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Simulations of Trains Traction of Locomotives Series Tent 443

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Abstract— **This paper defines methodological approach for traction - energy calculations, an alternative method for the dynamics of train traction of chosen series, based on simulated dynamic train model, modeling process of traction and traction parameters. Problems such as overload of traction motors, and behavior of locomotive traction in operational regimes is simulated and analyzed. Paper presents the results of simulation on nonlinear mathematical dynamic model of train motion, with locomotive TENT 443, based on the model of subsystems of traction drive linked in a functional unit. Simulation dynamic train model is implemented onto a graphic interface of computer program for dynamic system analyses- Simulink thus forming the train motion simulator. This simulator helps carrying out the analyses of electromechanical traction characteristics of locomotive TENT 443, and model results are in line with expected electrical and mechanical processes in operational conditions on track.**

Keywords- locomotives; TENT 443, traction,dinamic model;

I. INTRODUCTION

Thermal power plants “Nikola Tesla” dispose of ten electric locomotives of series 443 (Figure 1), constructed by Skoda and delivered only to this power plant. The locomotive was constructed with arrangement of axis Bo’- Bo’, adhesive mass 72t (+3%; -1%) and possible traction force on the wheel rim of 107kN. It was primarily built for shunting operations, with three traction operation modes: operation mode 5 km/h, operation mode 20 km/h and operation mode 80 km/h.

Figure.1. Locomotive TENT 443

Scheme of locomotive 443 traction circuit for normal driving operation mode of 80 km/h and easy driving operation mode of 20 and 5 km/h is shown in Figure 2.

For speed operation mode of 80 km/h two traction motors are connected in series in two parallel branches. Such connection enables operation with double DC supply voltage of traction motors, because the supply voltage is divided into electric motors connected in series. Using higher electric motor supply voltage at DC side reduces the electric power supply at AC high voltage side, thus relieving the contact network, and reducing the voltage falls along the contact line.

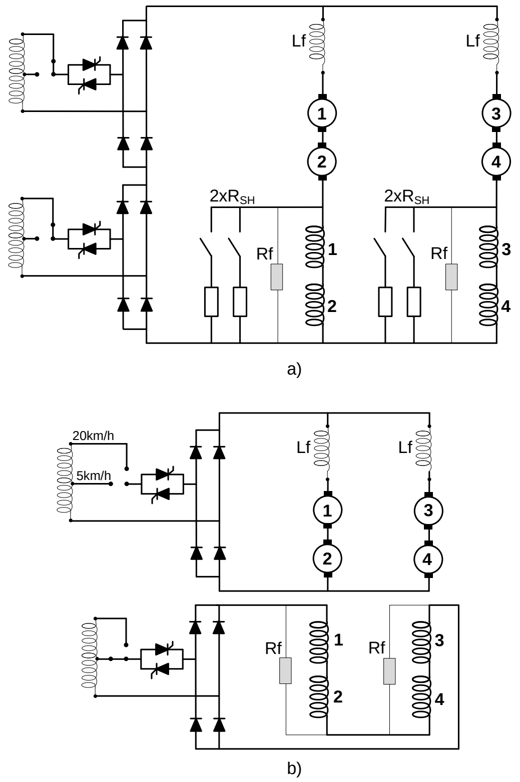

Figure.2. Traction motors supply scheme for:
a) normal driving operation mode of 80 km/h and
b) easy driving operation mode of 20 and 5 km/h

Motors in this operation mode work as series excitation DC motors. Control of driving torque (traction force) and electric motor speed is done by continuous control of DC supply voltage in range of 0- 750 V. Diode adapter bridges in this operation mode are connected in series so that their output voltages are added together. Adapter bridges current is limited to 2200 A thus limiting the traction electric motor current to 1100 A.

Traction motor speed increase beyond nominal speed is possible by reducing motor excitation (magnetic field) with shunt excitation in two degrees. For speed mode of 20 km/h two traction motors are connected in series and they are supplied from two parallel branches. Excitation windings of all four traction motors are connected in series and supplied from one diode adapter while the excitation current is controlled at a constant value of 670 A.

Rotors are supplied from another adapter. Speed control is performed by continuous control of fittings supply voltage. Adapter bridge current is limited to 2200 A in this operation mode. Traction electric motor current is also limited to 1100A.

Scheme of traction electric motors supply for speed mode of 5 km/h differs from the mode of 20 km/h only in the fact that the adapter bridge supplying the traction motor windings at AC side is attached to the main transformer lead exit which gives lower AC supply voltage. In this operation mode adapter bridge current supplying the traction motors fittings is limited to 2200 A.

