Applicability of IR-free interpolation method

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ABSTRACT

Knowledge on the IR-free potential at a coating defect is essential to validate the cathodic protection efficiency of the pipeline. The IR-free interpolation method can be used to have a better estimate of the true protection level of the pipeline. Once a coating defect has been localized by DCVG or ACVG, potential gradients are used to determine the IR-free potential.

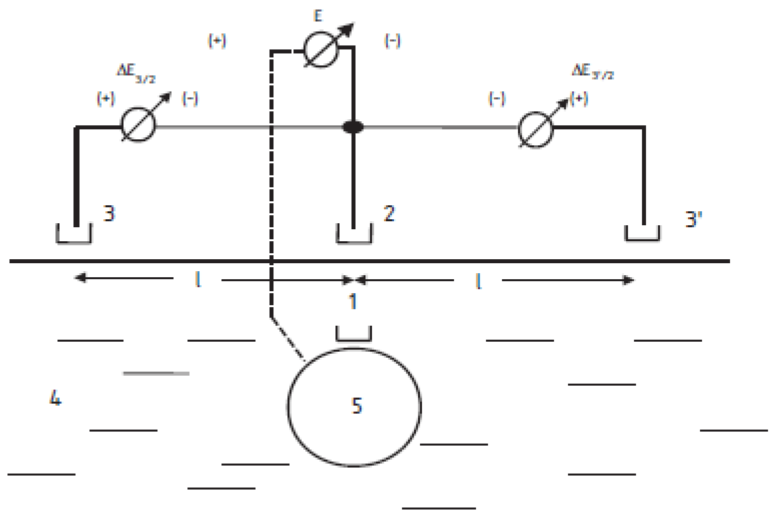
The IR-free interpolation method is relatively easy to apply but is prone to many measurement errors. In this article simulation technology is applied to determine the error on the interpolated IR-free from a theoretical point-of-view. A sensitivity analysis was performed for different coating defect configurations and reference electrode set-ups. The influence of stray currents was investigated as well.

Introduction

Ideally potential measurements of pipelines, indicating whether or not the protection potential is fulfilled, should be made right on the metal/electrolyte phase boundary, e.g. metal/soil boundary. However it is not feasible to bring a reference electrode close to the defect. In practice rectifiers are cyclic switched off to avoid any contribution from the CP system and an Eoff potential is obtained**.** However a full current free or potential undisturbed soil can hardly be obtained because of current discharges between anodic and cathodic areas on the pipeline, stray current from foreign installations etc. and therefore Eoff potentials still contain to some degree a voltage component that is caused by the ohmic drop in the soil leading to measuring errors. In the following chapters the IR-free interpolation method is described and the sensitivity of the method is discussed.

IR-free interpolation method

The EN13509 standard describes intensive measurements to determine the IR-free potential at coating holidays detected by various methods. The intensive measurement technique measures simultaneously pipe-to-soil potentials and associated horizontally opposed potential gradients according to Figure 1. The technique identifies coating defects and enables calculation of IR-free potentials at the defects.



Key

1, 2, 3, 3' Reference electrode locations
4 Soil
5 Pipe

Figure 1 - measuring set-up of the IR-free interpolation method

The IR-free obtained with this set-up is calculated according formula 1:

$$E_{IRfree} = E_{off} - \frac{\Delta E_{off}}{\Delta E_{on} - \Delta E_{off}} (E_{on} - E_{off}) \qquad (1)$$

Re-arranging formula 1 gives formula 2.

$$\frac{E_{IRfree} - E_{off}}{E_{on} - E_{OFF}} = -\frac{\Delta E_{off}}{\Delta E_{on} - \Delta E_{off}} \qquad (2)$$

The graphical representation of the formula (2) is given in Figure 2.The slope of the interpolation line is determined by the voltage gradient of pipe-to-soil-potential ratio. The IR-free is found by interpolating the line to a zero voltage gradient.

