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METHODS, SIMULATIONS AND EXPERIENCES ON DC-TRACTION INTERFERENCE ON PIPELINE NETWORKS

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ABSTRACT

The main gas operator in the Netherlands has about 12.000 Km of pipeline. Most of these pipelines are situated in congested right-of-ways (ROWs), including 1500 V DC traction systems. According to the Dutch Standards NEN EN 50162 and NEN EN 50122 it is likely that both systems interfere on each other. Looking at the field measurements one can conclude that about 50% of the pipeline network (including 120 DC-drain unit's that are operational) is under interference of stray current.

To get a better understanding of DC-traction interference, the Company started a joint working group with the Dutch railway. This technical committee aims at a better understanding of theoretical and practical principals of DC-traction stray current. It tries to approve field procedures and to get information on what has to be done to solve CP-related problems.

In this presentation it will be demonstrated how the field measurement technique that has been designed will be used. It will be discussed how the measured data needs to be interpreted to determine the rail resistance to earth and the risk area's for the pipelines.

Keywords: Simulation software, cathodic protection, pipeline network, DC-traction interference

INTRODUCTION

In the '90 the main pipeline owner in Holland[1] made an agreement with the DC-traction operator[2] how to measure and interpret field data. These where defined in the NPR 6912, "Cathodic protection on shore pipelines and metal constructions". If the criteria that was defined was not achieved, the results were sent to the DC-traction technical department to investigate the section where the measurements were done (Figure 1). The DC-traction technician inspected the railway section and looked for "earthing faults" (e.g. short between catenary support column

[1] Gasunie
[2] ProRail

embedded in concrete base and track). After the inspection and reparations, the CP-technician repeated the measurement.

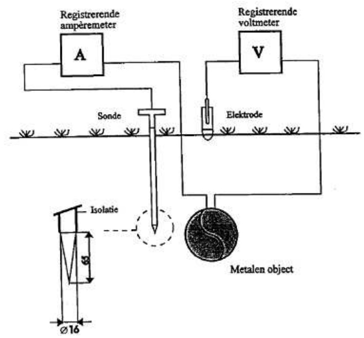


FIGURE 1 – Set-up to measure stray current interference

Sondestroom in procenten van de beschermstroom	Meettijd	
	In procenten van het beschouwde meetuur (*x*-as)	In seconden
%	%	
> 70 %	onbeperkt	–
70 %	40 %	1440
60 %	20 %	720
50 %	10 %	360
40 %	5 %	180
30 %	2 %	72
20 %	1 %	36
10 %	0,5 %	18
0 %	0,1 %	3,6

FIGURE 2 – DC-traction stray current criteria

If the reparation scheme as mentioned above did bring the system within the specs as required (Figure 2) the last option was to place a DC-drain unit. The unit used within the company is built up with a diode and a resistor in series. These units are very solid but have the big disadvantage that they disturb the CP ON potential when the rail potential gets negative (“shorted” diode). In a pipeline system with pipe diameters ranging between 12” and 48” (i.e. low longitudinal resistance), this means that the pipe to soil potential disturbance can be propagated up to 30 Km away from the DC-drain connection (in a system with minimum isolation joints). Examples of measured pipe-to-soil and track-to-remote-earth potentials are presented in Figure 3.

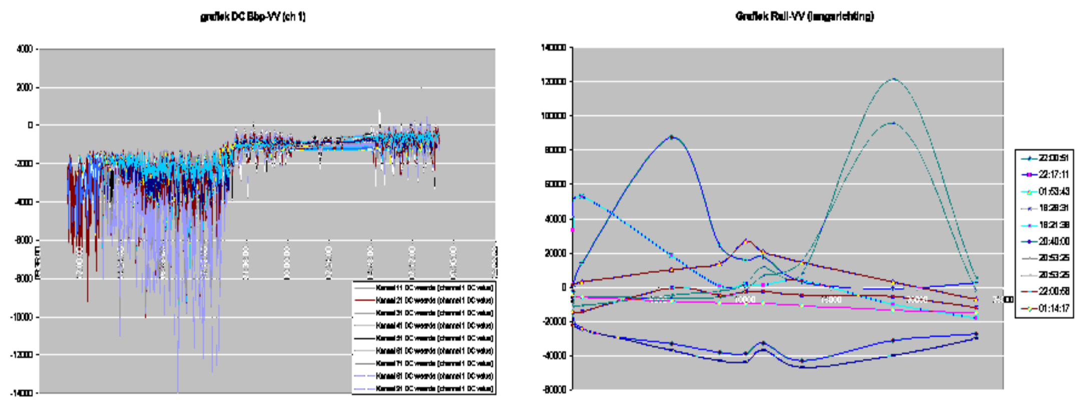


FIGURE 3 – Effect of DC-traction stray current
Left: Pipe-to-soil potential, Right: Track to remote earth potential

With the company's pipeline network getting older, and the requirement to keep the pipelines operating for at least two times the initial design lifetime, it is not surprising that there is a definitive need to interpret the CP-values correctly. This was the most important reason within the company to try to make progress in fighting DC-stray currents.

