COMPARATIVE STUDY OF THE ELECTRIFICATION SYSTEMS 1X25 kV AND 2X25 kV

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1. PURPOSE

The purpose of the present document is to present a comparative study of the two different power traction systems that are being used currently in the lines of the Spanish High Speed Network.

Specifically, in Spain there is one complete line with the 1x25 kV electrification system, Madrid – Sevilla Line, and also some sections of the Line Madrid - Barcelona, such as, the entry to Zaragoza Station or the entry to Barcelona. The rest of the high speed lines in Spain are electrified with the 2x25 kV system.

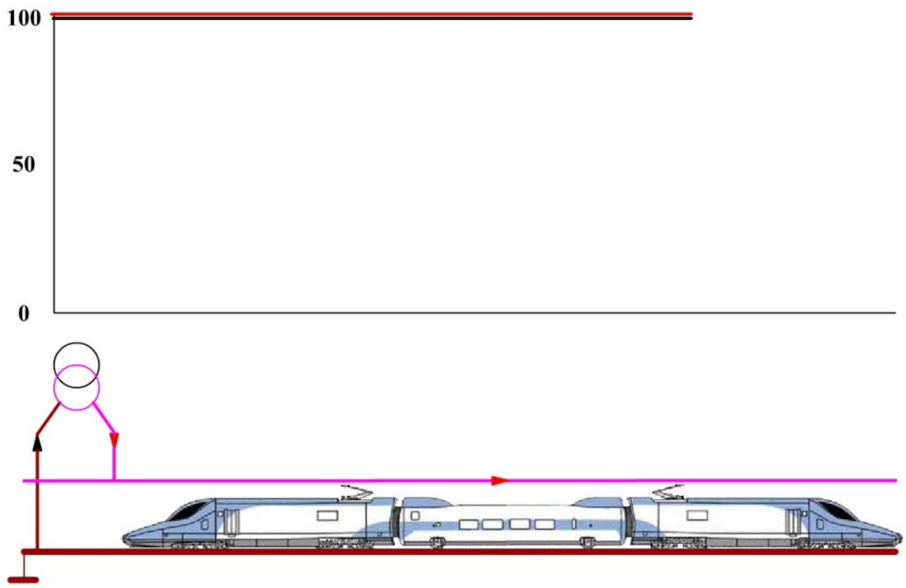
This document contains a brief description of each system, analyzing the operation of each one, together with a conclusion chapter that contains the main advantages and disadvantages that should be taken into account for the selection of the traction system.

2. System description

2.1. 1x25 kV System

This system was the one selected for the electrification of the first line fed with alternative current in Spain, Madrid – Sevilla line.

The principle of the system is quite simple, feeding the overhead line through a phase of a 25 kV substation and closing the circuit through the return circuit. The current flowing in the overhead contact line and the feedback loop is the same as can be seen in the chart below:



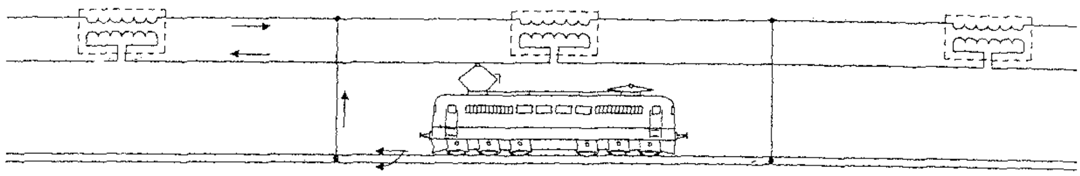
In order to reduce the impedance of the overhead contact line, at regular intervals (approximately every 10 km) the overhead contact lines of both tracks are connected in parallel. This provides distances between substations of 40 km, so under normal conditions, each substation supplies power to two sections of 20 km, one section before the substation and the other after it. Under degraded situation, with a substation out of order, the two collateral substations to the inoperative one have been sized in order to be able to feed the 40 km of distance between each one of them to mentioned substation.