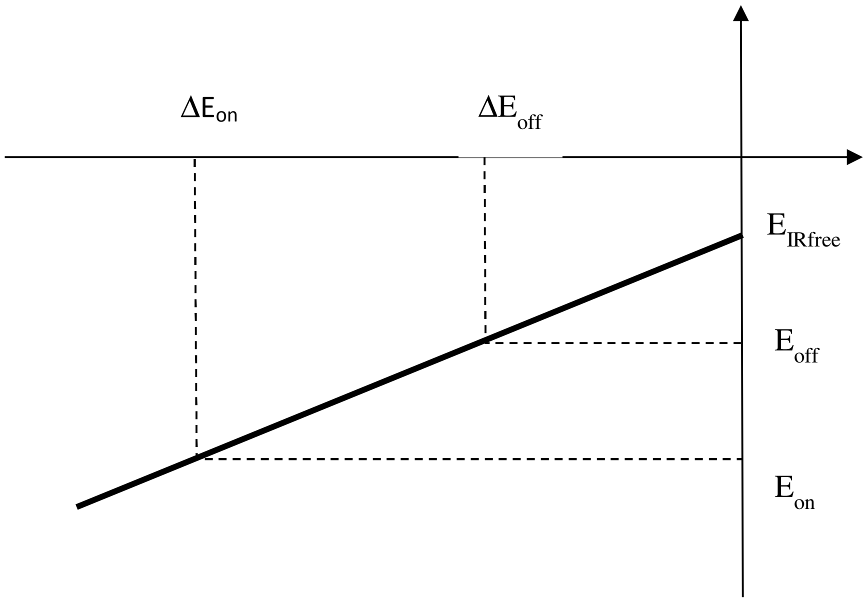


Figure 2 – graphical representation of the IR-free interpolation method

The IR-free interpolation method however can be applied only in case of constant stray currents if the structure is within the linear part of the potential gradient caused by the foreign current (remote) source, i.e. where the potential gradients are constant with distance. In other words the remote reference electrode (3 or 3’ in picture above) must be placed in a symmetrical way in accordance to reference electrode 2 for each measurement. Reference electrode 2 must be placed in the epicenter of the potential cone. Under DC stray current conditions the two measurements gives two different ¨IR-free potentials¨. After averaging these two ¨IR-free potentials¨ the correct IR-free potential is obtained.

So far it is not known to which extend the IR-free interpolation method is applicable in more complicated situations as encountered for real pipelines and how accurate the method is in practice. The sensitivity of the IR-free interpolation method is studied through simulation technology and a new set-up of the reference electrodes is proposed for improved accuracy.

The investigation was performed with Elsyca’s CPMaster 3D modeling software.

Computational model

The computational model consists of a pipeline section of 25 meters length buried in a soil with a specific resistivity of 100 ohm.m. A small and large pipeline diameter as being representative for Gasunie’s pipeline network was chosen:

- 8” pipe with a soil coverage of 1.0 meter
- 36” pipe with a soil coverage of 1.5 meter

The coating was considered as being a perfect insulator but having a coating defect of 100 cm^2 positioned in the middle of the pipe section at respectively 6, 9 or 12 o’clock on the circumference of the pipe. A fine volume mesh was foreseen at the measuring locations in order to obtain accurate calculations of the soil potential.