DC-TRACTION TASK-FORCE

In 2007 the Company started a joint working group with the Dutch railway and several other companies that worked on the phenomena of DC-traction interference on pipeline networks. This task-force for which the Company provided the convenor was unique since it combined expertise in modelling, measuring equipment, CP and DC-energy systems.

It was soon realised that in the past a lot of time already had been spent trying to solve DC-traction interference issues and that a clear and step-by-step multi-year plan was requested. The subsequent steps that formed the backbone of the plan are listed below:

In 2007

1. Study the theoretic principles of DC-traction interference and put them in a model
2. Fit the model to the Dutch railway parameters
3. Perform field measurement on a railway with standard techniques

In 2008

4. Design the ideal measuring system
5. Create a practical measuring device with the available data log-computers (9 programmable channels)
6. Start testing the advanced measuring method, first results

In 2009

7. Collect more data to define risk area's
8. Find methods to decrease risk area's

Modelling approach

The software used in this project is a numerical simulation software package for the design and optimization of the cathodic protection of complex pipeline networks, taking into account DC and AC interference. The basic idea of the model is to link the potential and current density distribution in the soil with the current and axial voltage drop along the pipeline. In addition, the local soil resistivity in the area around the pipe is taken into account in the calculation of the equivalent coating resistance.

As a result, the software is able to calculate the pipeline potential with respect to remote earth as well as the “On”, “Off” and “IR-free” potential. In addition it allows to model the influence of DC-traction systems taking into account the complete electrical behaviour of the rails (both axial resistance and resistance to earth) and overhead wires. Since the effect of the complete soil is taken into account the electrical network from the DC-traction system is in a natural way coupled with the pipeline system.

Figure 4 represents the traditional stray current situation for a railway and the modelling equivalent. Full details on the software model can be found in references [1-2].

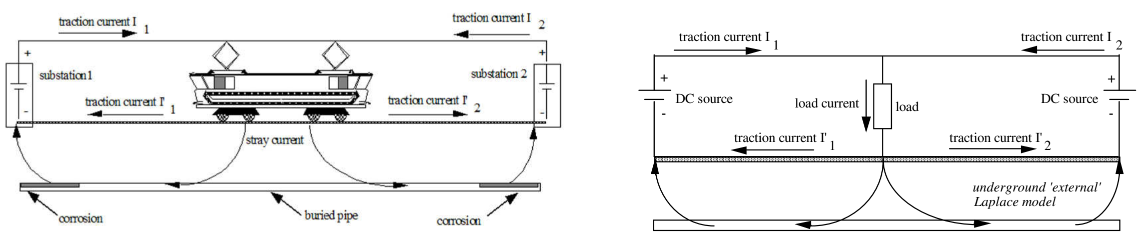


FIGURE 4 - Traditional stray current situation for a railway and CatPro model

In a first step the model has been used to investigate the effect of the number of rails. The key question both with respect to complexity of the model and optimization of calculation time was to see what happens if a number of rails are modelled as a single rail in the model.

From Figures 5 and 6 presenting the results for 1, 2 and 4 rails modelled as a single rail it is clear that the potential disturbance in a region that is about 5-10 m away from the track is identical regardless of the fact that 1, 2 or more rails are modelled. It is hence allowed to model the track system as a single rail which of course has the same axial resistance as the real system (both for rails as for catenaries) and the same overall resistance to earth. This is a very important result since it drastically reduces the model size and complexity. Indeed, the connections between parallel rails and catenaries that make the system electrically continuous are no longer required!

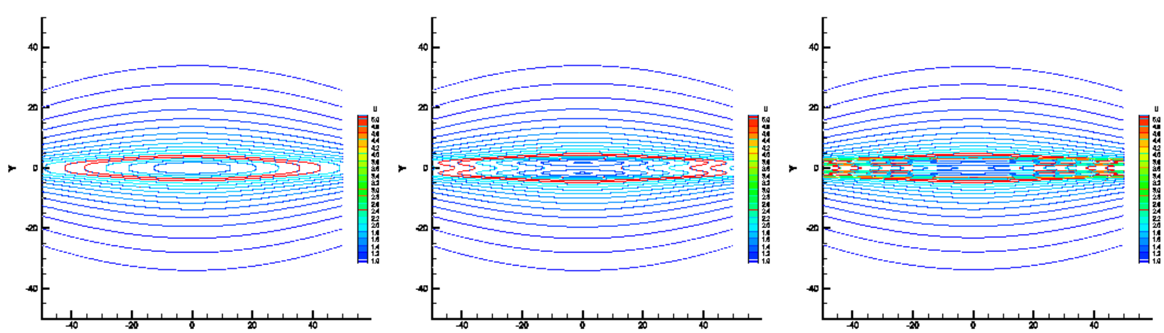


FIGURE 5 - Soil potential disturbance near track for model with 1, 2 and 4 rails

In a second step the effect or shorted portals (defect spark gaps) has been investigated. To that purpose the portal, with a given resistance as measured in the field, has been connected to the rail and the resulting potential disturbance around the portal has been calculated as can be seen from Figure 6.

