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Investigating railway corrosion caused by cathodic protection systems

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ABSTRACT

Under normal operational conditions corrosion of railroads of DC electrified systems is rather limited but can cause a serious threat to buried pipelines. In order to avoid stray current corrosion, pipeline operators install drainage systems and in some cases a CP impressed current system is directly connected to the railway infrastructure resulting in an increased corrosion attack of the rails, especially at the rail crossings.

The Belgian railway operator has started a campaign to investigate different alternatives to reduce the corrosion risk of its railway network in a region containing 320 km of rail tracks and 620 km of pipelines. A first step in the process was to build a computational model to calculate the current exchange between the rail and the pipeline network. The instantaneous corrosion rate of the rails and the potential variations of the pipelines were simulated for the complete region, given the position of the trains for every second during 24 hours.

The model allowed performing a sensitivity analysis, identifying the high risk zones and elaborating mitigative solutions such that the integrity of both railway and pipeline network is maintained.

Key words**:** DC traction, dynamic stray current corrosion, computational modeling, 24-hours simulations

INTRODUCTION

Infrabel[†] manages, maintains and develops the rail infrastructure in Belgium consisting of 3595 km of rail tracks and a total amount of 1848 rail crossings. Currently, there is need for a detailed examination of the network in a specific region with the main goals to:

- gaining a better understanding of the corrosion-issue of the rail network and the influencing parameters
- controlling and mitigating corrosion phenomena on the tracks, and, in particular, at the level of the rail crossings.

In general corrosion is caused when current is leaving the structure. In the case of a railway system traction current can leave the track and enter the soil at locations where the resistance-to-earth of the rail ballast is low. In practice current leakage per unit length is most significant at crossings where a lower contact resistance dominates due to the presence of for example deicing salt and trapped debris. The so-called stray current that leaves the tracks tends to return to the substation and may affect buried pipelines during its journey in the soil (see Figure 1 for details).

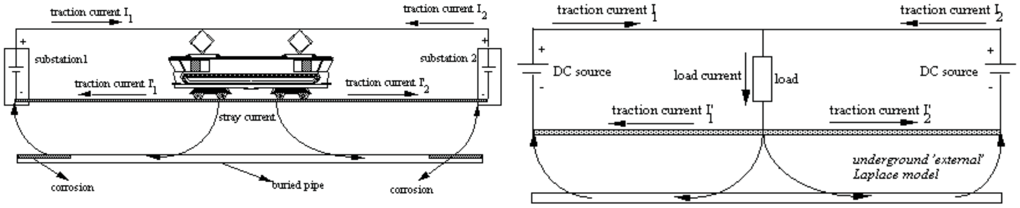

Figure 1: schematic representation of existing jacket complex

In Belgium pipelines near railway systems have a diode drainage system and a cathodic protection system connected to the railway. The diode drainage system discharges directly stray current back to the rail track when a potential difference between both structures is exceeded. The active CP system (current or potential controlled) is connected to the track and used for cathodic protection in this particular area. The tracks are in fact used as (sacrificial) anodes in order to protect the pipeline against electrical stray currents. The question arises if these cathodic protection systems do not accelerate the corrosion rate of the tracks, especially at the rail crossings, and if this system can be replaced by discrete anode beds.

Elsyca's CatPro[†] numerical modeling technology was used to study the coupling and interaction between the railway and pipeline network such that a detailed view is obtained on the corrosion risks of both networks. The computational model and preliminary simulation results are discussed in this paper. Additional field surveys are planned in the near future to further refine the model. The model will be used to elaborate various what-if scenarios for justifying new investments and improving the railway system performance with a minimal risk of stray current corrosion on pipelines.

[†] Trade name

COMPUTATIONAL MODEL

The railway network under investigation covers a region of 56 by 26 km (35 by 16 mi) and contains 320 km of rail tracks and 620 km of pipelines from 6 different pipeline operators. A computational model was built based on the input data as received from the railway company and pipeline operators.