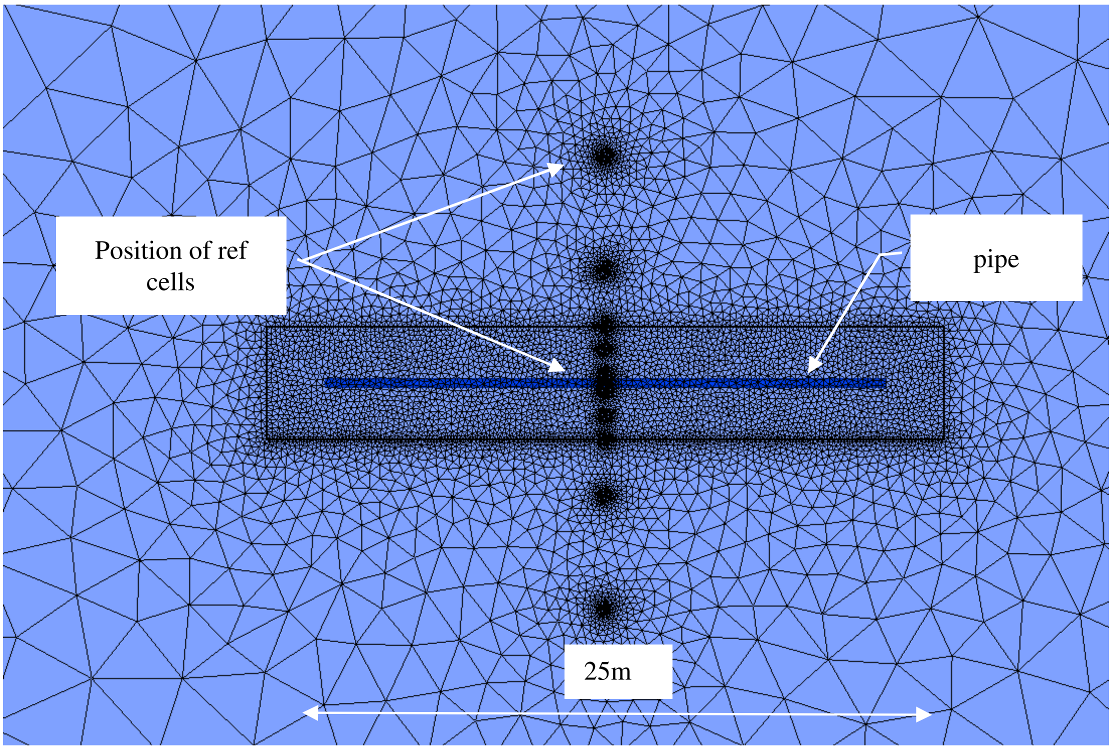


Figure 3 – 3D computational model of 25m pipeline section (top view)

Different scenarios were investigated to verify the sensitivity of the IR-free interpolation method for measuring errors, position of the reference cells and DC stray current. Finally a set-up with vertical alignment of the electrodes was elaborated.

1. Noise on the reference electrodes

Portable reference electrodes may produce a noise in the potential reading at the contact interface under certain soil conditions. This occurs only on grade level and not below the top soil surface. Gasunie has experienced variation up to 7 mV per reference electrode. This offset error will shift the IR-free interpolation curve.

2. Position of the remote reference electrode on grade level (cells 3 and 3' in figure 1)

Increasing the distance of the remote reference cell increases the potential gradient and thus the sensitivity of the measurement. However the measurement becomes more prone to stray current interference and potential disturbances caused by foreign objects close to the pipe. The remote electrode will be placed at respectively 5, 10, 15 and 20 m distance perpendicular to the pipe centerline.

3. Influence of stray currents

A homogeneous DC stray current is assumed having an electric field in the soil that is parallel to the pipe. The more anodic potentials are located on the left hand side and the more cathodic potentials are located on the right hand side in figure 1. Three different strengths of the electric field are considered.

4. Vertical position of the central electrode at epicenter (cell 2 in figure 1)

The two reference electrodes (2 and 3 or 3') are put in line in vertical direction at the epicenter of the potential cone. Reference cell 2 is below reference 3. Simulations are performed for different depth of the reference cell 2.

The model computes the potential in the soil for a volume of 500x500x500m. The pipe is polarized at -1400mV remote earth potential. A potential swing of 100 mV (ON/OFF) was applied and it was assumed that no depolarization occurs.

Under cathodic protection the soil resistivity near the defect can have a lower value than the bulk soil because of the electrochemical reactions taking place. A value of 10% of the bulk soil is possible. More current will be drained by the defect than is the case for an equal soil resistivity resulting in a larger voltage gradient and overestimation of the defect size. For simplicity only a uniform soil resistivity is assumed in the model. By consequence, the noise values on the reference electrodes and the electric field strength of the stray current must be reduced by a factor 10 for obtaining comparable results with field measurements. In the model the potential noise on the reference electrodes is therefore considered to be 0.2 or 0.5mV. For the stray current conditions, electric field strength of respectively 0.1, 0.3 or 1.0 mV/m is assumed. This approach is acceptable the investigation of the trends in IR-free interpolation method and to elaborate improved measuring set-ups.

Results

1. <u>Noise on the reference electrodes</u>

Figure 4 and 5 shows the results for respectively an 8 and 36 inch pipe with a defect at 12 or 6 o'clock respectively (no stray currents, measurement on one side). The reference electrode set-up according figure 1 is used. The reference electrodes are at grade level and some noise level is assumed. The noise shifts the interpolation line parallel to the original one resulting in an error of some tenth of millivolts on the IR-free determination. The impact is larger for the 36 inch pipe for which smaller gradients are measured. For a defect at the bottom of the pipe the error is approximately 50mV.