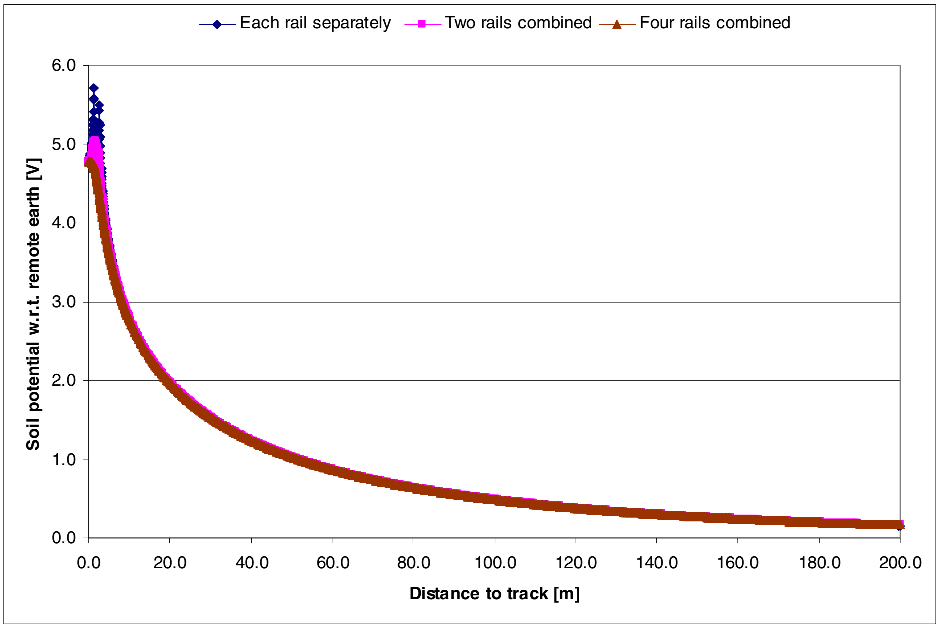


FIGURE 6 - Soil potential disturbance range near track (model with 1, 2 and 4 rails)

From the simulations as performed in this project, three important conclusions can be made:

- the rail has to be approached as being a line source
- the soil disturbance can go up to more than 200 meters (i.e. a soil potential shift of 5 V near the track can cause a potential shift of almost 200 mV at a distance of 200 m)!
- the effect of a point source (shorted spark gap) is only relevant in the neighbouring area

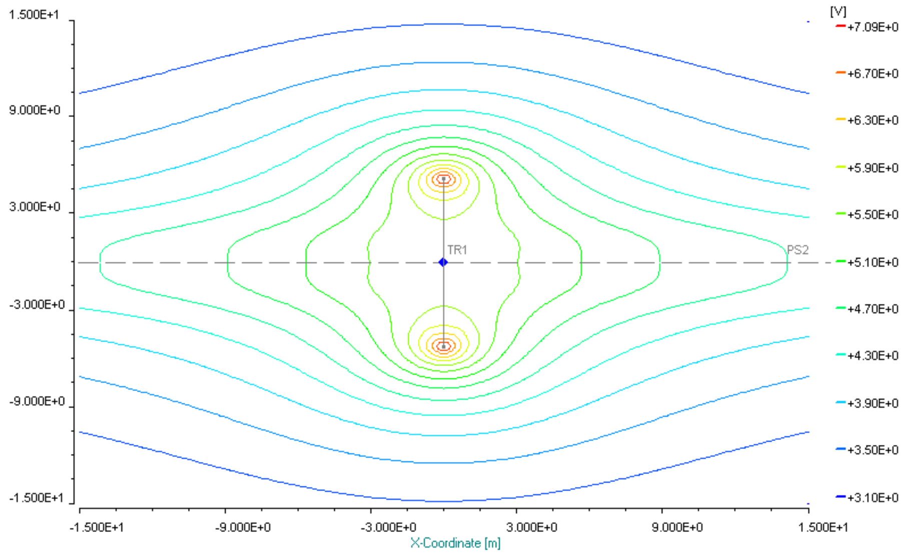


FIGURE 6: Effect of a shorted portal (defect spark gap)

FIELD MEASUREMENTS

Standard Approach

For the field measurements a railway section that could easily be separated from the total DC-powering system has been selected. In this way the railway could be approached as a pipeline which implied that the same coating survey methods as used for pipelines could be used and “compared” with existing experience on pipelines.

