INTEROPERABLE LOCOMOTIVE AT SLOVENIAN RAILWAYS

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In June year 2006 is on Slovenian Railways (SŽ) started to drive new interoperable three-system Siemens locomotive of kind Rh 1216.This event represents a major novelty in the fleet of traction vehicles in Slovenia. Apart from Slovenia, this locomotive can operate in all neighbouring countries and elsewhere in Europe. It features a modern technique of control, four systems of safety devices and is fulfilling all requirements, effective in Europe. Along with all advantages, the new type of electric locomotive will bring to Slovenian Railways many difficulties connected with the obsolete infrastructure at Slovenian Railways, greater impact on environment etc. At the moment is in Slovenia 20 these locomotives, the same kinds will buy SŽ still 12 locomotives in time period of one year.

Key words: locomotive, railway, power, overvoltages, stray currents

INTRODUCTION

Figure 1 is showing the interoperable locomotive, 541 series.

Figure 1. Interoperable locomotive on SŽ, 541 series

This is a three-system locomotive, which can be operated under the following systems of electric traction:

- direct current system 3000 V
- single phase system 25 kV, 50 Hz (Croatia)
- single phase system 15 kV, 16 2/3 Hz (Austria)

Technical data of the locomotive 541 series /1/:

- mass of the fully equipped locomotive, with new wheels and a 2/3 store of sand = ca 87t,
- wheel arrangement = Bo'Bo'
- nominal output on wheels = 6.4 MW for single phase systems, 6 MW for 3000 V DC system
- maximum traction force = 300 kN (starting traction) and 270 kN continuously
- maximum braking force = 150 kN
- output of the electric brake in the regenerative braking mode = 6.4 MW
- output of the electric brake in the rheostatic braking mode = 2.6 MW for the 3000 V DC system
- maximum operational speed = 230 km/h

For the estimation of the utilization value of a locomotive, the form of the traction characteristic, which shows the value of the traction force *F* (its variation) on the wheel rim depending on the speed, which is expressed in the following equation /2/:

$$F = f(v) \qquad (1)$$

Figure 2 /3/ is showing the traction characteristics of the three-system locomotive, operating under 3000 V DC, and under 25 kV AC, 50 Hz, single phase supply systems.

During the start the locomotive develops the maximum starting traction force of 300 kN on the wheel rim.

After accelerating to a speed of 80 km/h, the traction force is reduced to 270 kN under 3000 V DC and to 265 kN at 83 km/h under 25 kV AC, 50 Hz single phase.

The values 80 km/h and 83 km/h represent the critical locomotive speed at maximum traction force. This means that continuous travelling

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below this speed at full traction force would cause overheating of electric traction motors. Hence, the traction force is decreasing from the critical speed hyperbolically (equation 1.2) /2/.

$$F = \frac{P}{v} \qquad (2)$$

where

- F = traction force in kN,
- P = mechanical output of the locomotive on the wheel rim in kW,
- v = speed in km/h.

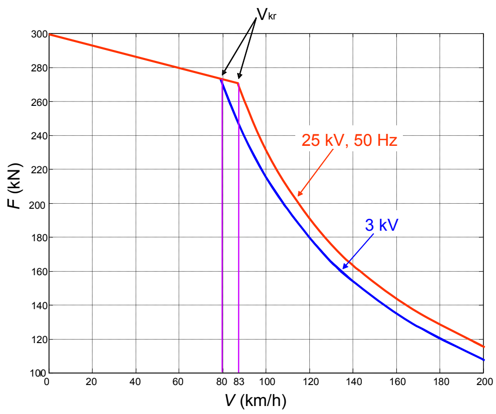

Figure 2. Traction characteristics of the three-system locomotive 541 series

DESCRIPTION OF OPERATION OF THE LOCOMOTIVE

The electric drive of the locomotive is fed from two converters with IGBT power semiconductors and asynchronous traction motors (ASM). Each of the converters is associated with one motor bogie.

Each of the four traction motors is equipped with one impulse converter (PRS) which is supplying the traction motor with variable voltage and frequency, one intermediate circuit, and one four-square converter (4KP) with the corresponding transformer winding.