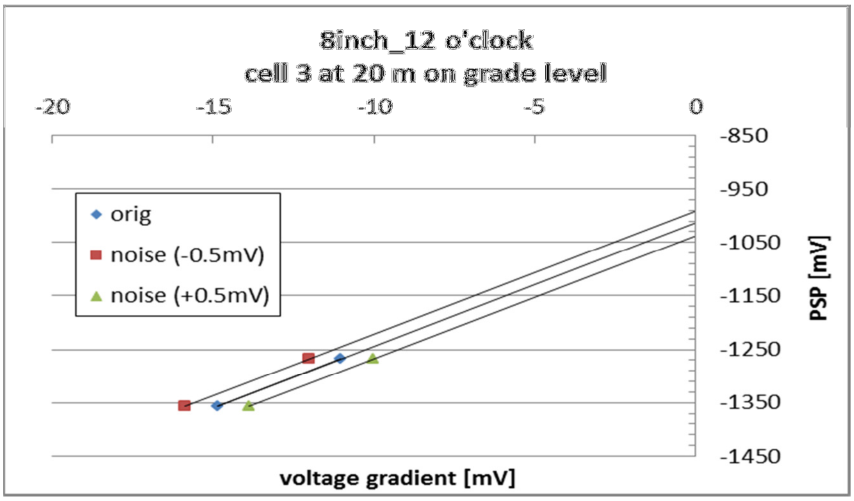


Figure 4 – effect of noise on reference cell for an 8" pipe with defect on top

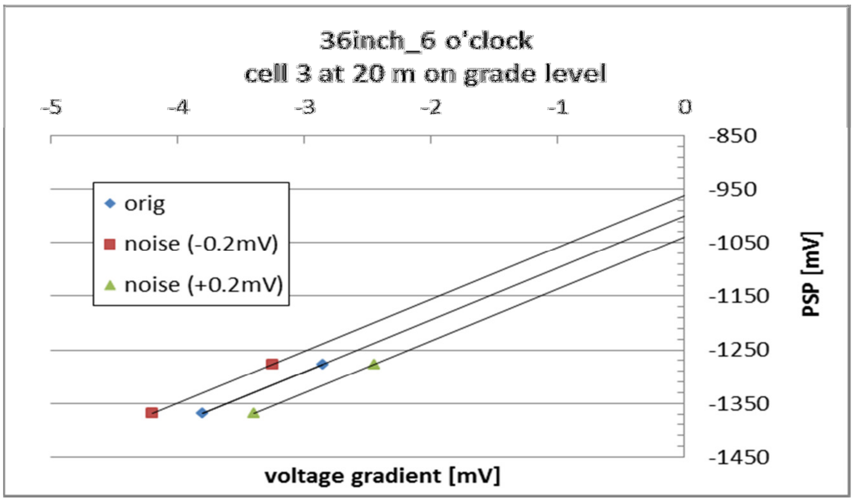


Figure 5 – effect of noise on reference cell for a 36" pipe with defect at bottom

2. <u>Position of the remote reference electrode</u>

In figure 6 the remote reference cell is moved towards the pipe. The potential gradients decreases with decreasing distance and the slope of the interpolation line changes. In this situation the electrodes at the epicenter and remote (cell 2 and 3 in figure 1) were put 0.25m below grade (no noise). The obtained IR-free is the same for all distances of the remote reference cell.