Charateristics of railway network

The railway system is a 3kV DC traction system and consists of

320 km of rail tracks
- 4 different track routings, three of them are double tracks
- 188 different track sections and 72 rail crossings for which simulation results can be obtained
- Linear resistance of the track: 32-38mΩ/km
- Linear resistance of the current feeder: 55-66 mΩ/km

6 substations
- Nominal operating voltage of 3kV DC
- Earthing system type Soulé
- Resistance-to-earth of grounding: 0.4 to 1.5 ohm
- Voltage and current output per station is given for every second in a time span of 24 hours

658 trains
- A time table is given with the position and traction current of each train for every second in a time span of 24 hours.

The earthing system of the substation is of type Soulé and is modeled as of a switch between overhead earthing wire between the poles and the earth grounding and a diode (in parallel) between the negative rail or track and the grounding system. The diode allows current discharge from the grounding towards the negative rail and limits as such negative voltage values of the rail with respect to earth. The diodes allow also stray current feedback to the rail. The earthing system in the model is represented by a diode in series with a voltage source connected to remote earth. It is assumed that the diode has a 0.7V voltage. The voltage source in the model has a value of 1V.

Characterisitics of pipeline network

623 km of pipelines
- Diameter: 100 to 1000 mm
- Coating of either asphalt/bitumen or 3 –layer PE with coating resistance ranging between 0.7 and 2870 kΩ*$m^{2.}$ The coating is considered to be uniform over the entire pipe length. The coating resistance is determined in an iterative way. Its value is tuned based on the given ON-potential and current output of the rectifiers.

29 rectifiers
- 4 voltage- and 25 current controlled rectifiers with total current output of 427 A
- 10 rectifiers (out of 29) are directly connected to rail acting as anode delivering 142 A in total

- 10 diode drainage systems connected to rail

12 bonds between pipelines

- diode or resistor connection between pipeline operators

Computational model

The overall computational model of the railway and pipeline network is given in Figure 2. The tracks are represented by equivalent pipe elements having a linear and tangential resistance that correspond with that of the rail track. The tangential resistance is in fact the ballast resistance. Its value was determined in an iterative way as will be explained later.

A special pre-processor directly linked to the database of the railway operator was developed to automatically up-date the model based on the given time table. For each desired time step the correct position of the trains and the traction current of each train are read from file and the parameter values are applied in the model.

A uniform soil resistivity of 100 Ωm was assumed for the entire region.