The intermediate circuits of the motor bogie are among each other separated with isolators. In case of operation under alternating current two four-square converters feed the connected intermediate circuits including the 100 Hz choking circuit, connected in parallel. The traction motors are then supplied through PRS.

In the direct current mode of operation the intermediate circuits are supplied through the two-step network filter directly from the overhead contact line. Now the secondary transformer windings and the chokes of the choking circuit are acting as the chokes of the network filter and the capacitor of the choking circuit as the capacitor of the network filter.

The two modules 4KP, which are not required in direct current operation mode, serve in this case together with two resistors, connected in series, as generators of electric braking.

In the regenerative mode of operation of the locomotive some of the mechanical energy released by the train in downward progress can be converted by the traction motors into electrical energy and returned to the supply system. In systems, where the return of energy is not possible, the generated energy is to a certain degree released through the resistors.

In case of a fault in power semiconductors of the converter or in one of the traction motors the concept of the circuitry enables the locomotive to continue operating at a reduced output and the faulty piece of equipment will be disconnected. With the remaining elements the locomotive still develops 75 % of the maximum traction force at the start and 75 % of its maximum output.

The main-circuit diagram for the operation of the locomotive under single phase AC supply system is shown in Figure 3 /4/.

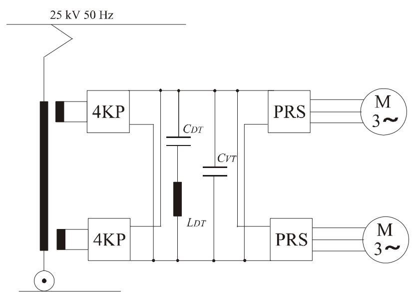

Figure 3. Main-circuit diagram for the operation of the locomotive under single phase AC supply system

The main-circuit diagram for the operation of the locomotive under DC supply system is shown in Figure 4 /4/].

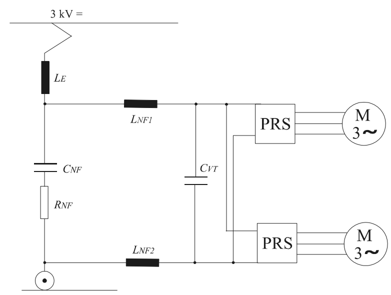

Figure 4. Main-circuit diagram for the operation of the locomotive under DC supply system

PERFORMANCE OF THE NEW MULTISYSTEM LOCOMOTIVE IN COMPARISON TO THE EXISTING MOST POWERFUL LOCOMOTIVE AT SŽ

Figure 5 is showing the French locomotive for DC operation, 363 series, which was until the arrival of the three-system locomotive the most powerful locomotive at SŽ.

Figure 5. Locomotive for DC operation at SŽ, 363 series

At present, this locomotive is mainly used for the traction of heavy goods trains on the railway line to Koper, therefore it is very interesting to study its performance, which is shown in the graph of the following Figure 6 /3/.

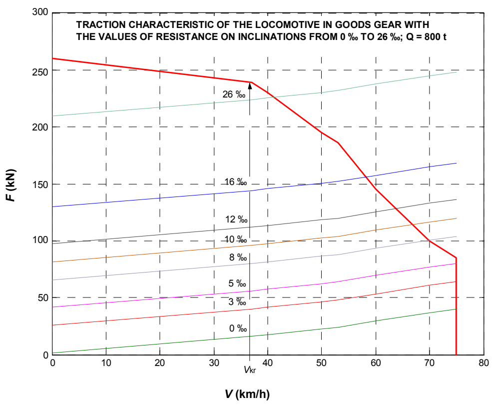

Figure 6. Traction characteristic of the French locomotive, operating at 3000 V DC

In Figure 6 the red line indicates the maximum traction output of the locomotive as a function of speed. Transverse curves represent the resistance to the traction force for a travelling train with a mass of 800 t. The intersection point of a resistance curve with the curve of the traction output is determining the maximum speed at this inclination. In the Figure is also indicated the critical speed of the train (37 km/h). This is the speed, at which the train is still permitted to travel at full traction force without damage to traction motors.

For comparison, Figure 7 is showing the traction characteristic of the new three-system locomotive with line resistances of a train with the mass of 800 t.