The inspection had to be done in the early hours (0:15 – 5:00) when there was no traffic on the track and needed a precise planning to make sure that 4 DCVG- and 2 CIPS-units inspected the complete 2,5 Km of railway. Because the railway was disconnected from the DC-traction system it was possible to impose an own “CP” rectifier signal (current) onto the rail. At one place an earth grounding was deliberately made to get a reference value (benchmark case) which the other results could be compared to.

As for a close interval pipeline survey a combined DCVG and CIP-survey has been conducted along the railway. The “defects” looked for in a DCVG survey on a railway are of course no traditional coating defects but spark gaps and badly insulated rail sections. Using the CIPS the soil with respect to remote earth (approx. 400 m) has been measured. At every “defect” the soil potentials has been measured at 5, 10 15, and 25 meter from the railway, against remote earth.

The process completion was finished in due time and with very good results due to the very strict measuring procedure that had been made. The results fitted quite well to the modelling results. The only drawback was that the inspected railway length was too small to be useful for further inspections or to get more information from other configurations, referring to time and cost.

The results of the first field measurement are presented in Figure 7. In total about 70 DCVG faults indications have been found, from which 7 (1 self-made) where severe. However, it can be seen that at the bigger faults the soil potential disturbance is very local which means that if the pipeline does not reside in the potential gradient of the track there is only a minor problem.

It can also be observed that indeed the railway system behaves like a line source. This observation is fully in line with the model predictions. After analysing the measuring techniques, the results, the operating and safety conditions and total time spent on the project it was obvious that a method had to be developed that works better, easier and faster.

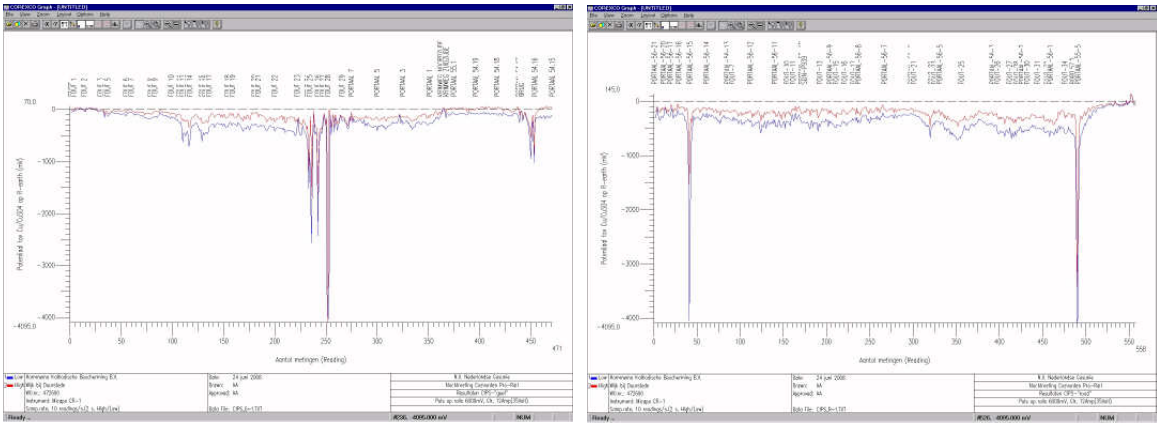


FIGURE 7: Rail-to-soil potential (on and off)

Field measurements – sophisticated approach

In cooperation with the railway company the existing system that was used during the implantation of the first 25 KV AC rail system in the Netherlands has been modified. The system exists out of a ruggedized computer with a 10 channel configuration and a software packet that is able to analyze and report the measured data.

The first challenge was to get this system to work with the input data provided. The second challenge was to define a formula that can be used in 80% of the cases taking into account the possibility that during field measurements a crossing near a traction system is made (the explanation of the procedure followed to derive the formula is out of the scoop of this project). The third challenge was to write a program that was field and technician friendly and of course fool proof.

The final challenge was to create the tools. The type of reference electrode that is used to measure the potential of the rail and soil with respect to remote earth is not important. The only requirement is to have a good contact with the soil which allows to use an iron pin with a foot stamp. The measuring cables used are shielded, numbered and put on special reels. After putting all the “ingredients” together the company finally did some laboratory testing (Figure 8) before starting the real field work that gave very good results.