The current return circuit, which will have the same value as the existing in the overhead contact line, comprises the rail, the return cable and the earth.

The grounding of the return cable is done at each catenary pole. The return cable is connected to the rails every 600 m or so. The current return through ground to the substation is around 20 to 23%.

Due to the system design, the traction current produces a loop, from the substation to the train. It is perpendicular to the ground what causes a high induction in conductors parallel to the railroad. In addition, the current that is closed by ground is elevated, to be around 20% of the current in the overhead contact line.

There is the possibility of installing booster 1:1 ratio transformers connected in series along the line every 3 to 8 km. These transformers are connected as follows: the primary is connected to the overhead line and the secondary to a return cable insulated from ground as shown in the figure below:



This design makes the current flow through rail is solely between the train and the nearest transformer and from there by the return feeder. Thus, the currents through ground are reduced, and since the return feeder is laying parallel to the overhead contact line, the inductions in parallel conductors are also reduced.

The use of booster transformers has two inconveniences apart from the price of the equipment. On the one hand, the serial installation increases the impedance of the line therefore the distance between substations is reduced. On the other hand, it is necessary the installation of section insulators in the overhead contact line in front of each transformer. In these insulators, electrical arcs are produced to the passing of pantographs causing a greater wear on the contact strips.

For the Madrid – Sevilla line, it was checked that the adopted solution in the return circuit was enough and the solution of the installation of booster was dismissed.

Therefore the system of 1x25 kV is a simple system not only from the constructive point of view, but also from the operation and maintenance. All switchgear required for its installation is single-phase so together with its simplicity it results a very economic system.

In case of being necessary the reduction of the electromagnetic induction or the reduction of current flow through ground and rail, it can be use the booster transformer. It increases the price of the installation due to the rise of the elements to be installed and also because it reduces the feeding area of each substation. It also implies a rise of the maintenance expenses of the pantographs of the rolling stock.

2.2. 2x25 kV system

The system 2x25 kV is based on the idea of distributing the voltage along the line at higher voltage (50 kV) and feeding the train at 25 kV. For this the substations feed the system at 50 kV and through intermediate autotransformer centres supply power to the rolling stock at 25 kV.

To implement the system, the substation will have transformers with secondary at 50 kV with intermediate tap. This tap will be connected to rail and ground performing the functions of neutral in the system. From the two phases, one will be connected to the overhead contact line and the other to the auxiliary feeder also known as negative (voltage is 180º out of phase with respect to the overhead contact line). Thus, between the catenary and the rail (rolling stock power supply) there is the required 25 kV. The intermediate autotransformer centres will be connected between the catenary and the negative, with the midpoint connected to rail and ground.

The feeding of the substation to the line will be in antenna, that is, without substations in parallel.

Moreover, as shown later, the system 2x25 kV should always finish in an autotransformer center, therefore at each side of the neutral zone between two substations, an autotransformer centre must be located. The rest of autotransformer centres will be located along the line.

This solution is used in almost all the high-speed rail network in Spain, with the exception of the Madrid - Sevilla line mentioned above. The distances between substations can reach 75 km without voltage problems and ensuring that in case of failure in a substation, the collateral is sized to power the entire 75 km. The placement of autotransformer centres will depend on the operational needs and the availability of high voltage power lines close to the railway. These autotransformer centres restrict the inductions over the parallel conductors, so that, they will be further needed when limiting the induction effect is more required. In Spain it is common to locate these centres every 10 - 12 km up to a maximum of 20 km in areas where mitigation is not necessary or even just at the endpoint of a substation feeding.

The return system is similar to that used in 1x25,that is, using the rail connected to return wire every 400 m. The return cable is connected to ground via 2 m rods on each support of overhead contact line.

2.2.1. Installation description

As above mentioned, this system (2x25) is mainly composed of substations and autotransformer centres.

Within the substations we will distinguish three parts:

- ✓ Incoming point.
- ✓ Transformer group.
- ✓ Medium voltage distribution and output.