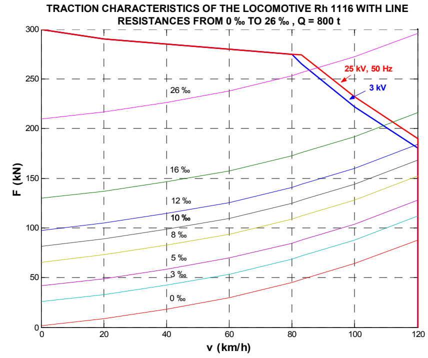

Figure 7. Traction characteristics of the three-system locomotive, 541 series

The three-system 6 MW locomotive operating under DC system is capable of travelling at full traction force at a speed of 80 km/h (critical speed), which is for the requirements of goods trains absolutely satisfactory. It can be seen from the graph that the locomotive is capable of pulling a train of 800 t at a speed of around 90 km/h on an incline of 26 ‰. When operating under AC single phase system the locomotive is capable of developing even a slightly higher output.

COMMUNICATION SYSTEMS ON BOARD OF THE LOCOMOTIVE 541 SERIES

Two types of communication systems are installed on board of the locomotive 541 series:

- radio dispatch interconnection (RDZ) of the type Kapsch (Figure 8)
- communication among individual locomotives

Figure 8. Radio dispatch interconnection on board of the locomotive 541 series

An RDZ is installed on the control desk in the driver's cabin. It serves for the communication between the driver and the line dispatcher during the journey (channel A) and for communication between the driver and the traffic personnel in the railway station area (channel C).

The data bus enables the driver to communicate with the other driver's cabin or with the other driver when two locomotives are coupled together.

THE INFLUENCE OF THE NEW INTEROPERABLE LOCOMOTIVE ON TRANSPORT INFRASTRUCTURE AND THE ENVIRONMENT

Railway DC overhead systems in operation are the cause of negative effects on the environment and on the infrastructure in the area of railway lines. First of all, there are two effects to be mentioned, when discussing the new 6 MW locomotive:

- stray return currents on the 3000 V DC railway line
- overvoltages in the supply network 3000 V

The traction vehicle, operating under 3000 V DC system is receiving electric power from the rectifier station (ENP) through the overhead traction network (contact line). The circuit is closed through the locomotive and the rails back to the rectifier station as shown in Figure 9.

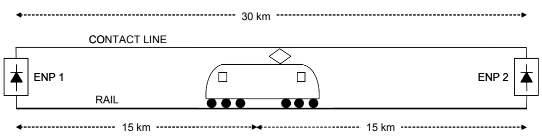

Figure 9. Working circuit of an electric traction vehicle

Rectifier stations at SŽ operate in parallel, which results in a duplicate supply of the electric traction vehicle, as shown in Figure 9. This means that the return current flows through the rails back to rectifier stations in both directions, to ENP 1 and to ENP 2. When the vehicle is approaching ENP 2, the load is decreasing on ENP 1. When the vehicle is very close to ENP 2, there is still a minimum return current flowing to ENP 1. A single line supply of the traction vehicle exists at SŽ only on railway lines towards neighbouring countries with AC single phase electric traction systems (Austria and Croatia) and during the outage of an ENP or during maintenance of ENP. The rails are laid across wooden or concrete sleepers on road metal and represent at the same time the earth electrode of the working circuit of 3000 V DC electric traction system, as shown in Figure 10.

