Measurements on 25 kV Traction Power Supply Systems

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Summary
At the moment 25 kV traction power supply systems are being introduced in the Netherlands. Currently in the Netherlands a 1500 V DC system is used, however due to increasing energy demands this system is no longer sufficient. For the high-speed lines and heavy freight lines, which are under construction, the 2x25 kV AC system has been chosen. Introduction of this new technology leads to differences compared to the existing systems. Of particular interest are EMC topics such as influence of the traction power supply system on signalling systems, or systems in the close vicinity of the railway system. The latter is especially important in the Netherlands where the railway system runs through densely populated areas.

A part of the first Dutch 25 kV line, the “Havenspoorlijn”, connecting the Rotterdam Harbour with the hinterland, will be used as a Pilot-Project. This line will be equipped with several measurement systems, to validate the system design. This project is financed by NS Railinfrabeheer.

Preliminary measurements have been performed on the 25 kV system of the Luxembourg Railways, in a way similar to earlier experiments along a TGV track near Lyon, France. Prerequisite for measurements is that the normal traffic is not disturbed, and that the EMC of the system complies with the harsh EM conditions in the very close neighbourhood of the railway. Special techniques and sensors have been developed which allow measurement of current distributions, voltages and magnetic fields, without hampering the normal traffic.

Measurements have been performed on a 25 kV RT system and a 25 kV AT system. For the RT system the measurements were done during normal traffic conditions. For the AT system the measurements were done during the daytime with the normal schedule. During the night a light engine was used, and different switching configurations of the supply system could be created.

Keywords: Environment, EMC, Measurement Techniques
1 Introduction
The introduction in the Netherlands of 25 kV AC traction systems will start with the Pilot-project on the “Havenspoorlijn”, at the end of 1999. During several months extensive tests will be carried out to validate the Dutch 25 kV system design.

In order to obtain experience in measuring in the 25 kV railway environment Holland Railconsult initiated a series of measurements on the 25kV system of the Luxemburg Railways (CFL).

The recently electrified North Line of CFL was chosen (Fig. 1) for these measurements. Two measurement locations were used, Kautenbach and Göbelsmühle. At Kautenbach measurements were performed on a RT-system. At Göbelsmühle measurements were done on an AT-system.

2 Measurements
On both measurement locations emphasis was on measuring the total current distribution of the system. This is of importance in order to calculate the earth return current, i.e. current not returning in any “proper” conductor. Also magnetic fields (both horizontally and vertically) in the close vicinity of the track were measured. Voltage or current in the cross-connection between mast and rail were measured. At Göbelsmühle 190 m of a shielded signalling cable of a type which is going to be used on the “Havenspoorlijn” was installed. Transfer impedance measurements were performed on this cable using the traction harmonics of the rolling stock normally present.

2.1 Measurement systems
The measurement systems relied on the D/I system (Differentiating/Integrating). This kind of DI-systems has been used before in a railway environment on the TGV line Paris-Lyon. The main advantage is that in harsh EM environments, like close to a railway track, reliable measurements are possible. The differentiating sensor amplifies high frequency signal components, thus giving a “sturdy” signal in the measurement cable. In the EMC Cabinet the signal is integrated, thus restoring the original signal and reducing the interference coupled in along the measurement cable.

For the measurement of the catenary current a HV-cable was installed, in series with an already present catenary-sectioning switch. Using the capacitance of the cable screen the voltage at the catenary was measured. A Rogowski coil was placed around the cable to measure the current. Special problem at this location was the negative feeder, located at a height of over 12 m. Cutting this wire and using a HV-cable for isolation purposes was not deemed to be advisable. A special sensor, which can be clamped on, was developed, see Figure 2. By correctly positioning this sensor with respect to the other conductors present, the influence of currents other then the negative feeder current is negligible. The sensor has been tested with respect to AC withstand voltage 30 kV, and lightning impulse tests up to 200 kV. The sensor has a mutual inductance with respect to the negative feeder of 0.33 μH, combined with an integrator the sensitivity is 2.2 mV/A, bandwidth is 1 Hz – 100 kHz.

2.2 Kautenbach
Of the measurements performed in Kautenbach, only a summary of the results will be given. The earth return current was calculated by adding all the measured currents. As all currents passing through the
“measurement plane” in actual conductors are measured the result must be the earth return current. An overview is given in Table 1. Earth return current percentage is defined as $I_{\text{earth}}/I_{\text{cat}} \times 100\%$.

Measurments 3, 4 and 5 represent pull-ups in Wiltz, distance between measurement location and train approximately 7-9 km. Measurements 1 and 2 represent pull-ups in Kautenbach. Notice the difference between # 1 and # 2. The train was at a position 50-100 m past the measurement location for # 1 and at 500 m for # 2.

<table>
<thead>
<tr>
<th>Measurm. #</th>
<th>Catenary</th>
<th>Protection Wire</th>
<th>Rails</th>
<th>Cable Bundle</th>
<th>Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19.3 A</td>
<td>-0.4 A</td>
<td>-18.8 A</td>
<td>-3.5 A</td>
<td>6 %</td>
</tr>
<tr>
<td>2</td>
<td>43.1 A</td>
<td>-8.0 A</td>
<td>-21.3 A</td>
<td>0*</td>
<td>24 %**</td>
</tr>
<tr>
<td>3</td>
<td>46.3 A</td>
<td>-7.5 A</td>
<td>-18.4 A</td>
<td>-3.6 A</td>
<td>35 %</td>
</tr>
<tr>
<td>4</td>
<td>50.8 A</td>
<td>-8.2 A</td>
<td>-19.9 A</td>
<td>-3.8 A</td>
<td>37 %</td>
</tr>
<tr>
<td>5</td>
<td>31.5 A</td>
<td>-5.5 A</td>
<td>-13.4 A</td>
<td>0*</td>
<td>29 %**</td>
</tr>
</tbody>
</table>

* Common mode current of the cable bundle was not measured (null measurement)
** Calculated assuming a cable screen current of 3.5 A (compliant with measurement 1, 3 and 4)

The results show that far from the train 40% of the traction current flows back through the earth, a few hundred metres from the train this is already 25%.