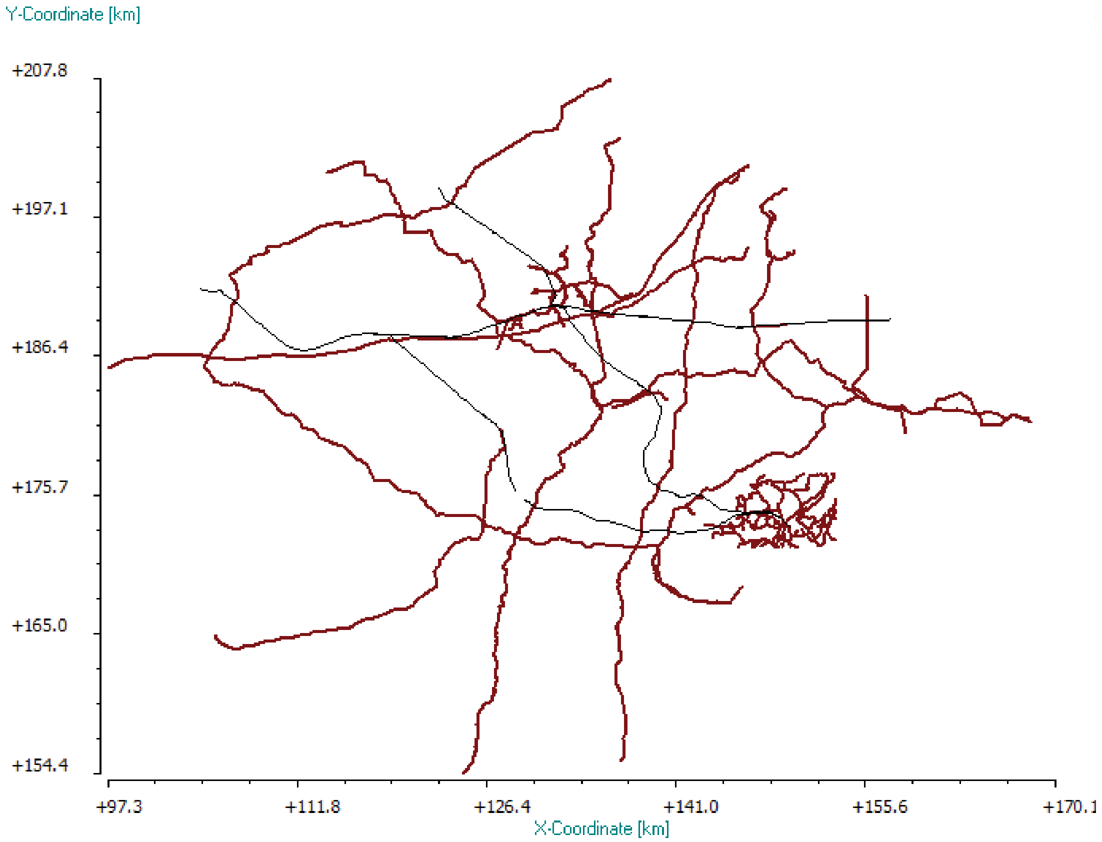

Figure 2: computational model of railway (black) and pipeline (brown) network

BOUNDARY CONDITIONS

The ballast resistance of the rail tracks and rail crossings is a very important parameter that determines the amount of stray current, and thus the corrosion rate.

In order to obtain the correct values of the ballast resistance-to-earth some field measurements have been executed:

- measurement of the ballast resistance of typical rail crossings
- monitoring of the voltage of the track at several locations where no rail crossings are present

At the rail crossings the ballast resistance is strongly determined by the components that constitute the rail crossing and the environmental conditions (de-icing salt, entrapped debris, humidity…) that are applicable. The ballast resistance was deterermined by measuring the voltage drop of the rail track before and after the crossing when applying a 2180Hz AC current signal. In some cases de-icing salt was added in a controlled manner. As can be seen in table 1 the ballast resistance is rather low and its value is strongly dependent on the condition of the rail crossing. In the model a value of 2.0 Ωkm was assumed for a rail crossing in normal dry condition, and 0.28Ωkm in wet condition.

Table 1
Measured ballast resistance of rail crossings

Location	Condition	ballast resistance [Ωkm]
1	as-is	1.61
	with salt (35g/m2)	0.65
2	as-is	0.41
	with salt (40g/m2)	0.34
3	as-is	0.8 – 1.7
	as-is	3.0 – 6
	as-is	0.4 – 0.53
	as-is	0.66-0.83
	as-is	0.85
4	with salt (35g/m2)	0.168
5	as-is, new crossing	0.42
6	as-is	0.80 - 4.60
7	as-is	2.52
	after cleaning	3.15
	with salt (35g/m2)	0.13

The voltage of the track far away of rail crossings was measured under dry and rainy weather conditions respectively at 5 different locations. The measurements were taken with a high impedance multimeter of 200 V peak range. Figure3 shows an example of a 24 hours monitoring of the voltage-to-remote earth at a specific location. Measurements were performed during a normal and raining period.

Under wet conditions the rail voltage drops by a factor of two compared with the results obtained during normal dry period, and the occurrence of a negative rail voltage value becomes more significant. A negative rail voltage results in a traction current leakage causing stray currents in the soil that can be picked-up and discharged by pipelines resulting in stray current corrosion. At this particular location the rail voltage was negative during 1.55 and 0.13% of the time in the case of wet and dry conditions respectively. The most negative rail voltage was approximately -25 V and is the same for the dry and wet state since it is limited by the diodes present in the earthing system of the substations. Note that the rail voltage is mainly positive with an offset value of about 10-20 V. It is believed that this is caused by the CP systems connected to the rail track.

