain sections as well as relatively intense long-distance and regional personal transport activity. These railways include Nymburk – M.Boleslav – Č.Lípa and Děčín – Č.Lípa – Jablunné. The designated locations of the power stations are at M.Boleslav (TPS1) and Č.Lípa (TPS2) according to the map in the Fig 2.

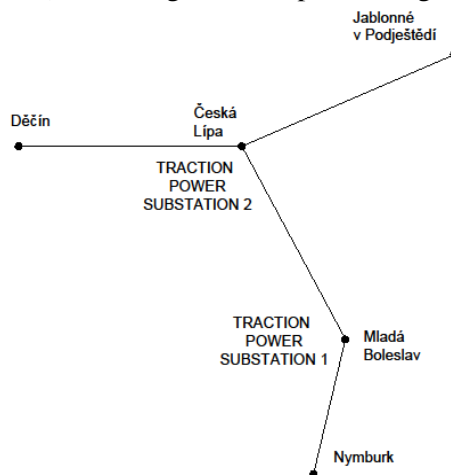


Figure 2 Map of the railway used for real operation simulation

2. COMPILATION OF THE WRITING SCHEME AND THE RELEVANT EQUATIONS

Simulation calculations were performed in the Matlab SW [7]. The results of simulation calculations use a traction network example in order to analyse power ratio in relation to the control of active power via change

the phase shift of converter-based power stations.

When applying the node voltage analysis method on a circuit, an equation is made for each node except for the point node (ground) and the nodes between the voltage sources and their internal impedances. Nodes for which circuit equations are made in each time sample can be subdivided into three groups:

1. Nodes where tracks are diverting
2. Nodes where power stations are connected
3. Trains

For elementary nodes, are made equations, can be depicted as per Figure 3 in the wiring diagram context. This node has a power station connected to it while also being a railway node. In Figure 3, U_2 , UV_4 , UV_5 , U_4 are the node voltage phasors relative to the reference potential, i.e., the common potential of the ground and the rails, ZV_4 , ZV_5 and Z_4 are the complex impedance values of the traction lines between node 2 and adjacent nodes, U_1 is the internal voltage phasor of power station 1 and X_T is the complex inner impedance of the power station U_1 . The impedance of the traction line was considered according to regulation [8] $Z = 0,26 + j0.55 \Omega$ for the conditions in the Czech Republic.

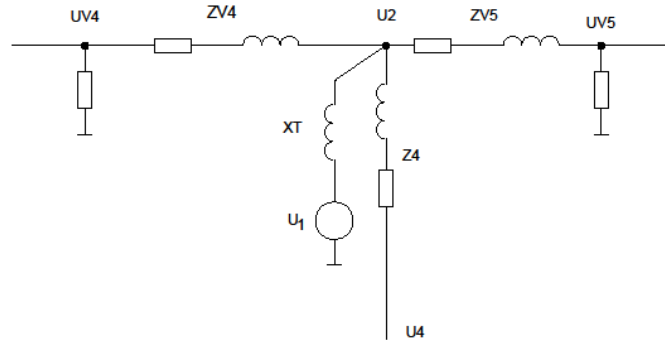


Figure 3 Example of wiring diagram representation of one node

According to the node voltage analysis method, which is based on the fact that the sum of all currents passing through a node is zero, the following equation can be made for Figure 3:

$$0 = \frac{\hat{U}_2 - \hat{U}_{V4}}{\hat{Z}_{V4}} + \frac{\hat{U}_2 - \hat{U}_{V5}}{\hat{Z}_{V5}} + \frac{\hat{U}_2 - \hat{U}_4}{\hat{Z}_4} + \frac{\hat{U}_2 - \hat{U}_1}{\hat{X}_T} \quad (1)$$

Analogous method is used to compose equations for all the nodes within the current time sample and the solutions of the equations are used to determine the voltage phasors within the analysed nodes. These node voltage phasors are used to calculate all of the analysed magnitudes, primarily effective node voltage values, effective power station and train current values, power station active and reactive power values and power station active and reactive energy values. The calculation of active power using the following equation is crucial:

$$P = \text{Re}[\hat{U} \cdot \hat{I}^*] \quad (2)$$

The equation (2) therefore takes the active power for a real part of the product of the voltage phasor and the complex compound current phasor [13].

