Introducing new rolling stock in existing railway systems, the best of both worlds?

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Abstract

In order to increase freight capacity, Comboios de Portugal is introducing new freight locomotives of the LE 4700 type. For the homologation process REFER, the Portuguese infrastructure manager uses standards like EN 50238 and EN 50388. Unfortunately these standards only give guidance on a high abstract level. Two issues were of special interest in the homologation process, system stability and compatibility with the train detection layer.

Due to the long economical and technical lifespan of infrastructure equipment, this is a legacy system, in which many relatively old systems are present of which requirements are not well known. Thus a homologation process is needed, which is complex, as it is difficult to prove that new modern equipment functions correctly, safely and reliably in the existing complex infrastructure. Concerning system stability, to assure that no inadmissible resonances occur in the traction power supply system, simulation studies on the entire Portuguese network were used, in combination with measurements of the locomotive (in dual traction) in various driving configurations. A clever combination of measurements and simulations made it possible to prove that system stability could be guaranteed.

Concerning compatibility with signalling systems, it was necessary to further define the immunity of the train detection systems. The steady state admissible interference currents of train detection systems are usually well known. In contrast, the dynamic behaviour, due to transients, is still largely an unexplored area. Normally this would lead to a very large number of test runs, as transients are by nature a stochastic process, and many train detection systems have to be researched. Combining simulations, measurements in laboratory and in the field, a full dynamic model of train detection systems was made. Using the model and actual measurements from the locomotive it was possible to analyse the situation. It came to light that wrong side failures could occur. However, it was demonstrated that compatibility could be reached by making modifications to the infrastructure. At the moment these modifications are being implemented in the infrastructure.

It can be concluded that this project demonstrates that a smart use of measurements, in combination with advanced modelling techniques, is beneficial for the homologation process as it reduces the amount of test runs needed. Thus it becomes possible to introduce new rolling stock in existing railway systems, increasing the capacity and services and at the same time guaranteeing the safety, reliability and availability of the transport system.

Introduction

In order to describe the interface requirements between rolling stock and fixed infrastructure, and to provide guidance to TOC’s when ordering rolling stock REFER has developed the internal standard ITE GER009.

This standard relies heavily on international standards like [1] (Interaction train detection), [2] (Interaction traction power supply system), as well as experience gained during homologation processes in the past. REFER specification [3] describes 19 requirement areas, of which compatibility must be proven. Basically the homologation process as described in [1] has been used. For parties involved, see Figure 1.
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In the case of the LE4700 loco, the TOC, Rolling stock operator is C.P. (Comboios de Portugal), Rolling Stock Industry is Siemens, Laboratory is ATS6 (a Siemens Affiliation), Infrastructure Manager is REFER, Signalling Laboratory is REFER EMC Lab (as they have the most experience with the systems in use in PORTUGAL. The formal accepting body is IMTT (part of the Ministry of Transport), which acts and decides upon the advice of REFER. As it can be concluded from the above, a clear separation of roles and parties is missing. For this reason (and for technical expertise and knowledge of the Portuguese Infrastructure) REFER commissioned Movares to perform the role of ISA.

Overview of homologation process

For each requirement it was decided which party had the main responsibility to check and demonstrate that the requirement has been met. Decisions were based on pragmatic reasons like experience available, and level of interest of requirement to parties involved (for instance compatibility with track circuits is extremely important to REFER, whereas primary and secondary suspension is of less importance to REFER, but is of importance to the TOC). An overview can be found in Table 1.