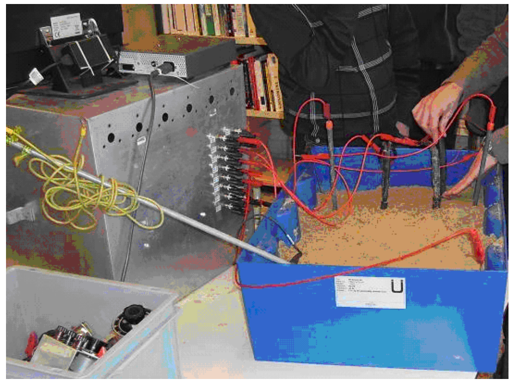


FIGURE 8: Laboratory tests to validate the new measuring approach

One of the questions that came up was how to be sure that al the input signals are correct. Since some cables are up to 240 m away from the command post it is impossible to see if a cable is accidently disconnected. This open question and some other practical considerations resulted in a new approach to measure soil and track potentials and resulted in the design of a new measuring device. The principle is based on the scheme of Figure 9.

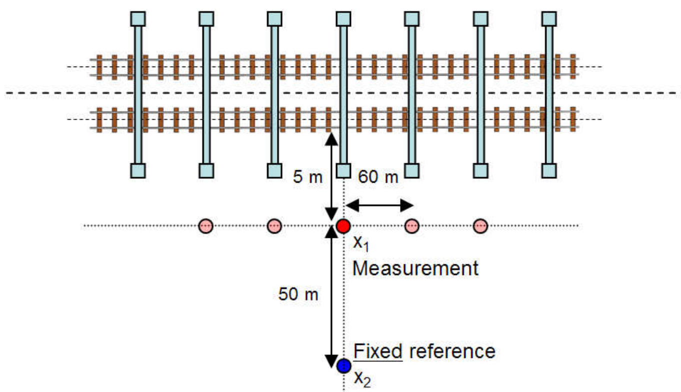


FIGURE 9: Measuring potentials without the need to go to remote earth

This approach allows to measure soil and pipe potentials without the need to go to remote earth:

- A "local remote earth" at 50 meters away from the track is used to measure the potentials. By using the software model and analytical equations a formula has been derived that allows using a local earth instead of real remote earth.
- The soil potential is measured in 9 equally spaced reference points along a line that runs 5 m parallel to the track. The distance between the reference points is about 60 m max. and the potentials are measured with respect to the local remote earth. The soil- and rail potential shifts may be measured in "high ohmic" mode using the metal pins, because soil potential shifts do not have any influence.
- After completing the experimental set-up and wiring the measurement has started. When a train shifts the track potential with a value of at least 2.0 V the average value in a span of 1 second before and after the trigger moment is send to the computer. Both the 2.0 V threshold as the 1 s span are arbitrarily chosen but can be adjusted when needed.

Figure 10 presents the computer set-up as developed, showing the following parameters:

- Real-time voltage of channels 1 – 10
- Min/max voltage of channels 1 -10
- Number of triggers (times the voltage passed the potential shift criteria)
- Frequency spectrum (FFT)
- Visualizes the alpha's 1 – 9, along the railway
- Opportunity to show the representative of the measurement of each channel
- GPS positioning
- Add comments to every session
- Set points, filenames and software version

Because it is assumed that the measured soil and rail potential vary with respect to each other in a linear way it is possible to visualise the nine ratio's between the soil and rail potential (α = soil potential/rail potential), being the slope of the nine regression lines. By using these α's the potential shifts between reference electrodes are not an issue. By visualising each channel in a separate window it is possible to find discrepancies in the measurement.