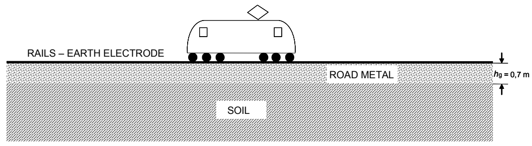

Figure 10. Earthing of the operating circuit of electric traction

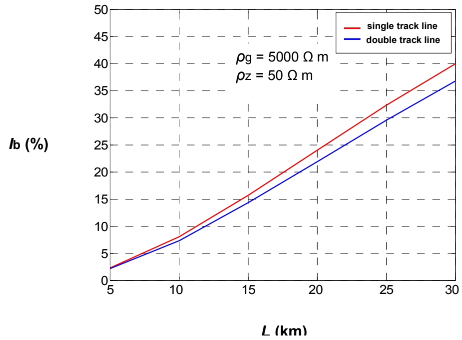

Figure 11. Graphical presentation of stray currents

As shown in Figure 11, the value of stray currents depends on type of soil, and on the quality of road metal. Figure 11 /3/ is showing the value of stray currents for the case under discussion for a distance of 15 km between the locomotive and the ENP, an earth resistivity of 50 Ωm, and a specific resistivity of road metal of 5000 Ωm. Because the new locomotive has more than twice the output of the existing locomotive 363 series, it also causes higher current loadings and consequently a higher percentage of stray currents. Therefore the number of rectifier stations at SŽ should be increased to reduce the distance between two adjacent stations to maximum 15 km. As a consequence the distance between the locomotive and ENP would be twice shorter and stray currents would also be reduced.

In addition to stray currents, the new 6 MW locomotive is also introducing another problem into SŽ, i.e. the operational overvoltages. Traction motors on the locomotive are asynchronous machines, which act during braking as generators. Thus, it is possible to return the generated energy back into the supply network, but this energy can not be used at SŽ. Therefore the energy is converted into heat in the braking resistor of the locomotive. Figure 12 is showing the traction/braking characteristic of the locomotive 541 series /3/.

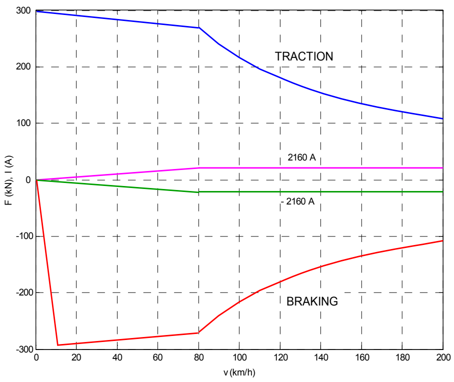

Figure 12. Traction/braking graph of the three-system locomotive 541 series

It can be seen from Figure 13 that the locomotive develops during traction and during braking a force of up to 300 kN and a current of 2160 A at a rated voltage of 3000 V. Discussed will be the case, where there are two 6 MW locomotives at a distance of 10 km (node 1 and 2) between two rectifier stations which are 30 km apart, whereat one locomotive is pulling with a current of 2160 A and the other one is braking with the same current (Figure 13).

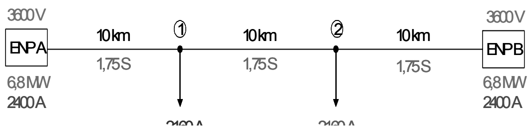

Figure 13. Traction and braking of two 6 MW locomotives

The following result is obtained after performing the calculation:

$$U_v = \begin{matrix}1\\2\end{matrix}\begin{bmatrix}4011\\3189\end{bmatrix} \text{V} \qquad (3)$$

The voltage on the pantograph of locomotive 1 which is braking, has risen to over 4000 V, which actuates the electricity supply protection. The overvoltage protection device on the locomotive is set to 4200 V. For this reason is the electric braking force of locomotive 541 series limited to 150 kN for operation under 3000 V DC system and the voltage rise of the traction network is in this way prevented to rise over 3900 V during braking.

POWER SUPPLY OF SLOVENIAN RAILWAYS AND 6 MW LOCOMOTIVES

The new 6 MW locomotive has the following impact on the power supply of Slovenian Railways:

- output of the locomotive is 6 MW, outputs of rectifier stations are mainly below 6 MW, which means power insufficiency – incomplete utilization of locomotives,
- rectifier stations are not able to return energy, generated by regenerative braking back into the public supply network – occurrence of overvoltage,
- the overhead wire system on single track lines is insufficiently dimensioned to carry the current of these locomotives, which is causing excessive current density in the wire system - heating of conductors,
- there exist 18 rectifier stations at SŽ, for the full power utilization at least 30 would be required.

AC single phase traction system at Slovenian Railways

As the locomotive under discussion is of the three-system type, it is a matter of interest how the conditions would change in case of 25 kV, 50 Hz AC single phase traction system at SŽ. With regard to requirements, 6 substations of 30 MW output are needed at Slovenian Railways for the 25 kV, 50 Hz AC single phase system, as shown in Figure 14 /3/.