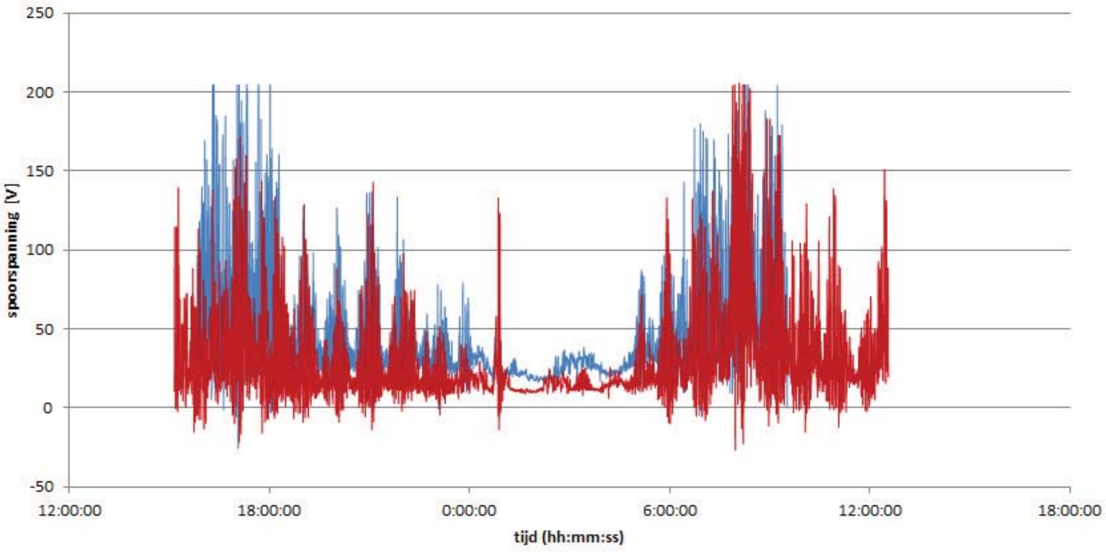

Figure 3: measured voltage of track at specific location during dry (blue) and wet (red) period

The proper ballast resistance of the tracks was found in an iterative way. The value in the model was adjusted until the simulated rail voltage obtained at the 5 locations is in line with the measured values. Each iteration step consisted of 720 time step simulations. An example of such a comparison is given in Figure 4. The best match is obtained if a ballast resistance of 20 Ωkm is chosen for the dry and 10 Ωkm for the wet condition respectively. The overall ballast resistance in the model is summarized in Table 2. The overall ballast resistance is a result of the section length of the tracks and the amount of rail crossings present.

