50 Hz Track Circuits Parallel to a 25 kV 50 Hz Railway Line

R. Koopal, E. P. Evertz
Arcadis Nederland BV, Amersfoort, The Netherlands

Abstract

In the port of Rotterdam a new freight line, the so-called ‘Havenspoorlijn’, is built partly alongside an existing DC subway line (‘Erasmuslijn’, see figure 1). This freight line will be equipped with a 25 kV 50 Hz power supply. The signalling system of the subway uses 50 Hz track circuits for train detection. There is a significant hazard that these track circuits falsely interpret an external 50 Hz current from the freight line as an unoccupied track.

As previous research [3] on similar 25 kV 50 Hz rail tracks alongside DC tracks has shown, a significant part of the 50 Hz ground return current will be coupled into the subway track. Hence the 50 Hz track circuits in the proximity area where the freight line and subway line are running parallel to one another, cannot be retained without modifications or replacement. This proximity area is indicated in red in figure 7. However, if no additional measures are taken, the area where the track circuits must be modified will be much wider. This is the case because the 50 Hz current is conducted towards the outer regions of the subway track and leaks away only slowly towards earth. Therefore, a method is needed in order to ‘peel off’ the currents in the subway track more quickly. An overview is given of current research on a method to restrict the induced 50 Hz currents to a smaller area.

Figure 1: Location of lines

Normally, reducing the track-to-earth voltage and leading away the current is done by earthing the track. Since the subway line has a DC power supply and there are several potential stray current victims such as the metro civil structure and pipe lines for the petrochemical industry in the area, earthing the line directly is not an option. Therefore, research is being carried out on a capacitive earthing method in which the subway tracks are earthed by large capacitors, which will avoid the DC current returning to earth through the subway line outside the proximity area.

Train detection on the subway line

For the train detection on the subway line both single and double rail track circuits are used. Balanced double rail track circuits with 50 Hz tuned impedance bonds are most common.
For the detection a track relay based on a small induction motor is used. When no train is present, the track relay is energised through the rails. When a train is occupying the track, its axles short-circuit the rails, the rotating stator field in the track relay is disturbed, the motor stops and the presence of the train is detected.

The voltage over the track coil depends on the total shunt resistance, which consists of the axle shunt and rail-to-rail resistance. A value higher than the Pick Up voltage $V_{pu}$ indicates that the section is unoccupied, a voltage lower than the Drop Away voltage $V_{da}$ indicates an occupied section.

For an unoccupied section the working voltage will be significantly higher than $V_{pu}$. A residual voltage over the track coil will always be present at an occupied section due to a small but not negligible shunt resistance of the axles. This will be significantly lower than $V_{da}$. A small proportion of the total margin between the working voltage and $V_{pu}$ or the residual voltage and $V_{da}$ may be used to allow electromagnetic disturbance of the freight line.

For the permissible disturbance fault conditions within the track circuit and asymmetry in the components are also taken into account. The results of this analysis have been used to determine the susceptibility levels for the track circuits with a 50 Hz working frequency that will be maintained far outside the proximity area.

Within the proximity area the working frequency for the track circuits has been changed. Tests on the track relay show a considerable increase of the susceptibility level for 50 Hz disturbance with this new working frequency.
**Description of capacitive earthing**

By earthing the line with capacitors an unacceptable increase in DC stray currents is prevented. A capacitive earthing system should achieve disturbance levels lower than the susceptibility level of the 50 Hz track circuits within a given safety margin. We strive towards reaching this point within 5 km from the proximity area.

<table>
<thead>
<tr>
<th></th>
<th>Proximity area</th>
<th>5 km from the proximity area</th>
</tr>
</thead>
<tbody>
<tr>
<td>V Without capacitive earthing</td>
<td>31 V 1</td>
<td>27 V 1</td>
</tr>
<tr>
<td>I</td>
<td>20 A 2</td>
<td>1.1 A 1</td>
</tr>
<tr>
<td>V With capacitive earthing</td>
<td>30 V 1</td>
<td>1.0 V 1</td>
</tr>
<tr>
<td>I</td>
<td>24 A 2</td>
<td>0.12 A 1</td>
</tr>
</tbody>
</table>

Table 1: Voltages and currents of the subway line with and without capacitive earthing

At a capacitive earthing location two earthing electrodes will be drilled and a capacitor bank will be connected to each. Saltish ground water conditions in the area make it possible to drill sufficiently low impedance earthing electrodes. To prevent galvanic connection the capacitor banks consist of a larger number of small capacitors that are individually protected by a fuse which blows in case of a capacitor fault. A bleeding resistor for safety during maintenance is included.