II. DYNAMIC MODEL OF TRAIN MOTION

During the motion of maneuver train with locomotive TENT 443 the traction force of the locomotive Fv overcomes different resistances, some of which are constantly present and some occasionally. In order to overcome the motion resistances and achieve the set speed or controlled acceleration, the traction vehicle shall, in accordance with the resistances, achieve the respective traction force Fv on the drive wheels rim.

Hence, during the train motion we have:

- Constant resistances,
- Occasional resistances and
- Acceleration resistances.

Traction resistances depend on lots of different factors, some of which are very hard to determine analytically. Therefore we use equations from experience for calculation of some resistance types, which may differ in different countries.

Some of the equations have been chosen for simulation of train motion resistance, since there are no special equations for the particular locomotive and freight train with wagons for coal transportation. The choice may not be the best; however it is easy to implement any of the calculation variants in the simulation diagram Simulink.

Specific constant traction resistances –f_{CONST} created by

- Friction in bearings,
- Friction due to drive wheel rolling,
- Air resistance,

are simulated in the equation:

$$f_{CONST} = 2 + m\left(\frac{v_v}{10}\right)^2 \frac{1}{101.97}\left[\frac{N}{kg}\right] \tag{1}$$

where the coefficient m is within the limits 0.02 - 0.1, depending whether it is about passenger train or freight train. The speed v_v is given in km/h.

Among the occasional traction resistances which may occur the following were simulated

- Rise and fall resistance
- Curve resistance
- Mass inertion resistance during train acceleration.

Specific resistance of route slope, **rise or fall,** – f_{RISE} was modeled in the equation:

$$f_{RISE} = g\sin(\alpha)[\frac{N}{kg}] \tag{2}$$

where g is acceleration of earth gravitational force and α is slope angle.

Specific slope resistance – f_{SLOPE} was modeled in the equation:

$$f_{SLOPE} = \frac{800}{R}10^{-3}[\frac{N}{kg}] \tag{3}$$

where R is slope radius in m. Train length wasn't modeled.

Influence of mass inertion resistance to the train motion speed change (acceleration) is included in the differential equation of train motion.

$$m_{LV\_corr}\frac{dv_v}{dt} = F_v - F_{RES} \tag{4}$$

where

- Fv - locomotive traction force [N]
- F_{RES} - total traction resitances defined by the equation:

$$F_{RES} = (m_L + m_V)(f_{CONST} + f_{RISE} + f_{SLOPE})\ [N] \tag{5}$$

where

- m_L locomotive mass [kg]
- m_V train mass [kg] defined by the equation:

$$m_{LV\_corr} = (m_L + m_V)\,(1 + \varepsilon)\ \ [\text{kg}] \qquad (6)$$

Where is ε - **Mass correction factor** – which quantifies the influence of accumulated power in rotary parts of locomotive and train through mass correction in differential equation of translational motion. The above factor stands for the power share in locomotive and train rotary parts (motors, railroad bed) in the total motion power. Its values are within the range from 0.01 to 0.08, depending on the train type.

Mass correction factor ε is within the range from 0.01 to 0.08, depending on the train type. Since the influence of rotary masses during the locomotive maneuver operation is relatively small, the factor is to be ε=0.03.

Based on the previously defined equations the block scheme of **train motion dynamics** can be drawn, which is presented in the Figure 3.

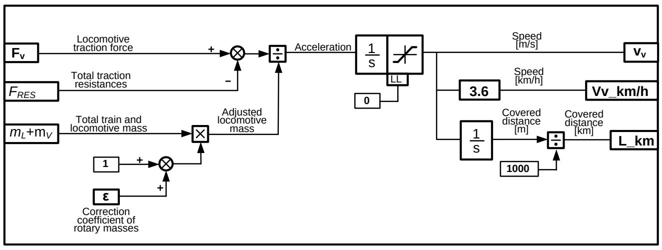

Figure3. Block scheme of train motion dynamics

Block scheme of specific constant resistances $f_{CONSTANT}$ is shown in the Figure 4.