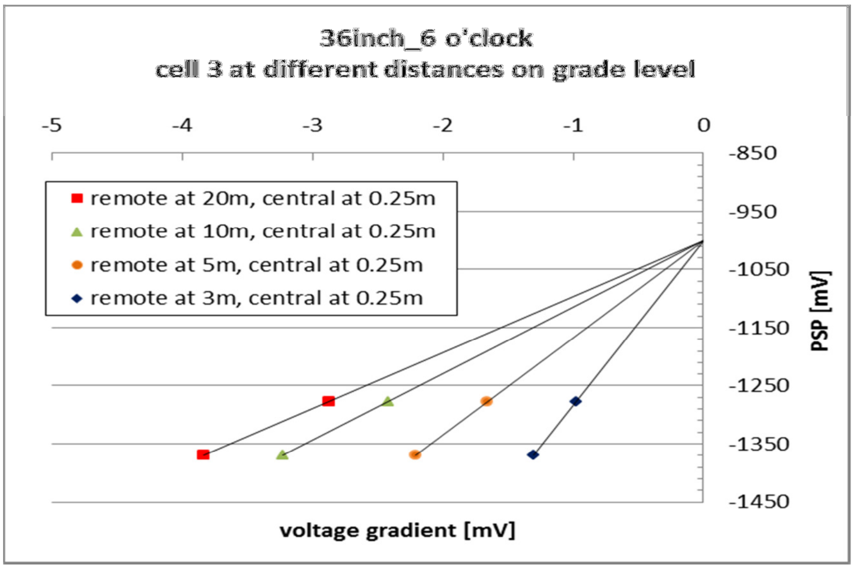


Figure 6 –remote reference cell at different distances for 36" pipe with defect at bottom

3. <u>Influence of stray currents</u>

In the case of stray current interference the average value of the IR-free potential is taken from measurements on both sides of the pipe. The remote reference electrode (cell 3 and 3' in figure 1) is placed at 20 m distance from the pipe. If the system is fully symmetric a correct IR-free determination is possible by averaging the values of the IR-free potentials. As an example the situation is investigated for an 8 inch pipe with a defect at 9 o'clock and weak stray current. Figures 7 and 8 show the shift in IR-free potential in both positive and negative direction as function of the position of the remote reference cell. After averaging the IR-free potentials the correct IR-free potential is obtained as shown in figure 9. Note that for this example a noise was introduced.

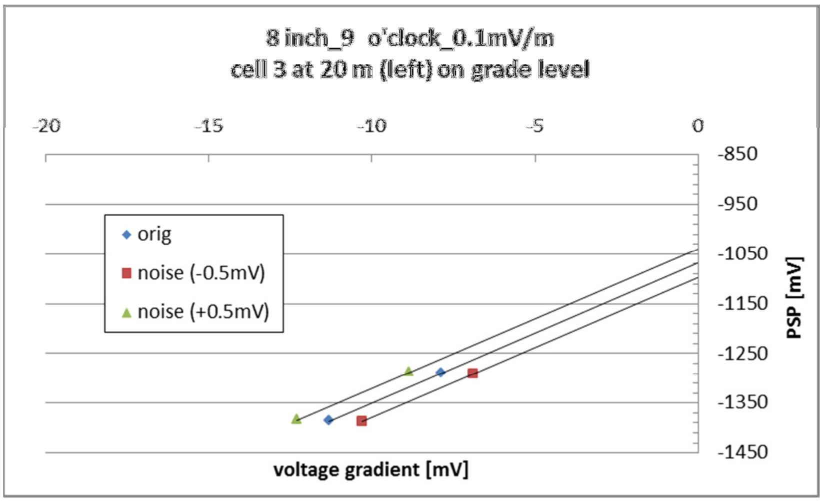


Figure 7 – remote reference cell on left side (8" pipe, weak stray current, defect on the left side)

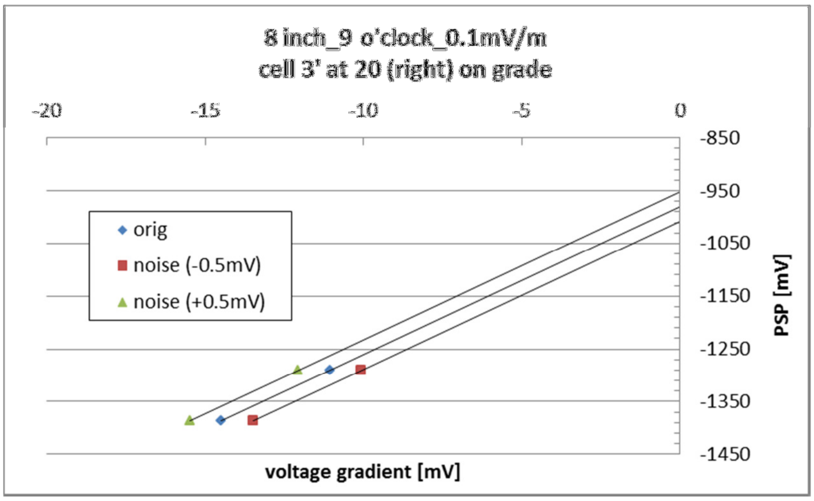


Figure 8 – remote reference cell on right side (8" pipe, weak stray current, defect on the left side)