In order to reduce the effects of the unbalances created by connecting a single-phase transformer to a three-phase network, the incoming power supply will be done from a network with a high short-circuit power or by using very expensive phase compensation systems. This problem also exists for the 1x25 kV.

The traction transformer has one primary winding and two secondary. The secondary ones are connected to each other 180º out of phase, so the connection group is II0-ii6. The connection between both windings is connected to ground and rail and therefore it will be used as neutral for the installation. From each transformer it will undertake to two-phase busbars ± 50 kV or 25 kV referenced to ground.

The scheme will be the following:

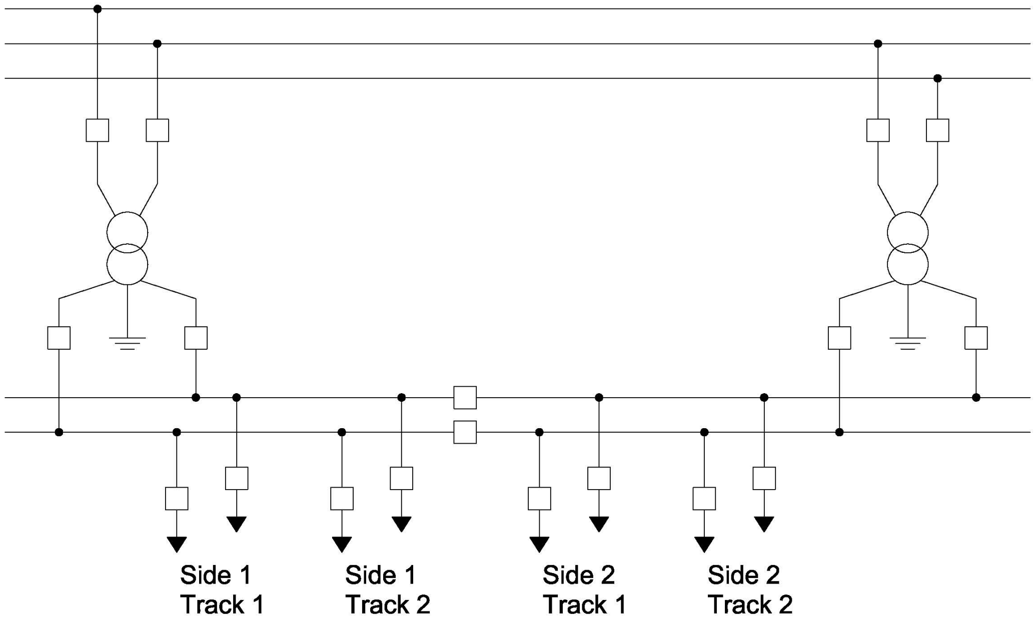
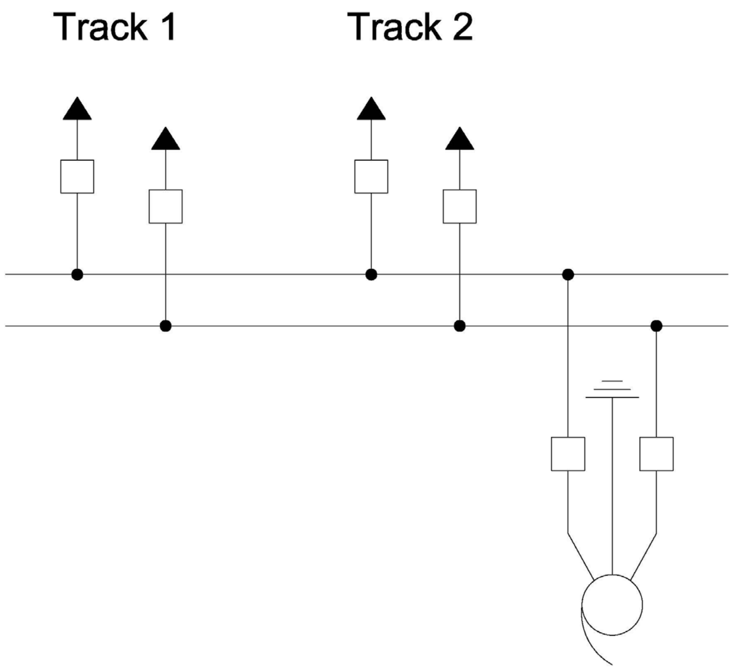


Image below shows a traction substation belonging to Madrid – Barcelona high speed line. Substation of the Utility Company is located annexed to the traction substation.