3. SIMULATIONS OF REAL OPERATION VARIANTS

In order to determine the power supply ratios, a simulation was performed for two hours of train operation with a total number of 37 trains with real drive trajectory. Out of this number, 12 were cargo trains weighing from 500 to 1,500 t, and the rest were passenger transport trains, both long-distance and regional, led by 2-car or 4-car electric units. The following variants of traction power supply were compared during the simulations:

1. Conventional power supply (only transformer) for isolated track sections, with neutral isolated fields, as well as half-way through the route between the stations TPS1 and TPS2 (TT variant)
2. Conventional TPS1 power station and converter-based TPS2 power station (3 phase controlled pulse rectifier, DC link, 1 phase inverter), station active power not limited (TC variant)
3. Conventional TPS1 power station, converter-based TPS2 power station, active power of the second station limited (TCR variant)

4. Converter-based TPS1 and TPS2 power stations, active power not limited (CC variant)
5. Converter-based TPS1 and TPS2 power stations, active power in TPS2 station limited (CCR variant)
6. Converter-based TPS1 and TPS2 power stations, active power TPS1 station limited (CRC variant)
7. Converter-based TPS1 and TPS2 power stations, active power limited at both stations (CRCR variant)

Table 1 Comparison of total energy ratios for 37 trains travelling

	TT	TC	TCR	CC	CCR	CRC	CRCR
Common. E+ (kWh)	10410	9516	9465	9618	9501	9525	9406
Efficiency (%)	98.65	98.51	98.48	98.70	98.67	98.66	98.62
Losses E (kWh)	170	173	175	152	155	156	158
E+ of TPS 1/2 (kWh)	5,499/ 4911	4,408/ 5108	4,312/ 5153	5,443/ 4175	5,268/ 4233	5,438/ 4087	5,277/ 4129

Table 1 shows the summary comparison of energy ratios within the traction network for individual power supply variants. The deciding factor for the railway manager is the total amount of paid energy taken from the Common E+ traction power stations. Losses E is, in the used circuit model, the energy that has turned into heat loss in the resistances of the traction circuit. Efficiency η_E , which is specified in Table, is the ratio of the total energy consumed in the traction circuit E_C and the total energy supplied into the traction circuit – E_S . E_{CT} in (3) is energy consumed by trains, E_{RN} is energy recuperated into the energy network, E_{CN} is energy taken from the energy network, E_{RT} is energy recuperated by trains to traction network.

$$\eta_E = \frac{E_C}{E_S} = \frac{E_{CT} + E_{RN}}{E_{CN} + E_{RT}} \quad (3)$$

The last row in the table contains data on the distribution of energy supply between stations TPS1 a TPS2. The figures show selected value courses from the calculations; their overview results are listed in Table 1. Courses calculated for the CRCR variant are listed for illustration.

Figure 4 illustrates the course of instantaneous power transfer efficiency through the traction system and shows the course of time dependency of effective voltage value on the pantograph of the traction vehicle throughout the simulation.

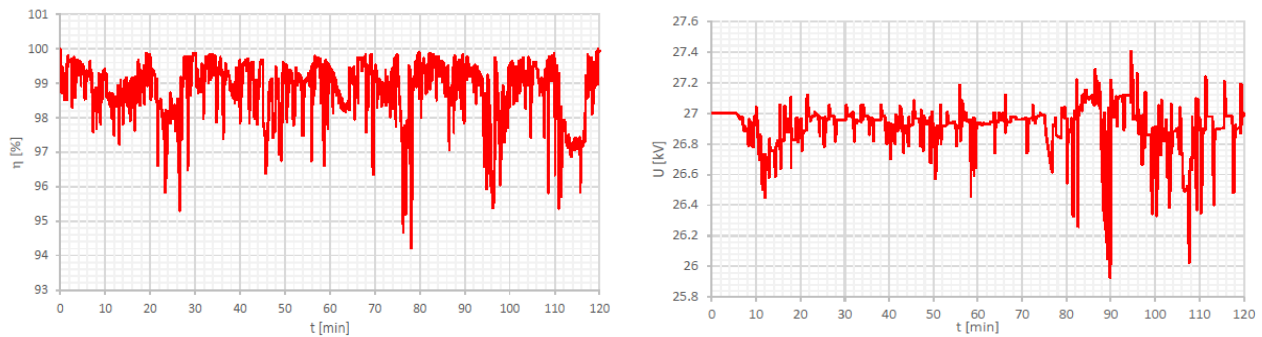


Figure 4 Total dependence of the instantaneous power transfer efficiency in the traction network and time dependency of effective voltage value on the pantograph of one of the trains

4. CONCLUSION

It is apparent from Table that the value of energy supplied into the traction network is highest in the case of conventional power supply. The decrease of total energy consumption always comes in when at least one converter-based power station is used. The active power control of converter-based power stations is primarily applied when eliminating recuperation into the energy network. When controlling the active power limitation, however, there is a certain increase of energy loss, which is determined by the changes of power flows in the traction system. Controlling the active power limitation always increases the usage of recuperated energy

within the traction network. This is most apparent from the CRCR case, where the recuperation into the energy network is limited for both power stations. Compared to the conventional power supply system, the total energy consumption by the traction network is reduced by over 10%.

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