Table 1 Requirement areas of homologation process LE 4700

<table>
<thead>
<tr>
<th>Req.</th>
<th>Description</th>
<th>Main checking authority</th>
<th>Scope of ISA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EMC / Compatibility with Track Circuits</td>
<td>REFER</td>
<td>yes</td>
</tr>
<tr>
<td>2</td>
<td>Radiated Emissions, Magnetic Fields, Immunity</td>
<td>REFER</td>
<td>yes</td>
</tr>
<tr>
<td>3</td>
<td>Harmonic Content Injected on the Primary Network</td>
<td>REFER</td>
<td>yes</td>
</tr>
<tr>
<td>4</td>
<td>4 Convel TOC</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>Train radio TOC</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>EMC / Telecommunications</td>
<td>REFER</td>
<td>yes</td>
</tr>
<tr>
<td>7</td>
<td>EMC / Voltage on the panto when braking with</td>
<td>REFER</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>recuperative energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Substation, EN 50388, resonances</td>
<td>REFER</td>
<td>yes</td>
</tr>
<tr>
<td>9</td>
<td>Compatibility between Pantograph and Catenary</td>
<td>REFER</td>
<td>yes</td>
</tr>
<tr>
<td>10</td>
<td>Running Behaviour</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>11</td>
<td>Forces on track</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>12</td>
<td>Dynamic Gauge</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>13</td>
<td>Primary and Secondary suspension</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>14</td>
<td>Wheel Profile</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>15</td>
<td>Track Gauge</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>16</td>
<td>Weight of locomotive</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>17</td>
<td>Anti-Slip / Slide Protection</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>18</td>
<td>Other requirements</td>
<td>REFER</td>
<td>Yes if used</td>
</tr>
<tr>
<td>19</td>
<td>Not used</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>20</td>
<td>Brake Distance</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
<tr>
<td>21</td>
<td>Noise Emission</td>
<td>TOC/Manufacturer</td>
<td>No</td>
</tr>
</tbody>
</table>
As it can be seen from Table 1, in those cases where REFER did the main checking, the ISA played a role, as well as for safety related issues. For tests involving measurements on 25 kV installation, the differentiating/integrating system was used very often [4]. A large number of requirements mentioned above can be dealt with using Standards. Track circuits (No.2) are however not described fully in standards. Moreover, in Portugal, 12 different systems are in use for train detection, see table 2.

Table 2, Train detection systems

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Remarks</th>
<th>No.</th>
<th>Name</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FTGS 4/6</td>
<td>Audio frequency, coded, asymmetrical</td>
<td>7</td>
<td>ITE</td>
<td>Symmetrical</td>
</tr>
<tr>
<td>2</td>
<td>FTGS 9/17</td>
<td>Audio frequency, coded, asymmetrical</td>
<td>8</td>
<td>ER428</td>
<td>Level crossings</td>
</tr>
<tr>
<td>3</td>
<td>Siemens 125 Hz</td>
<td>Asymmetrical</td>
<td>9</td>
<td>CSEE 8700 Hz</td>
<td>Level crossings</td>
</tr>
<tr>
<td>4</td>
<td>Ericson 125 Hz</td>
<td>Asymmetrical</td>
<td>10</td>
<td>Axle counters</td>
<td>Alcatel AZA type 70/30</td>
</tr>
<tr>
<td>5</td>
<td>UM 71</td>
<td>Audio frequency, coded, symmetrical</td>
<td>11</td>
<td>Electronic pedal</td>
<td>EFACEC</td>
</tr>
<tr>
<td>6</td>
<td>Siemens DRS</td>
<td>un-coded d.c. asymmetrical, only in 25 kV and diesel areas</td>
<td>12</td>
<td>Siemens – 50 Hz</td>
<td>only in 1.5 kV d.c. areas</td>
</tr>
</tbody>
</table>

Of the list given above number 7 and 12 are not taken into account. ITE is, due to the way it is functioning considered to be immune to traction harmonic currents, and Siemens-50 Hz is not used in 25 kV areas, where the LE 4700 is operated. Gabarit values for these systems are given in [3]. For a number of train detection systems gabarits were subject of discussion, and have been studied in more detail, see below. Based on the gabarits given in [3] for each type of train detection, specific details for the measurement chain have been derived.