Autotransformer centres will have the connection or feed, from the line to the bar and also the own autotransformers groups.

As in the case of the transformers of the substation, the midpoint of the autotransformer will be connected to ground and to the rail track, that is, the neutral of the installation.



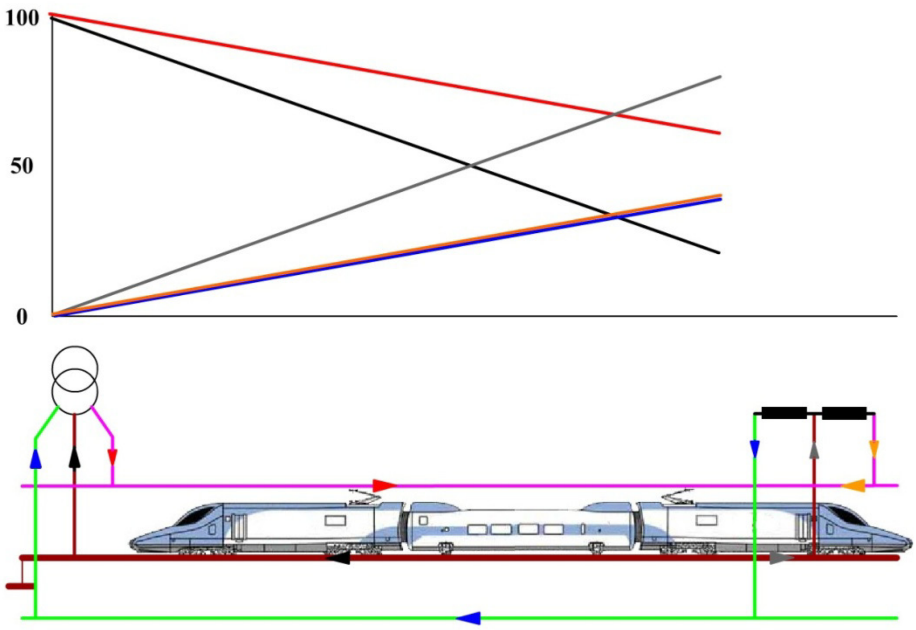
In the case of the final autotransformer centres, opposite to the neutral areas inter-substations, there are two independent autotransformers, each one with its own set of bars. In order to feed from a collateral substation, in case of failure of the substation, joint bars are located in the final autotransformer centres from which the neutral zone is bypassed.

Following figure shows the current variation as the train moves away from the substation to the first autotransformer centre.