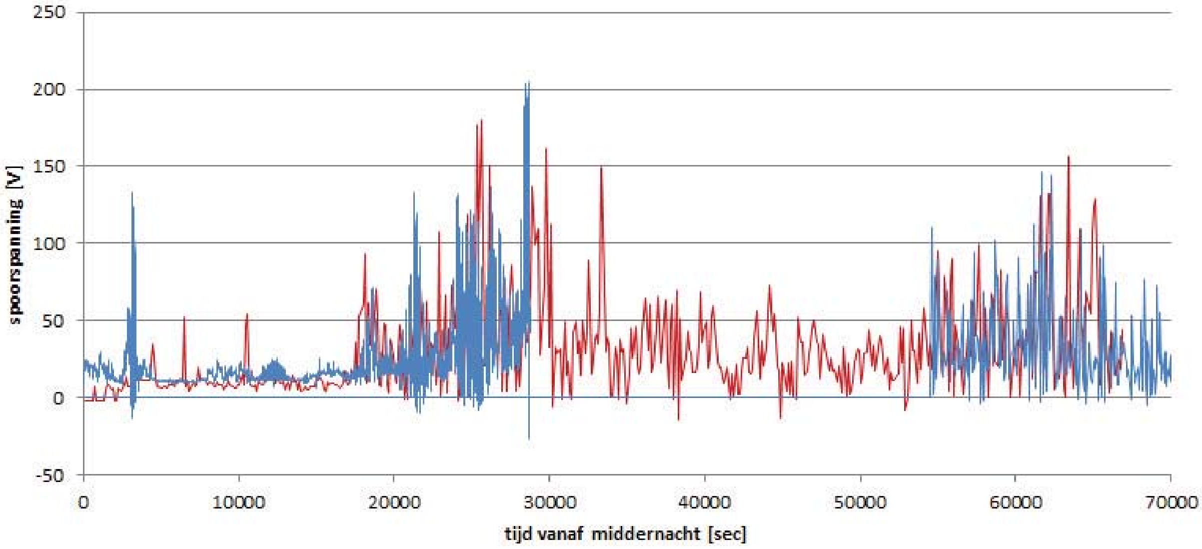

Figure 4: comparison between simulated (red) and measured (blue) rail voltage at specific location

Table 2
Ballast Resistance of Railway Network in the Model

Track	Overall ballast resistance [Ωkm]	
	dry	wet
1	11.1	6.2
2	6.8	4.6
3	18.6	9.9
4	8.3	4.8

SIMULATION RESULTS

The corrosion rate of the railway system was simulated for a period of 24 hours with a time interval of 2 minutes. For each time step the model calculates the following parameters along the entire track routing:

- voltage-to-remote earth
- axial current through rail beams
- current density exchange with the soil

and for the pipeline network:

- pipe voltage-to-remote earth
- ON and IR-free potential
- axial current through the pipe wall
- current density of pipe
- current through bonds
- current through diode drainage systems

Figures 5 and 6 show examples of typical simulation results. The track voltage distribution of the complete railway network during night and during the morning rush hour period is seen in Figure 5. In Figure 6 the change in the pipe ON potential with respect to the train activity is shown for the center of the region. Pipes colored grey have ON potentials that exceed the legend scale (range between -1.25 and -4.50 V_{CSE}) of Figure 6.