2.3 Göbelsmühle

In Göbelsmühle measurements were done during the daytime, with normal schedule and during the night, where a dedicated light engine (type CFL 3600) was used. Pull-ups were made at different positions along the line. Two different switching configurations of the supply system were used (Figure 3):
1. Negative feeder disconnected from AT Troisvierges (rest intact).
2. AT Mersch disconnected (rest intact).

The results can be found in Table 2. Earth return current % is defined as $I_{\text{earth}}/(|I_{\text{cat}}| + |I_{\text{lf}}|) \times 100\%$. For the specified positions $|I_{\text{cat}}| + |I_{\text{lf}}| = I_{\text{traction}}$. The results show that the AT-system reduces the earth current to 20% for remote train-positions. This reduction is one of the reasons to choose an AT-system instead of an RT-system. Another reason is the reduction of external magnetic fields

Table 2 Nighttime measurements Göbelsmühle, currents in [A].

<table>
<thead>
<tr>
<th>Load Pos.</th>
<th>Config.</th>
<th>Catenary</th>
<th>Negative Feeder</th>
<th>Rails</th>
<th>Cable bundle</th>
<th>Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>#1</td>
<td>61.4</td>
<td>-25.4</td>
<td>-36.6</td>
<td>4.3</td>
<td>7%</td>
</tr>
<tr>
<td>2</td>
<td>#1</td>
<td>51.5</td>
<td>-26.0</td>
<td>-9.6</td>
<td>-1.6</td>
<td>21%</td>
</tr>
<tr>
<td>1</td>
<td>#2</td>
<td>69.3</td>
<td>-30.2</td>
<td>-32.9</td>
<td>4.0</td>
<td>10%</td>
</tr>
<tr>
<td>3</td>
<td>#2</td>
<td>61.4</td>
<td>-32.1</td>
<td>-10.9</td>
<td>-1.7</td>
<td>18%</td>
</tr>
<tr>
<td>4</td>
<td>#2</td>
<td>37.9</td>
<td>-21.5</td>
<td>-5.6</td>
<td>-1.0</td>
<td>16%</td>
</tr>
</tbody>
</table>

Apart from the current distribution the voltage between rail and mast was measured. Maximum occurring voltage at the instances of the measurements was 9.5 V. At the measurement position the current through the protection wire was negligible (0.1A).

At Göbelsmühle 190 m of signalling cable was installed. Both ends of the cable screen were connected to the rail. The common mode current on the cable screen was measured as well as the resulting differential mode voltage between two wires and the common mode voltage between a wire and the screen. Thus the transfer impedance ($=Z_t$) can be determined. See Figure 4. These results are
consistent with measurements performed in a laboratory, where for the wire-wire configuration 130 \( \mu \Omega/km \) and for wire-screen 6.7 \( \Omega/km \) was found, both at 50 Hz.

### 3 Consistency analysis

Determining the reliability of the measurement data can be done in three ways:

1. Calibration of measurement equipment;
2. Comparison of measured B-fields with B-fields calculated from currents and conductor positions;
3. Compare results with expected currents.

The first method was done in advance. For the second method we examine one measurement for each location where the train is close to the measurement position, as we expect the return current through earth to be small in this case. The local magnetic field is due to the currents through conductors. Using the positions of the conductors we can apply consistency check no. 2. We assume that the current flowing through earth is not contributing to the B-field. For Kautenbach #2, Table 1 is suitable. We can see that the current through earth is only \( 6^{+16} \) \% of \( I_{cat} \). The measured and calculated fields are shown in Figure 5 & 6. The deviations between measured values and calculated ones are \( 19^{+2} \) \% (x-dir.) and \( 11^{+1} \) \% (y-dir.), which is a satisfactory result. For Göbelsmühle we examine #4, Table 4, the RMS value of the sum of all currents is \( 14^{+10} \) \% of \( I_{cat} \) so that part must flow in the earth. The deviation between the measured values and the calculated ones is \( 33^{+3} \) \% (x-dir.) and \( 20^{+11} \) \% (y-dir.), which can be explained by the large current through earth. The third method where measurement results are compared to simulations will be presented later.

### 5 Conclusions

The consistency analysis shows that the D/I measurement techniques used in Luxembourg can be used with success in a railway environment. Therefore it seems logical to use these techniques on the Rotterdam “Havenspoorlijn” Pilot-Project. The obtained experiences are useful for future measurements.

The transfer impedance measurements performed in an actual railway environment give comparable results to measurements performed in a laboratory. The transfer impedance concept can be used in a railway environment.

The current through the earth, characteristic of all 25 kV systems using “earthed rails” is depended on the kind of traction system used. For an AT-system values of 20\% are found, while the corresponding value for the RT-system is up to 40 \%. When distances between AT-locations are limited, the current returning through the earth, can be kept small.