2.2.2. Operation of the system

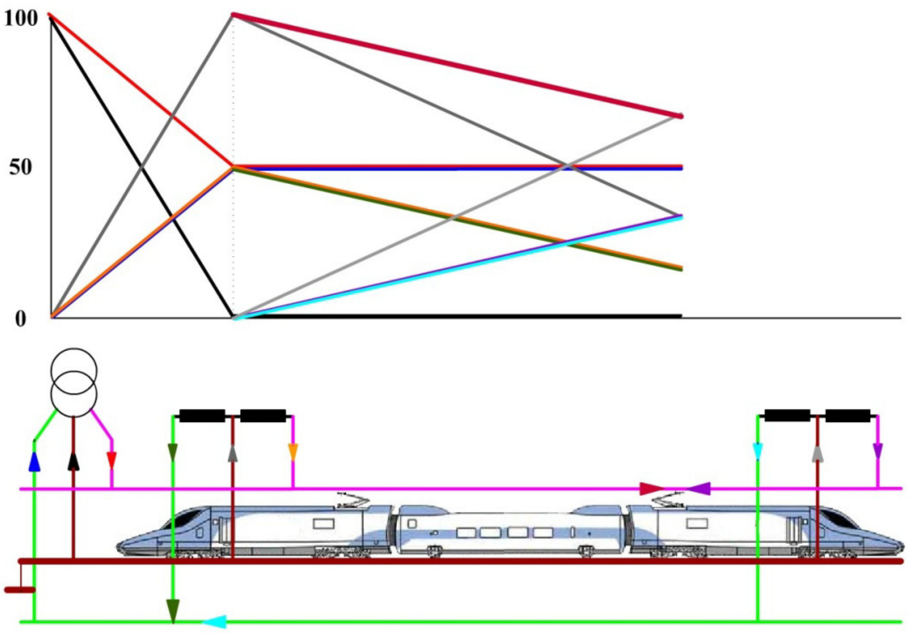
The operation of the system depends on the position of the train regarding the substation and the autotransformer centres.

Following figure shows the current variation as the train moves away from the substation to the first autotransformer centre.

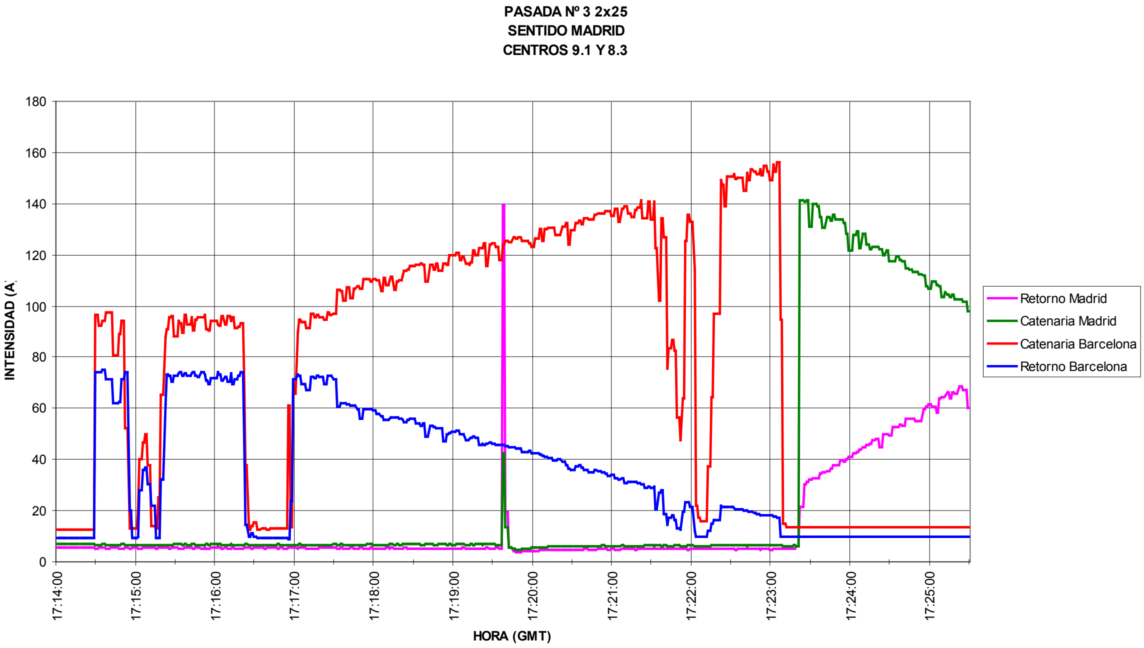


As the train moves away from the substation, the current supplied from the substation to the overhead contact line decreases from 100% to 50%. The rest is supplied by the autotransformer centre through the negative feeder. Therefore from the autotransformer centre is supplied between 0% and 50 % of the current consumed by the train. Current from the train is closed through the neutral (rail) to the substation and the autotransformer centre. The current flowing through the return system goes from the 100% when the train is in front of the substation to the 0% when the train reaches the first autotransformer centre.