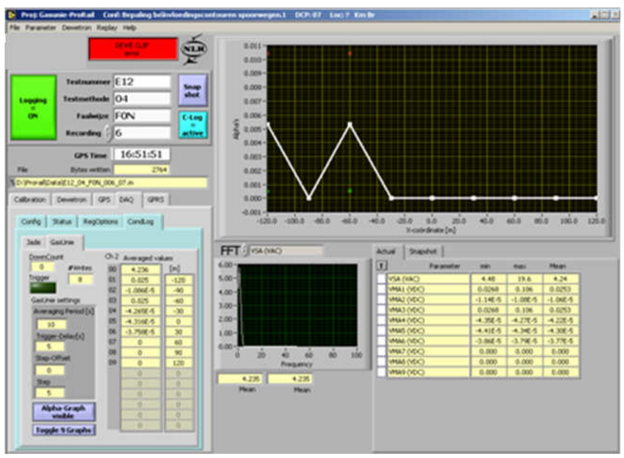


FIGURE 10: Computer set-up with real time result visualization

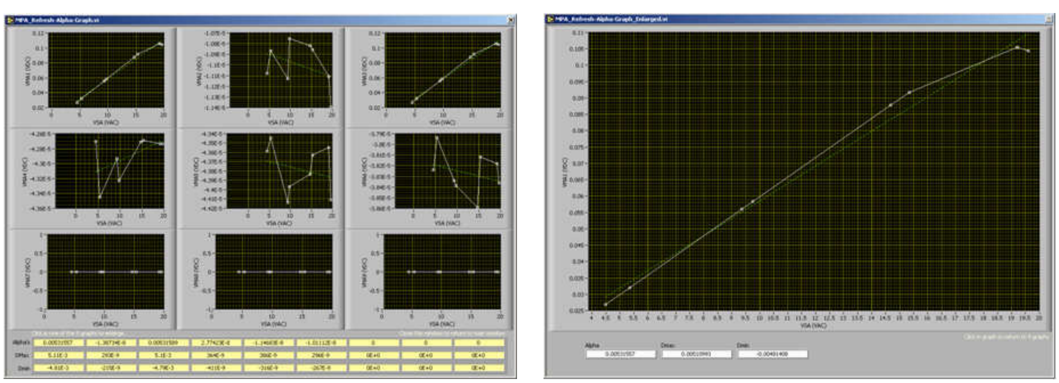


FIGURE 11 - Field measurements - interpretation

The biggest challenge is to interpret the complex phenomena that can occur in the field and to give a practical advice to solve interfering problems. First a closer look at some of results that have been measured will be given.

Example 1
Reference: 01_0_031_07, DC-drainage Hooghalen “On”, reference 1-9 = 6meter from rail, distance between reference 1-9 = 30 meter. Latitude = '52.89231N'; Longitude = '6.53510E'; Sample Rate = '100(Hz)';

The following observations can be made with respect to example 1:

- When the rail potential is positive the soil potential shows a linearity (Figure 12)
- A dip in the lines between 18 and 23 volts (rail potential) with a possible negative alpha can be seen (Figure 13).
- When the rail potential becomes negative one can see three types op “reactions”
  1. the soil potential stays linear with quadrant one (alpha is equal)
  2. the soil potential bends linear into quadrant three (alpha is bigger)
  3. the soil potential flattens in quadrant four (alpha even gets negative)

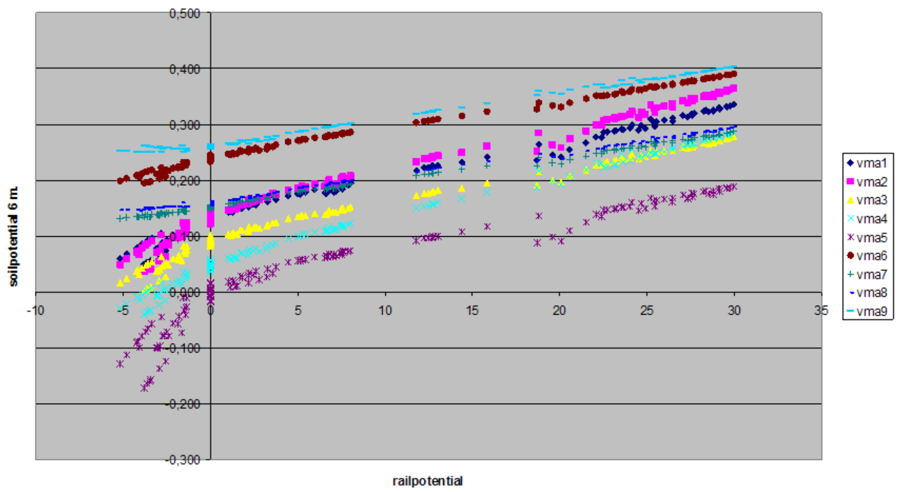


FIGURE 12: Soil potential versus rail potential – example 1

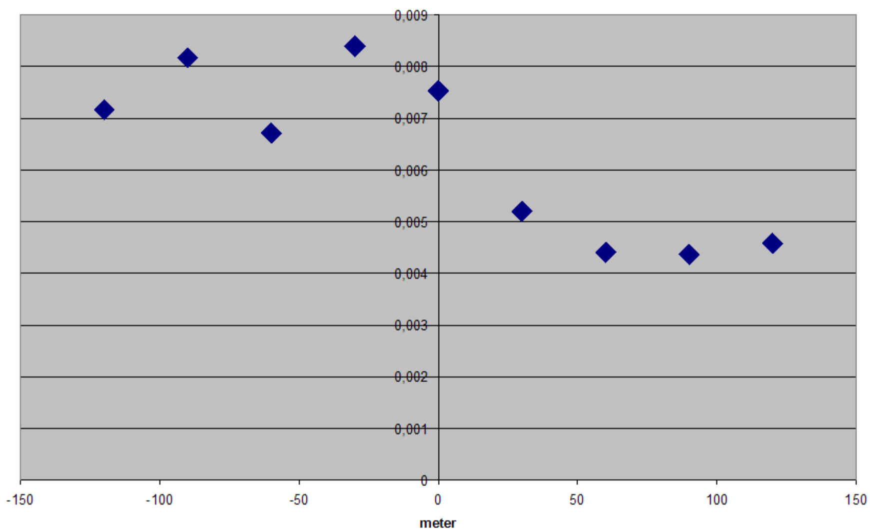


FIGURE 13: Ratio between the soil and rail potential – example 1

Example 2
0_008_07, DC-drainage Hooghalen "Off", reference 1-9 = 5 meter from rail, distance between reference 1-9 = 30 meter. Latitude = '52.90657N'; Longitude = '6.54017E'; Sample Rate = '100(Hz)';