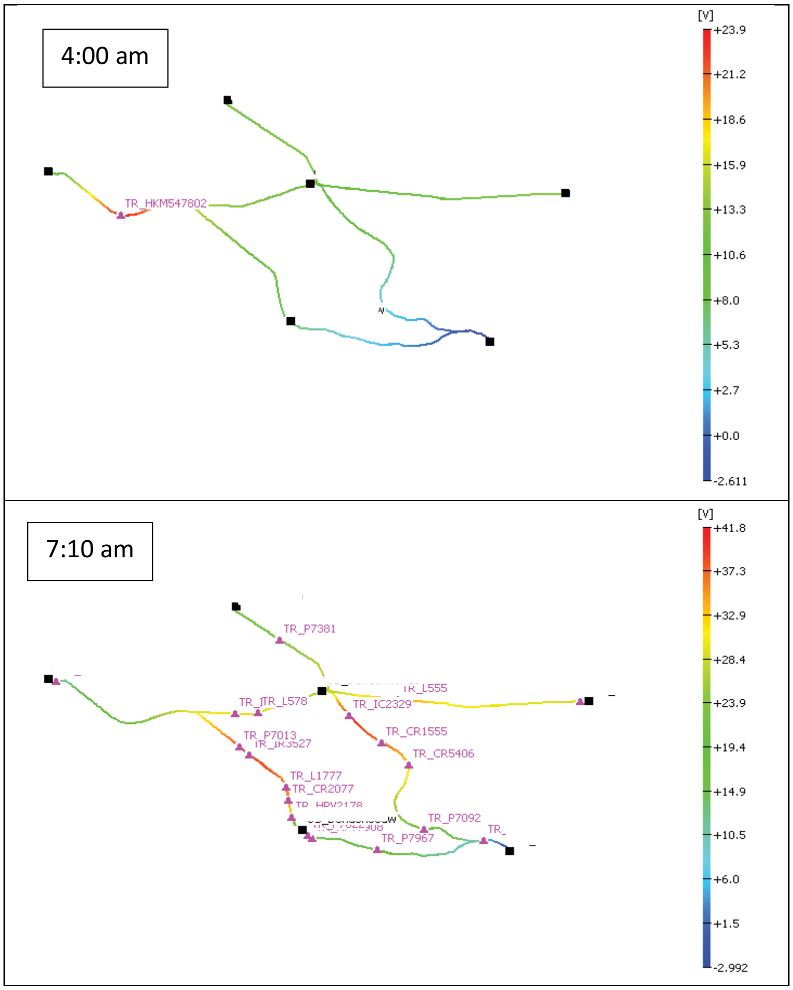

Figure 5: simulated voltage of rail network at 4:00 and 7:10am

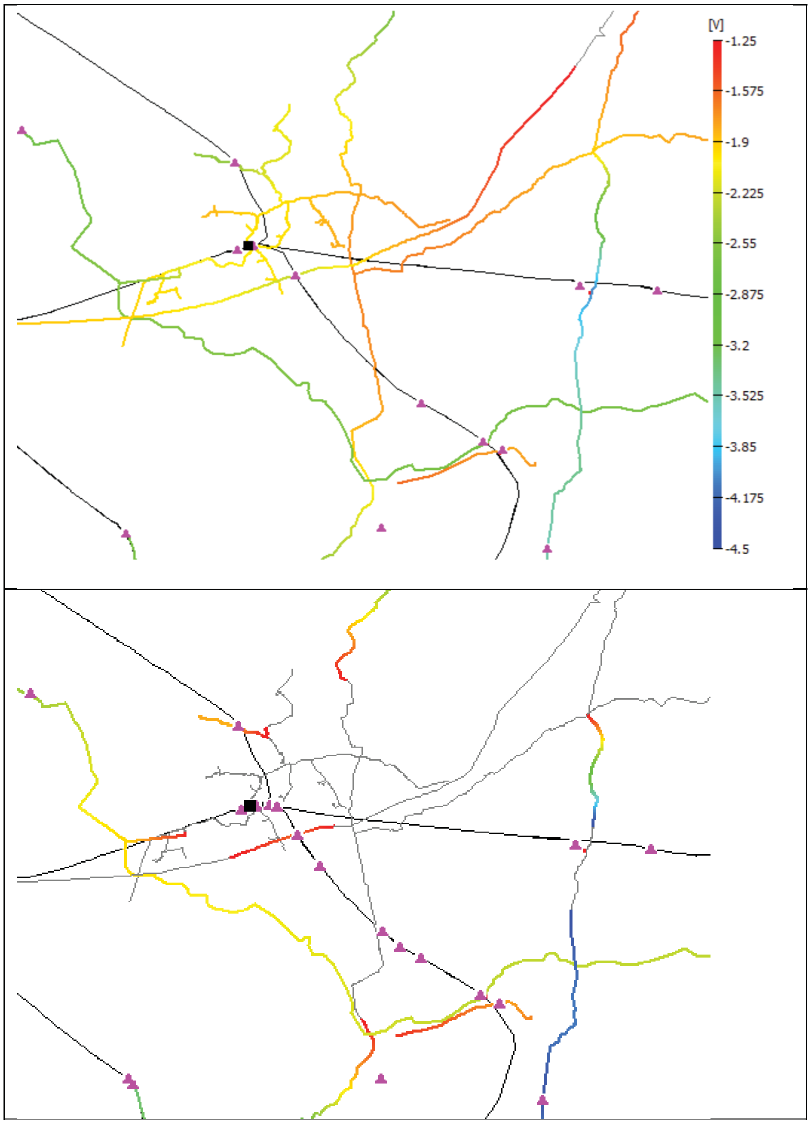

Figure 6: simulated pipe ON potential in the absence (top) and presence (bottom) of traction current

Table 3 shows the frequency (number of times) and the minimum negative rail voltage that occurs in simulations based on 720 time steps. It follows from the table that lowering the ballast resistance results in more frequent occurrence of a negative voltage, while the difference in the minimum negative rail voltage is negligible between dry and wet conditions. This is explained by the action of the diodes in the grounding systems of the substations.