Of importance is to realise that [1] requires to study all realistic driving modes and degraded modes. The locomotive is meant to be used as single unit, as well as double unit. An overall view of the electrical installation of the locomotive can be seen in Figure 5. As it can be seen from this Figure, after a mains transformer the unit has two 4 QC inverters to feed a d.c. bus, and two auxiliary inverters to feed auxiliary equipment, and two traction inverters. When combining two locos this leads to 12 main components which can be active. This leads to 4096 different modes. Of course this is too much to check. So using a methodical approach eliminating doubles and symmetry the set of modes to be tested was reduced to 1 normal mode and 25 degraded modes. As all working points of inverters need to be tested, a number of dedicated driving cycles was developed.

Figure 2 Lab setup sensitivity Siemens 125 Hz
1. Stationary (limited time);
2. Acceleration from stationary to maximum speed, 100 % traction effort;
3. Braking from maximum speed to stationary, 100 % (electric) braking effort;
4. Acceleration from stationary to maximum speed, 50 % traction effort;
5. Braking from maximum speed to stationary, 50 % (electric) braking effort;
6. Acceleration from stationary to maximum speed, with pulsating traction effort (100% - 0% - 100%), with coasting at 45 km/h and 90 km/h;
7. Braking from maximum speed to stationary, with pulsating (electric) braking effort (100% - 0% - 100%), with coasting at 90 km/h and 45 km/h;
8. Acceleration from stationary to maximum speed, with pulsating traction effort (50% - 0% - 50%), with coasting at 45 km/h and 90 km/h; Braking from maximum speed to stationary, with pulsating (electric) braking effort (50% - 0% - 50%), with coasting at 90 km/h and 45 km/h;

**Figure 3** Results sensitivity transients Siemens 125 Hz

**Figure 4** Overview of field tests Torre de Gadanha
Gabarit studies

During the testing of the compatibility of the track circuits a number of violations of the steady state gabarit were observed. Upon closer inspection it became clear that all surpassings were related to transients, either caused by opening or closing of the main switch or by loss of current collection, for instance due to bouncing of the pantograph. The opinion of the test lab, that these gabarit violations could be ignored as they are caused by transients, was not shared by REFER and ISA. Therefore, a study was started to determine the gabarit for transients. An overview of the setup used can be found in figure 2 and 6. The setup consists of a laptop with a Labview application and multiple DA and AD converters. The Labview application is programmed in such way that it generates the Nominal 125 HZ signal for the local phase (using an amplifier and transformer). At the same time the 125 Hz signal for the track is generated, including transients. Using current & voltage probes, the input signals of the relay are monitored by the laptop, as well as the behaviour of the contacts. Using an automated process, it was possible to subject the relay to a large number of transients. Finally a relation was found between amplitude and duration of the transient and the state of the contacts, see Figure 3. Here too transients measured are given. It can be seen quite clearly that the transient caused by operation of the main switch is able to bring up an unactivated relay.
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Normally only the inadvertently bringing up of the relay is considered to be a wrong side failure, as this could lead to the conclusion of the track circuit being unoccupied, while there is a train on the section. However a temporary drop of a relay can also lead to a wrong side failure. In case a shunt route has been set, the temporary occupation of a track circuit at the end of this route might lead to the interlocking concluding that the route has been fully travelled, and can be cancelled. This might free the interlocking for the setting of a conflicting route, and thus leading to the risk of collisions and/or the moving of a point under a moving train.

For the DRS system a lab test similar to the one used for 125 Hz was developed, see Figure 4. First the resistance and inductance of the relay coil as function of applied voltage and frequency was determined in a lab experiment. Due to losses in the iron of the magnetic circuit and the skin effect for the windings, this is not trivial.

A number of synthetic test signals was defined and fed into the relay. Based on a large number of measurements the following conclusions can be drawn: The energy deposited in the relay by the quasi d.c. part of the signal is decisive. The contribution of the 50 Hz signal can be neglected. In case this energy is larger than 20 mJ, the relay can be activated.