The substations of the subway line located immediately before and after the proximity area are the first choice for the locations for capacitive earthing. The 50 Hz ground current from the freight line is effectively coupled into the track as well as into the 3rd rail of the subway. Due to the low 50 Hz small-signal impedance of the substations both the current through the track and the 3rd rail can easily return to earth here. If necessary, cross-bonding locations without a substation can be used, however such locations have no reducing effect on the current through the 3rd rail.

Since a single capacitive earthing location on both sides does not provide sufficient reduction, the capacitive earthing has to be repeated at substations further away from the proximity area. The distance between the chosen locations is essential because the impedance of the ground return will provide the extra impedance needed to reduce the current in each mesh. Simulations will help to find the optimum configuration for the capacitive earthing.

![Figure 4: Mesh currents around proximity area](image-url)

**Model**

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1. **100Ωkm**: Highest considered track-to-earth resistance, which is worst case for common-mode voltages along the subway track and currents outside the proximity area.

2. **1Ωkm**: Lowest considered track-to-earth resistance, which is worst case for ground-coupled currents in the proximity area.
To accurately calculate the induced 50 Hz disturbances in the subway tracks it is necessary to create a simulation model which takes the effects of ground coupling into account.

**Geographic**

With reference to the geographical situation of figure 7 the Havenspoorlijn between substation Dintel and the voltage lock at Vaanplein is modelled using line constants in the EMTP. The line constants are based on the Carson equations [1]. Figure 6 shows a graphical representation of the resulting model. The subway uses a 750 V\textsubscript{DC} power supply in this location and the dual tracks are above ground level. Direct freight trains will be shunted via the Kortsluitroute. This main route has an AT power supply. The route towards railway yard Waalhaven and the outer tracks are electrified by means of an RT power supply. The innermost tracks of the railway yard Waalhaven uses an ST traction power supply. The subway tracks of the Calandlijn are modelled from substation De Akkers at the far south to substation Vijfsluizen at the far north. The model utilises a termination impedance to include the tracks beyond this point. The Erasmuslijn is modelled from its division point of the Calandlijn to substation Leuvehaven.

**Sections**

Each model section, which is identified by two alphanumeric characters as indicated in figure 5, is constructed as a pi-section with the track-to-earth resistance as lumped impedances on the beginning and end of each section. The track-to-earth resistance can be specified for different regions of the model. This way it is possible to take local variations of the track-to-earth resistance into account.

All conductors within two times the ground penetration depth of the freightliner will be influenced by means of ground coupling [2]. In the EMTP this is taken into account by placing all these conductors in the same line section. Using Carson terms, the program will then calculate the mutual impedances of all conductors in a section [1]. To facilitate this, the conductors must run in parallel. Therefore in each section all conductors are located at their average distance to the freight line according to the CCITT guidelines given in [2].

**Crossings**

The locations where the subway tracks cross the Havenspoorlijn at perpendicular or oblique angles are modelled as short sections with negligible influence since measurements of similar crossings have shown this to be the case.

**Parametric variation**

To calculate disturbances 25 kV\textsubscript{AC} trains and 750 V\textsubscript{DC} trains are placed in the model. Because EMTP uses static modelling, the train positions are varied by means of an external script. If required one or more fault conditions can also be introduced and their location varied in the same way as the trains. In an automated post-processing step the worst case 50 Hz disturbance for each simulation section is determined. This way we can assure that the highest possible disturbance for each location is calculated.
Localisation of the disturbances

Since the model proved that the influence of the 50 Hz currents in the proximity area will be too high (as was expected), the focus of the model was shifted towards maintaining as much as possible the unmodified track circuits outside of the proximity area.

Different scenarios for capacitive earthing solutions were considered at this stage using the EMTP model. Only those positions of trains and fault conditions which are expected to produce the highest disturbances outside of the proximity area were considered at this stage. For the most promising scenarios a wider range of positions had to be considered.

Two failures have been identified which cause the greatest increase in respectively common mode currents and voltages respectively outside the proximity area. A broken rail in a single rail track circuit causes some currents to seep directly through the track relay of the section but most of the currents will now simply flow through the parallel track, greatly increasing the common mode currents there. As described before, two capacitor banks are present at each earthing location. If one capacitor bank fails or is shut down for maintenance, the common mode voltage in the surrounding area will rise significantly.