Table 3
Statistics of simulated Rail Voltage at Monitoring Locations

Condition	Track	Negative rail voltage	
		Frequency	Minimum [V]
dry	1	23	-1.74
	2	3	-16.9
	3	14	-21.6
	4	42	-13.59
wet	1	13	-1.49
	2	56	-16.53
	3	77	-34.97
	4	51	-14.39

The total current that is exchanged between the entire railway network and the soil at a given time step is shown in Figure 7 and 8. Current that leaks through the ballast towards the ground is considered to be positive and current entering the rail tracks is considered to be negative. The positive current leaving the rail track is responsible for corrosion. The traction current that leaves the rail is higher than the traction current entering the rail. The difference is the current that returns back to the grounding system of the substations.

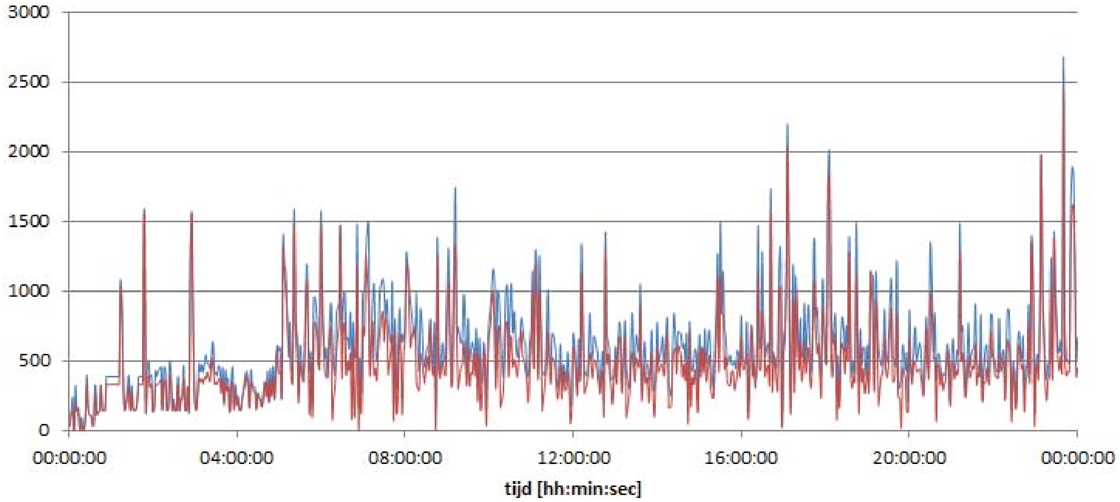

Figure 7: Total current that leaves the railway network at given time (blue:wet condition, red:dry condition)