The following observations can be made with respect to example 2:

- The rail potential is positive the soil potential shows a linearity
- There is a movement in the lines between 14 and 18 volts (rail potential)

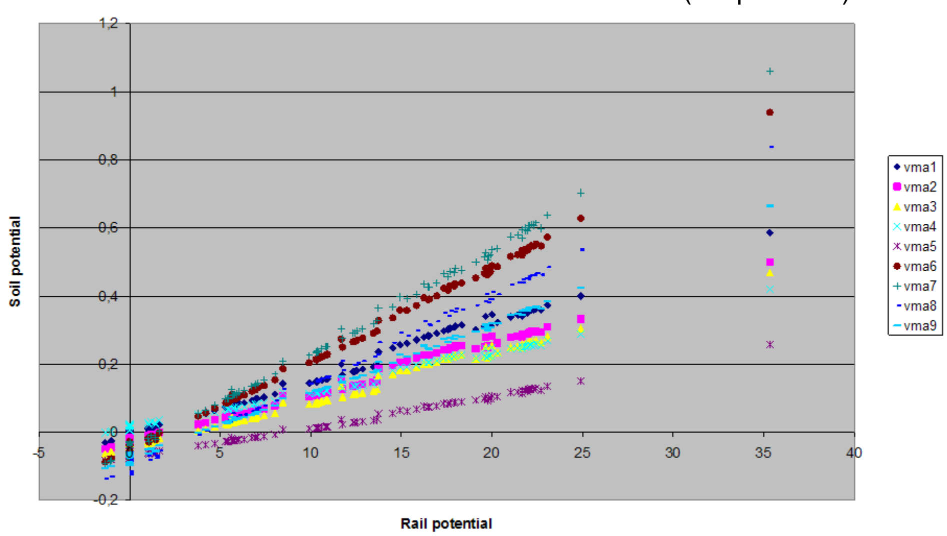


FIGURE 14: Soil potential versus rail potential – example 2

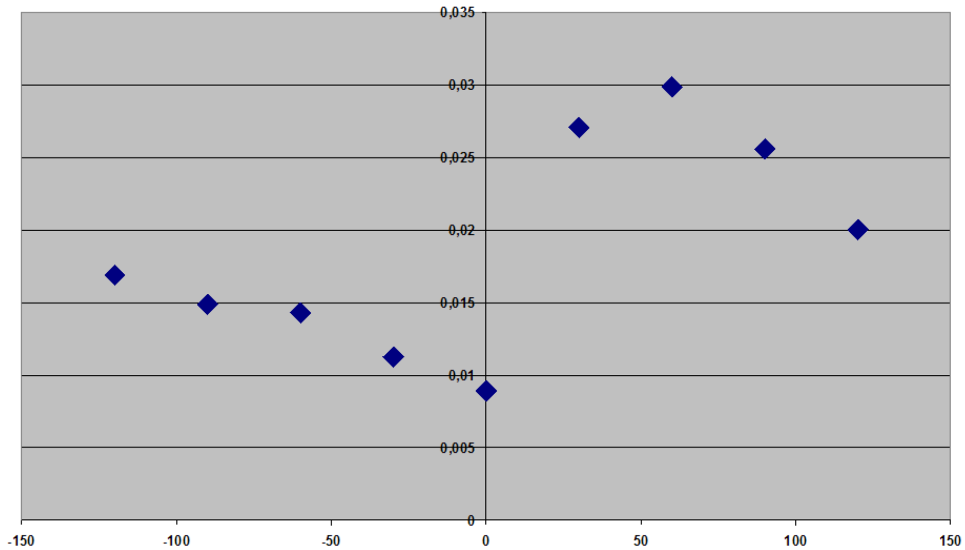


FIGURE 15: Ratio between the soil and rail potential – example 2

ANALYSING THE RESULTS

In the case that all α's have more or less the same value the rail behaves as a line source. The constant alpha values are a direct input to calculate soil potential disturbance along the track as a function of distance to the rail (safety contour) according the maximum and/or minimum rail potential. In this way (safety) contours can be signed up (in accordance with NEN EN 50162: -200 mV < allowed soil potential shift < 500 mV) and it is able find out if the pipeline is in a risk area. If the soil resistance is measured, the rail resistance can directly be calculated from the constant α value.