Simulations

EMTP-calculations provide a good prediction of the disturbance voltages and currents in the proximity area based on ground coupling [3]. Uncertainties exist mainly in the reduction at a given distance due to unknown surrounding conditions such as a varying track-to-earth resistance or the presence of track insulation faults. For the validation of the calculations, tests need to be carried out. However, since both the 25 kV 50 Hz power supply and the capacitive earthing locations are not yet available, it is not possible to do a full-scale EMC test. Therefore, an additional test with a simplified configuration has been carried out in order to minimise this risk of a delayed commissioning of the freight line as a consequence of required extra modifications to the detection system of the subway line.

This reduced test is done using a 48 Hz generator, which injects a 50 A current into the subway line in one direction according to figure 6. This alternative frequency makes it possible to distinguish between the injected current and existing 50 Hz currents (e.g. of the signalling system and disturbances of the utility power supply).
On the locations where capacitive earthing is planned the earth electrodes of the DC substation are temporarily connected to the return conductor rail as indicated in figure 7. Planned capacitors have a sufficiently small impedance to allow for this testing method. At several locations along the line the current through the track and the track-to-earth voltage is measured.

For the side west of the proximity area three earthing locations were applied, whilst for the side to the east only two locations were installed. As predicted by our model, the measured disturbances in this last case were still slightly above the susceptibility levels of the detection systems. In this situation only a solution with three earthing electrodes seems feasible. For this reason we present here the results of the measurements to the west of the Erasmuslijn.

![Figure 6: Current injection and disturbance measurement](image)

**Track-to-earth resistance**

A determining parameter for comparing the simulation results with the measurements is the track-to-earth resistance. Unfortunately, this parameter depends on a great deal of variables such as weather conditions, track contamination, type of foundation and soil water levels. Consequently, the track-to-earth resistance varies both in space and time whilst it is impossible to monitor it for every section in the area. Within the given timeframe it was possible to measure the track-to-earth resistances of two representative sections with different foundations.

<table>
<thead>
<tr>
<th>location</th>
<th>foundation</th>
<th>resistance [Ωkm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>concrete slab</td>
<td>15</td>
</tr>
<tr>
<td>II</td>
<td>ballast track</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2: Measured track-to-earth resistances for the west tracks

![Figure 7: Test locations for capacitive earthing](image)
Results

Test results are compared to simulations with an identical earthing configuration based on 1, 3 and 10 Ωkm track-to-earth resistances, as shown in figure 8. (Note the change of scale for the detailed curves on the right side.) The test results in this simplified test condition match with the simulation results within a deviation that could be expected from a realistic variation of the track-to-earth resistance during the test based on the results of table 2.

Conclusions

The reduced tests have produced very hopeful results. They show that the model described here can be used to calculate disturbance levels in the subway tracks outside the proximity area with a fair degree of accuracy. With this knowledge we can predict the disturbances under worst case operating conditions once capacitive earthing has been fully implemented and show that they are well below the safety levels of the existing track circuits.

Consequently, it was decided to implement the capacitive earthing solution as proposed by Arcadis. Full-scale tests at this location with both the capacitive earthing and the 25 kV system operational are planned for the fall of 2008. These must provide the definitive proof.

Meanwhile full scale tests at another location with a longer proximity area but less sensitive track circuits have been carried out and are currently being analysed. These results will further help to prove the concept of capacitive earthing and offer a better understanding of secondary effects like the interaction between train power electronics and the earthing capacitors. The first analysis looks very promising based on initial results.
Acknowledgements

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References


Authors’ Biography

René Koopal and is currently a Senior EMC Consultant at Arcadis. Over the past eight years a significant part of his work involves EMI research between railway lines with an AC and DC power supply. He received his Electrical Engineering Master’s degree in 1994 at Eindhoven University of Technology, The Netherlands. His areas of interest include electromagnetism, modelling and simulation, power supply, and signalling.

Erik Evertz received his MSc degree in Electrical Engineering in 1998 from Aachen University of Technology, Germany. After joining Arcadis as a Consultant, he did extensive research into EMI aspects of 25 kVAC tracks to be built alongside existing DC railways. His field of expertise consists primarily of the modelling and measuring of induced disturbances into existing railway lines and examining their influence on related safety and communication systems. In the period 2003-2004 he was Product Engineer with a public utility company, following a career at the R&D department of Elin Holec High Voltage, a manufacturer of gas-insulated switchgear.