A model was developed in Microcap, to determine the transfer function between transients injected in the track and voltage across the relay. As this transfer function is very important, the correctness was verified by a field test, see Figure 4. At the station of Torre de Gadanha, (Diesel line, mechanical signalling). Two long DRS Track circuits including cross-bonds were realised. Thus it was possible to determine the transfer function, in case of normal operation, but also in case of broken rail (traction rail or signalling rail). It turned out that the field measurements and the simulation model transfer function showed a difference less than 10%. A measured transient (inrush of main transformer) was converted into a synthetic signal. Then, using the transfer function the resulting voltage across the relay was determined. By calculating the energy, and comparing it to the 20 mJ mentioned earlier, the behaviour of the relay could be predicted. It turned out that the quasi d.c. part of the inrush of the main transformer of the LE 4700 could activate a DRS Relay. In Figure 7 we can see Test Signal 3 which is a worst case approximation by 10% of the worst inrush of the LE 4700 locomotive as measured by ATS6.

From Figure 8 we can see that the relay is activated by the transient and that the contacts will remain closed for approximately 1,85 s. Note that the relay drops at 0,66 V.

The solution to overcome possible wrong side failures in the case given above is twofold. First it is possible to delay the DRS relay by two seconds, a second solution is to link the cancellation of a route setting in the interlocking to the activation of not a single section, but to the activation of two consecutive sections, as the likelihood of two sections being liberated by the same transient is very small. The solution to delay the DRS relay by 2 seconds has been chosen.

![Figure 7 Worst case inrush of LE 4700](attachment:image)
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EMC

For EMC, both emission as well as immunity, REFER uses the Standard [5] which has proven to be sufficient in the past. The locomotive passed the test described by these standards without major problems, see Figure 9.

Figure 8 Behaviour of DRS relay for inrush of Figure 7

Figure 9 Radiated emission measured in accordance with [5]
System Stability

An important issue for REFER is system stability as described in [2], as the refurbishment of train sets has led to severe resonance problems in the past, reported in [6]. Between TOC, Test lab and manufacturer it was decided not to perform the theoretical study as described in [2]. Thus using the results from impedance studies in the past, and a spectrum from the locomotive, a risk analysis was performed on which substation were most endangered, see Figure 10. The most endangered were:
1. Fogueteiro;
2. Amadora;
3. Irivo;
4. Tunes;
5. Rodão

![Figure 10 Overview of substations and resonances](image-url)

All of these substations were tested thoroughly. No anomalies were found, only in the case of Rodão a surpassing of the limit of harmonics injected in the primary network was observed.

Catenary

Interaction between the pantograph and the catenary was tested by Schunck, the manufacturer of the pantograph on the line Poceiraõ – Pinhal Novo, equipped with catenary designed for 140 km/h. These test were passed successfully after some small modifications, see Figure 11.
Conclusions

The 4700 locomotive passed the homologation process successfully, but some modifications in the infrastructure were necessary to obtain this compliance. Once again it became clear, that when adding a new component to legacy system, quite often precise knowledge of the existing system is lacking. This was also true in the case we are discussing here. In order to be successful, these gaps in knowledge had to be closed in an ad-hoc fashion at short notice. Based on the above the main conclusion can be that it is indeed possible to successfully add new rolling stock to an existing infrastructure. Unfortunately, due to the split between TOC’s and infrastructure managers, (which is mandatory by EU regulations) and due to lacking knowledge of the fixed infrastructure on the side of manufacturers, an optimisation is very difficult, and we might never obtain the best of both worlds.

Acknowledgements

The authors would like to express their gratitude to all persons which helped during the field tests. Manuel Oliveira Jesus, as always was very handy with electronics and signalling systems. Pedro Almeida, Nelson Sousa, Mr. José Campaniço & Marco Santos performed very well in installing sensors in substations. Mr. Tomaz (CP) has proven himself to be an excellent driver, performing all those crazy driving cycles requested. Dr João Heitor was an excellent manager, never loosing his course in the large amount of paper and documents, produced during the homologation process. Thanh Le Quoc was excellent in data analysis and programming the software needed. All persons mentioned above made it possible to turn the crazy technical ideas of a bunch of wild engineers into correct and reliable functioning measurement systems. The jokes and cakes during the test runs of Mr. Roosevelt (CP) were very much appreciated. Hans Minkman came through just in time with his safety analysis of the measurement system.

References


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