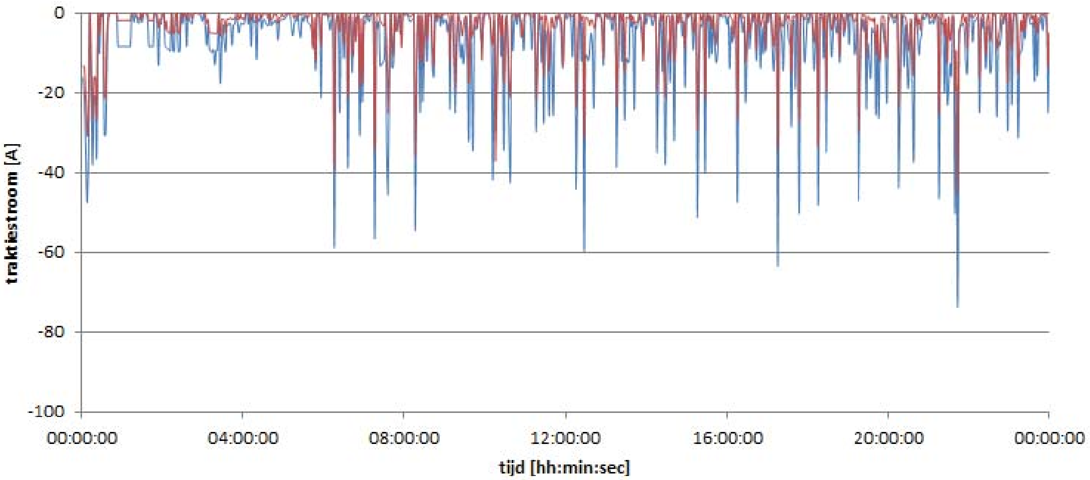

Figure 8: Total current that enters the railway network at given time (blue:wet condition, red:dry condition)

The contact between the rail beam and the sleeper is assumed to be the active surface. An overall average value of 0.116 m^2 per meter track length was calculated for 50 and 60 kg rail beams. A current density of a specific section is obtained by dividing the current by the total active surface area of the section. The corrosion rate is calculated according to Faraday's law and by integrating the positive current density of the rail track over a 24 hours period. Simulations have been performed for the as-is situation with the CP systems connected to the railway and for the situation where they are disconnected. Table 4 shows that the CP systems have an important effect on the corrosion rate of the railway system, especially at the rail crossings. Note that the local corrosion rate of a rail crossing can be much higher since the ballast resistance over that section may vary significantly depending on the way water is entrapped. For example higher corrosion rates have been observed at the extremities of some rail crossings.

Table 4
Simulated Corrosion Rate of Entire Railway Network

	Average corrosion rate [mm/y]			
	dry		wet	
	track	crossing	track	crossing
CP connected	0.01 - 0.07	0.11 - 0.52	0.01 - 0.48	0.18 - 0.76
CP disconnected	0.01 - 0.06	0.02 - 0.06	0.01 - 0.47	0.17 - 0.66

CONCLUSIONS

The corrosion risk of a railway network in a specific region was investigated through numerical modeling. The model contains 320 km of rail tracks and 623km of buried pipelines. CP systems, diode drainage devices and pipeline bonds are included in the model. The aim of the study was to identify if significant corrosion is caused by the CP systems that are directly connected between the rail tracks and pipelines.

Time dependent simulations have been performed for a 24 hours period. First, correct values of the ballast resistance in the model were determined for respectively tracks and rail crossings based on field measurements. For the rail crossings, values have been provided by the railway company while for the tracks, the ballast resistance was indirectly determined by comparing simulated with measured rail potentials at 5 different locations. A ballast resistance of 20 and 10 Ωkm was found for the tracks and 2.0 and 0.28 Ωkm for the rail crossings under respectively dry and wet conditions. Secondly, the current exchange between the rail and the soil was simulated for a 2 minute time interval. The positive current density that leaves the rails was determined and used to calculate the corrosion rate of 188 individual track sections and 72 rail crossing in the model.

The model has shown that the corrosion rate is higher at the rail crossings than for the tracks, and that corrosion of mainly the rail crossings is accelerated by the CP system. Table 4 shows that the corrosion rate at the crossings decreases when disconnecting the CP system from the railway. The effect is most pronounced under dry weather conditions when the difference in ballast resistance between tracks and crossings is more significant than in the case of wet conditions

New field measurements are planned to further refine the model, e.g. making more differentiation of ballast resistance values. The model will also be used to study what-if scenarios in a cost –effective way such studying the impact of additional substations in the network, determining the effects of modifications to the earth grounding system, optimizing alternative CP system installations, renewing track sections or purifying ballast.