However when the α's differ substantial the rail no longer can be approached as a line source which could indicate that there do exist additional disturbances. Suppose that there do exist n additional sources (e.g. shorted portals) at locations x_i along the track. The equation below provides a formula that links the α's in the nine measuring points with the soil resistivity and ratio soil/rail resistance and soil/additional disturbance resistances:

$$\alpha_{k=1\to 9} = \left(\frac{\rho}{R_t}\right)\frac{1}{\pi}\ln\frac{d_{50}}{d_5} + \frac{1}{2\pi}\sum_{i=1}^{n}\left(\frac{\rho}{R_{d_i}}\right)\cdot\left(\frac{1}{\sqrt{(x_k - x_i)^2 + 5^2}} - \frac{1}{\sqrt{x_i^{\,2} + 50^2}}\right) \qquad (1)$$

With:

- ρ = soil resistivity in Ωm
- R_t = resistance-to-earth of track in Ω
- d_{50} = 50 m distance to centre of track in m – see Figure 9
- d_5 = 5 m distance to centre of track in m – see Figure 9
- R_{di} = resistance-to-earth of additional disturbance point (e.g. shorted portal) in Ω
- n = number of additional disturbance points
- x_k = position of measuring points along track in m
- x_i = position of additional disturbance points along track in m

The first term in equation (1) accounts for the effect of the rail (through the ratio ρ/R_t), while the second term is the combined effect of all additional disturbance points (through the ratio ρ/R_{di}).

The idea is to find the optimal values of (ρ/R_t), (ρ/R_{di}) and the locations x_i such that the nine analytical values obtained using equation (1) are as close as possible to the measured α's. Currently developments are going on to adapt the software in such a way that the optimal values are automatically obtained.

Finally with the obtained values of (ρ/R_t) and (ρ/R_{di}) and the measured soil resistance (ρ) the absolute rail and additional disturbances resistances are obtained.

The alpha values give an idea about the size and location of the additional disturbances. High alpha values at the boarders of the inspected area indicate that the additional disturbance(s) are outside the inspected area. When high alphas are found, inspection should be done to analyse what the cause is of the additional disturbances and to see what has to be done to increase the rail to soil resistance. If the rail resistance is not in accordance with NEN EN 50162 additional matters have to be addressed.

CONCLUSIONS

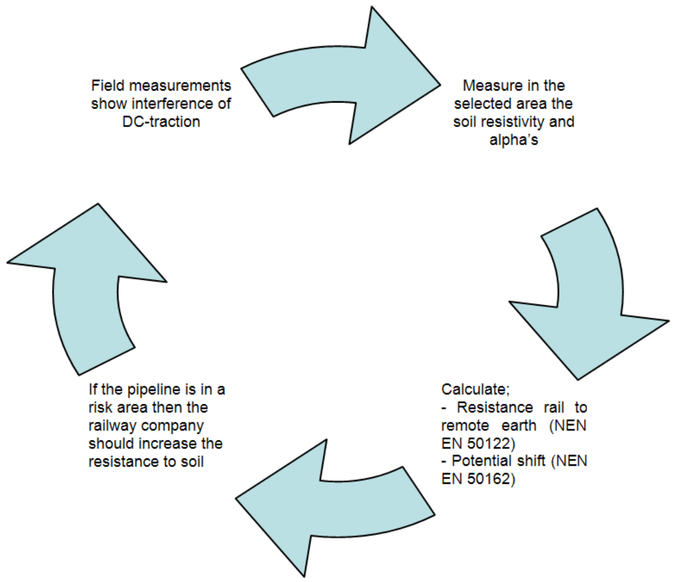
In this presentation a new method to measure and quantify DC-traction interference on pipeline networks as adopted has been described.

In a first step the theoretic principles of DC-traction interference have been studied and validated by means of advanced simulation software which has been customized with the Dutch railway parameters. This resulted in the development of analytical formula's that describe the potential disturbance in the soil originating from line sources (rails with non-ideal resistance-to-earth) and from point sources (shorted portals, spark gaps, etc.).

In a second step the above results have been validated using standard measuring techniques. The obtained results were very promising which resulted in a more advanced approach in which a data logger with 9 programmable channels is used to measure the soil potential disturbance near the track at 9 locations in real time.

This new method makes it easier to find and interpret spot locations. In addition it should be possible to inspect about 5 km/day using a team of 2 to 3 people. Measuring of the rail-to-earth resistance is possible without "cutting" the railway.

The chart below gives an overview of the subsequent steps that need to be followed.



NEXT STEPS

The current research is still going on. Future steps to further optimize the approach and reduce the DC-traction interference on neighbouring pipeline networks include:

- Additional measurements to get a better feeling with the α's
- Updating the software to optimize the α's
- Optimization of mitigation techniques to decrease the risk area (e.g. isolating the rails or looking at the possibility to rearrange (clean) the ”stone ballast”)
- Removing as much as possible the DC-drain units
- Creating a set of design parameters for the distance between railways and steel pipelines
- Further optimization of the complete method to target inspection rates of up to 10 Km/day

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