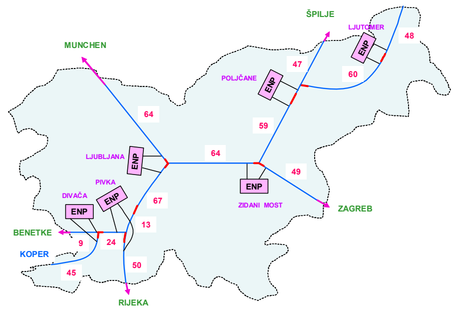

Figure 14. Arrangement of AC single phase substations ENP, 25 kV, 50 Hz for electrified railway lines of SŽ

Figure 14 is showing a simplified arrangement of all six substations ENP. A single line supply of the contact line is provided from each substation. All contact lines are among them separated by means of a dead line, shown in the figure in red colour. The line from Pragersko to Hodoš, which is at present not electrified, has also been taken into account. ENP in Divača is covering only 54 km of electrified railway lines, of which 9 km towards Sežana and 45 km towards Koper. The reason is the expected construction of the second track between Koper and Divača and the extremely difficult configuration of this line with an incline of 26 ‰. In this case only single line supply is provided, whereat the sections of the railway line are about 70 km long. Figure 15 is showing relations, when there are over a distance of 70 km three locomotives, each with a load current of 285 A.

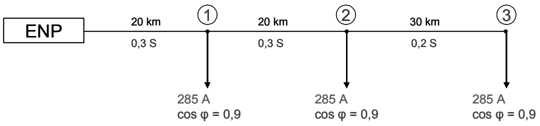

Figure 15. Single line supply of three trains under 25 kV, 50 Hz AC single phase system

The calculation provides the following result:

$$U_v = \begin{matrix} 1 \\ 2 \\ 3 \end{matrix} \begin{bmatrix} 22435 \\ 20725 \\ 19443 \end{bmatrix} \text{V} \qquad (4)$$

In the worst case the voltage drops to 19 kV, which is by all standards of the above mentioned AC single phase system sufficient for normal operation of traction vehicles.

OPERATIONAL COMPATIBILITY OF THE LOCOMOTIVE 541 SERIES WITH OTHER LOCOMOTIVED IN EUROPE

The computer system of the locomotive makes the operation of two or more locomotives of this kind yoked together and controlled from one driver's cabin possible. This is also possible in combination with other series of locomotives at SŽ and in Europe /1/:

- D – loc. Rh 2016,
- E – loc. Rh 1016,
- E – loc. Rh 1116,
- E – loc. BR 189….

CONCLUSION

The locomotive 541 series positively represents a great achievement for Slovenian Railways. At present locomotives with similar performances like locomotives 189 series operate at SŽ. When driving such locomotives, attention must be paid to loading currents to prevent the disconnection of supplying rectifier stations. Many raise the question why three-system locomotives are needed. But then the single-system 3000V DC locomotive would suffice for Slovenian Railways. Three-system locomotives are required because they can also operate in neighbouring countries as well as in other European countries. On the other hand, the three-system locomotive represents a demanding technology. It is a transitional phenomenon for the period of time before a unified traction supply system i. e. 25 kV, 50 Hz AC single phase will be introduced in all European countries.

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INTEROPERATIVNA LOCOMOTIVA NA SLOVENSKIM ŽELEZNICAMA)

U junu 2006. godine na Slovenačkim železnicama počela je da se koristi nova interoperativna Siemens-ova trosistemska lokomotiva tipa Rh 1216. Ovaj događaj predstavlja glavni novitet u voznom parku šinskih vozila Slovenije. Nezavisno od Slovenije, ova lokomotiva može se koristiti u svim susednim zemljama, kao i bilo gde u Evropi. Njene odlike su moderna tehnika za kontrolu, četiri sistema sigurnosnih elemenata i činjenica da ispunjava sve zahteve, posebno u Evropi. Uporedo sa svim prednostima, novi tip električne lokomotive doneće Slovenačkim železnicama mnoge poteškoće vezane za zastarelu infrastrukturu Slovenačkih železnica, povećan uticaj na okolinu i ostalo. Trenutno je na Slovenačkim železnicama 20 ovakvih lokomotiva, a u toku sledećih godinu dana planirano je da se kupi još 12 istih.

Ključne reči: lokomotiva, železnice, snaga, prenaponi, električno rasipanje