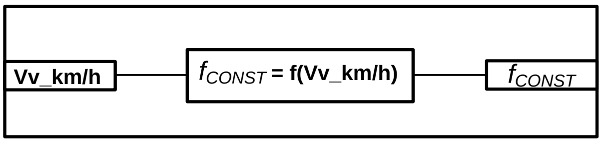

Figure 4. Block scheme of constant traction loads

Block scheme of specific slope resistances f_{RISE} is shown in the Figure 5. The logical loop for set slope switching on and off at certain distances of railway line is shown in the diagram. Different railway clearances may be simulated by repeating the same assembly.

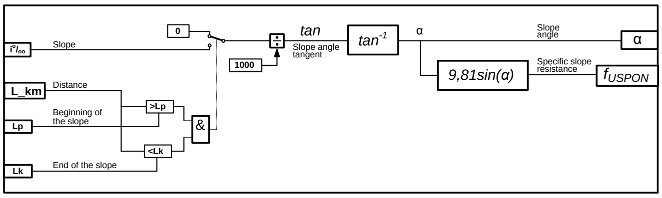

Figure 5. Block scheme of specific slope resistances f_{RISE}

Block scheme of specific slope resistances f_{SLOPE} is shown in the *Figure* 6. The logic for including the specific slope resistances in the total motion resistances operates in the following way. When the train enters the curve at the defined position of the line the **curve memory** is switched on, which informs that the train entered the curve and thereby includes the curve resistances into the total motion resistances. Subsequently the total train distance covered in the curve is measured, which corresponds to the length of the bend fragment which was set by the radius ***R*** and deflection angle ***β***. When the train covers the length of the curve road, the curve memory is switched off which leads to switching off the curve resistances. After switching off the curve memory the speed integrator, which measures the road, is restarted and thereby the complete assembly becomes ready for the next switching on, i.e. the curve. Since the train has been observed as the concentrated mass point in the train model execution, the length of the train which is important here, wasn't included in the model and the equations which are used do not take into consideration the train length.

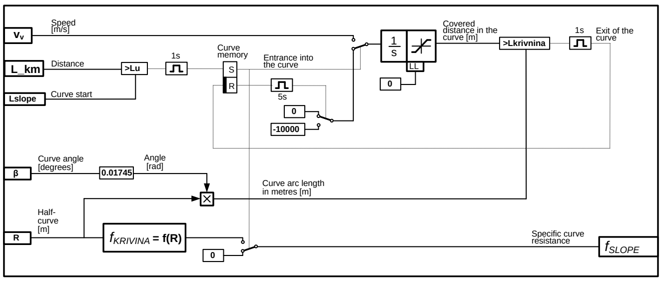

Figure 6. Block scheme of specific slope resistances f_{SLOPE}

Based on the performed individual models of elements of locomotive and train traction system as a whole, the complete **simulation block scheme of train motion** has been formed, which presents **nonlinear mathematical dynamic model of train motion**, shown in the Figure 7 Block scheme gives clear insight into the interaction of all elements and variables of traction system which determine train motion dynamic.

The scheme shows the places specially marked for manual setting of model parameters, such as:

- traction force control by changing the supply voltage of traction electric motors,
- train acceleration beyond nominal speed by setting the manual command for resistor switch on for field shunt,
- setting the locomotive mass and load, traction freight mass, vertical and horizontal route profile

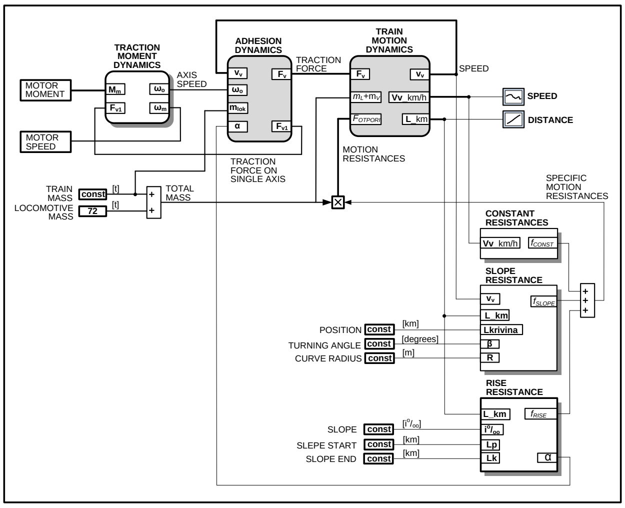

Figure 7. General block scheme of nonlinear dynamic model of train motion, locomotive TENT 443

III. SIMULATION OF TRAIN TRACTION OF LOCOMOTIVES SERIES TENT 443

Results of locomotive TENT 443 operation simulation, at train traction with the load of 500 t, obtained in Matlab/Simulink, are shown in the figure 8. Simulation shows the behavior of a train and traction motors in the following situations:

- motion and acceleration of a train up to the speed of 80km/h, by gradually bringing supply voltage of traction motors to nominal 283V,
- check and display of train acceleration function from 80km/h up to 100km/h by field shunting in two degrees,
- reduction of train speed to 60km/h, by reduction of supply voltage to 200V,
- behavior of a train and traction motors at overcoming the rise of 5 and 7$^{o}/_{oo}$ and behavior at slope decline of -7 $^{o}/_{oo}$
- passage through the curve *R*=200m

In the Figure 8, apart from track diagram, following typical parameters of traction motors and a train, for the given change of supply voltage of traction motors and route conditions, are shown:

- supply voltage of traction motors in ***Ua*** [% Un]
- traction motors current in ***Ia*** [% In]
- change of adhesion coefficient ***μ*** depending on the traction force
- train speed ***V*** in [km/h]
- covered distance ***L*** in [km]
- coming across the rise and fall and driving in those conditions ***I*** [$^{o}/_{oo}$]
- binary information of passing through the curve with set curve parameters [0,1].

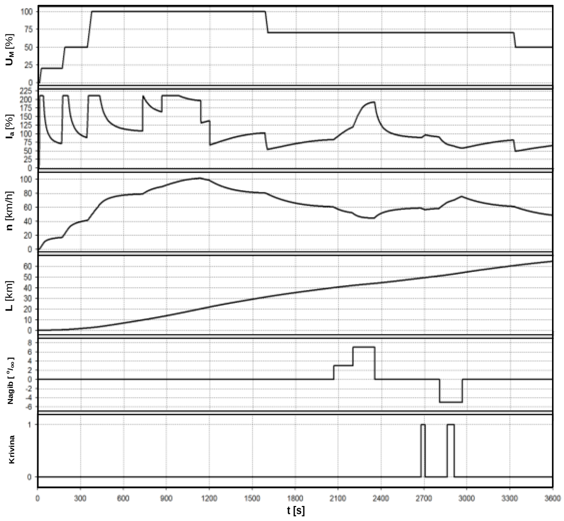

Figure 8. Simulation of dynamic traction characteristics of locomotive TENT 443, for the regular drive regime of 80km/h- option of road diagram at the load of 500t

Diagram in the Figure 9 shows dynamic electro mechanic traction characteristics of locomotive TENT 443, for easy drive regime of 20 and 5 km/h, with the load of 500 t. The following operational situations have been simulated:

- motion and acceleration up to nominal speed in the drive regime of 5km/h
- response of traction system at the change of traction resistance ±25% of traction nominal force
- acceleration up to nominal speed in the driving regime of 20km/h
- response of traction system at the change of traction resistance ±25% of traction nominal force and
- acceleration above nominal speed, as well as gradual speed reduction.

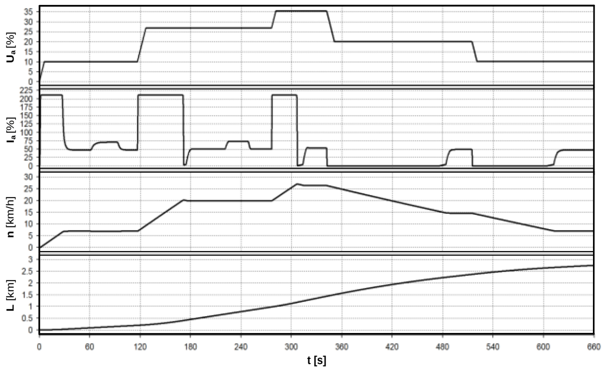

Figure 9. Simulation of dynamic traction characteristics of locomotive TENT 443, for the easy drive regime of 20 and 5 km/h, road diagrams at the load of 500t

IV. CONCLUSIONS

Analysis and simulation of the locomotive TENT 443 behavior in the normal traction regime of 80km/h and easy drive regime of 20 and 5 km/h, is possible by representing traction system elements through the appropriate modules and ways of their connection in compliance to the traction circuit.

This kind of an approach provides analysis of work of locomotive traction system in all operational conditions, with different parameters, in addition of monitoring interaction of typical parameters and volatile systems. It is especially important that operational conditions in which it comes to the overload of traction motors and which can endanger operation of motor and other equipment, can be simulated.

The results of simulations show correct behavior of model according to expected physical processes in electro and mechanical part.

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