In case of being between two autotransformer centres, the current supplied by the substation will be 50% since it returns through the negative and so that there is not current flow through the neutral (rail) between the substation and the autotransformer centre. Power supply to the train is done from the autotransformers varying between 50% and 0% depending on the proximity of the train. Thereby when the train reaches the first centre, 50% of the required current comes from the catenary from the substations and the other 50% from the autotransformer centre. When the train is in front of the second autotransformer centre 50% of the current comes from the substation through the catenary and the other 50% from the second autotransformer centre. If there is no a second autotransformer, we will always have the 50 % from the substation and the 50% from the first autotransformer so that once the train passed the first autotransformer, through the overhead contact line flows the 100% of the current, as happens in the system 1x25 kV.



The operation described is theoretical since in practice, due to impedance imbalance between the Overhead Contact Line (OCL) and the negative feeder, the current that goes through the OCL and through the negative feeder is not equal, therefore there is always a current flow through the return circuit. The value of this current depends on the material of the conductors and the geometry of the overall system. The following graph shows this effect, however it is not totally representative since it comes from a testing environment. The represented data are the results of the measures carried out during the testing period in the Madrid – Barcelona High speed line for the area around Peñalba.



The 2x25 system has a more complex operation which implies a more expensive installation since it includes not only the negative feeder and the installation of autotransformer centres but also all the switchgear has to be bipolar. This greater number of facilities also implies a higher maintenance cost.

On the other hand, the distance between substations is higher (almost double) therefore fewer substations have to be built, however the power of each substation is greater (almost double) so the connection points to high voltage network require higher short-circuit power.

3. Main differences

It is not entirely correct to talk of advantages but rather of characteristics of a system that may advise its use in each application.

The principal characteristic of 2x25 kV system is that since the distribution of the power is done with the double voltage of the 1x25 kV system the current flowing is reduce to half. It involves:

1. Minor losses by Joule effect in the line
2. Minor electromagnetic interference to other installations
3. Minor voltage drops in the overhead contact line

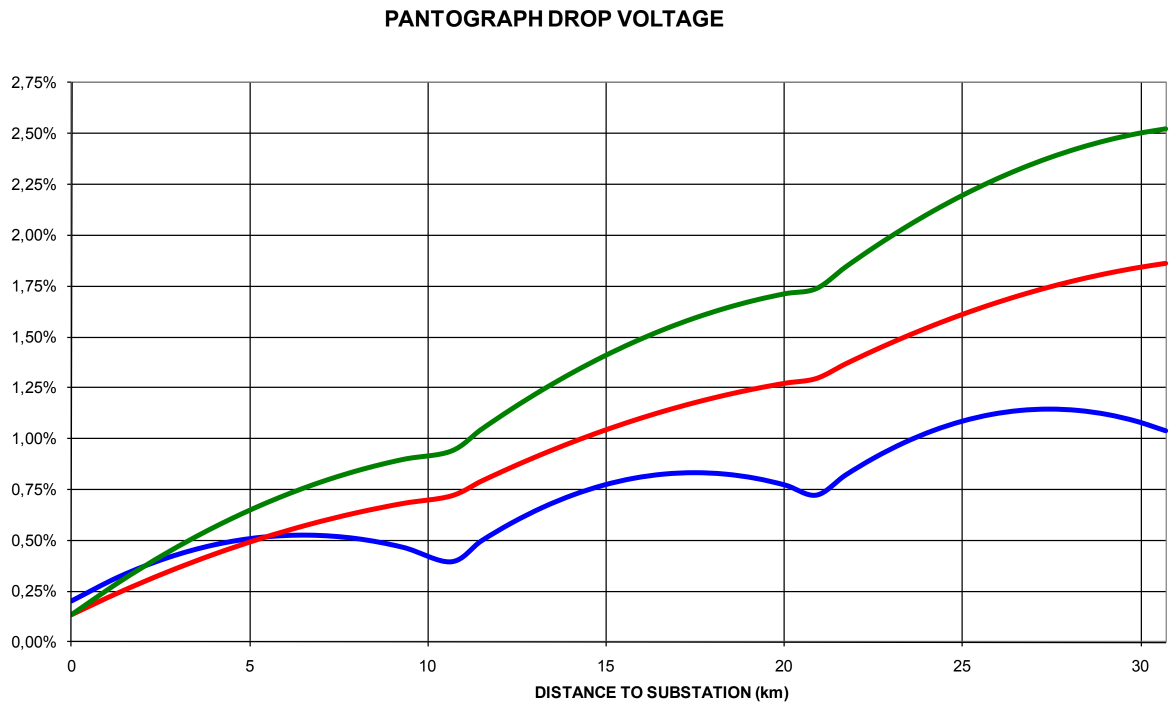
The first two characteristics are obvious advantages for the system operation. On the other hand, minor voltage drops have two significant effects:

- ✓ A more uniform voltage profile in pantograph with a better performance of the traction units.
- ✓ Minor quantity of substations for the power supply to the line.

The minor quantity of substations implies the construction of minor quantity of connection lines (incoming supplies points) with the consequent reduction of social, visual and environmental impact that these installations involves. However the power required is higher.

Moreover, 2x25 system is a more complex system that requires a larger number of facilities/installations and equipment, which makes a more expensive maintenance and that the installation may be also more expensive than other systems. For the Spanish case the overhead contact line in 2x25 kV is around a 15% more expensive than the 1x25, mainly due to the installation of the negative feeder. The cost of the autotransformer centres is higher than the savings coming from the reduction of the substation number. However in this value it has not been included the cost of the high voltage line for the connection of the incoming power supply that in some cases can result greater than the substation itself, nor the cost of the land required for the construction of the substation and the autotransformer centres, that may be an important value in urban areas.

It has to be taken into account that the 2x25 kV system uses more quantity of conductor so that it would be normal that the equivalent impedance is less. In the chart below the voltage drops in pantograph are represented for a rolling stock unit, feed with 1x25 kV (green line) and 2x25 (blue line) and the 1x25 kV with the same total section than those used in 2x25 kV (red line). Results show that the more efficient system is the 2x25 kV.



4. Conclusions

The selection of the electrification system between 1x25 and 2x25 kV requires a detailed study of each case, including both technical and economical evaluation of the benefits of each system. It is even possible that the more appropriate solution will be a mixed solution where in the same line both systems coexist, such as in Zaragoza environment, belonging to the high speed line Madrid – Barcelona, where laying a negative feeder was impractical.

For the Spanish scenario, where the high speed lines have long sections in parallel to the conventional railway lines electrified with direct current, the 2x25 system was selected since in this way the interferences of the line electrified in alternative current over the line in direct current would be reduced. In addition, since fewer substations are needed and therefore minor quantity of high voltage line for the connection to the incoming power supply, the negative impact of high voltage lines on the environment is reduced.

In recent studies, the new railway layout run through areas of lower electric development, so that the incoming power supply points with adequate characteristics are fewer and the necessary very high voltage lines are increasing. In these cases, the system 2x25 has been proved to be the most economical option for electrification.

For all presented above, the best conditions for installation of 2x25 kV system are given in the following cases:

1. Long distance railway lines with a high power demand
   - ✓ Due to a high operation speed
   - ✓ Due to a high traffic demand
2. Layouts with high difficulty for electrical power supply
   - ✓ Electrical infrastructure underdeveloped
   - ✓ Areas with high ecological value
   - ✓ Areas with high social and/or visual value

Nevertheless, for every situation it will be necessary to carry out the appropriate technical-economical study, in order to determine the optimum electrification system to be installed.