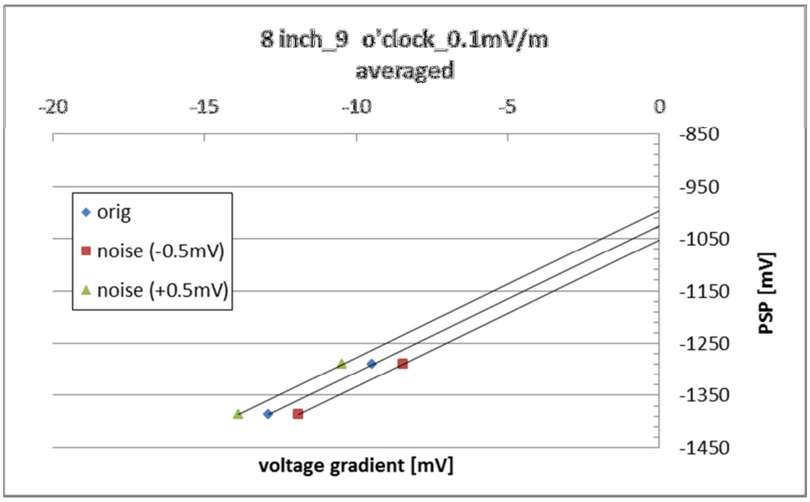


Figure 9 – averaged voltage gradients obtained from both sides of an 8 inch pipe

For the case of a 36 inch line under significant stray current the IR-free interpolation lines looks different due to the distortion of the electric field by the pipe itself. After averaging the IR-free potential values, a correct IR-free value is obtained.

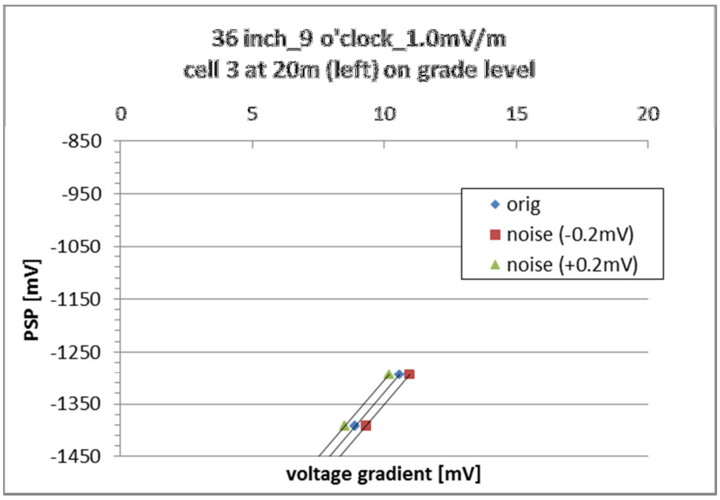


Figure 10 – remote reference cell on left side (36" pipe, strong stray current, defect on the left side)

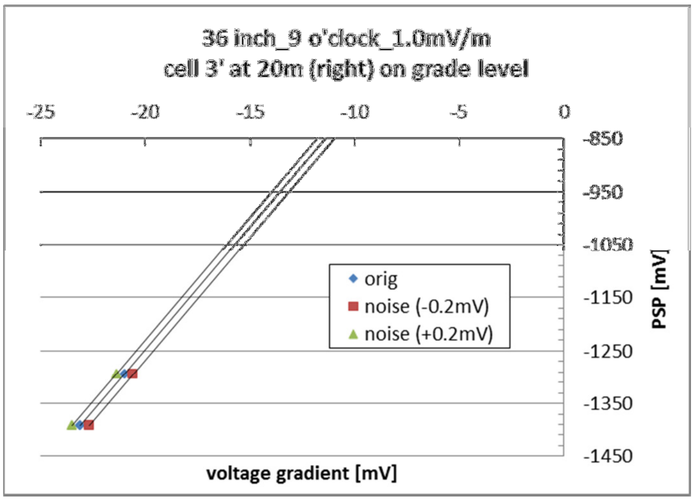


Figure 11 – remote reference cell on right side (36" pipe, strong stray current, defect on the left side)

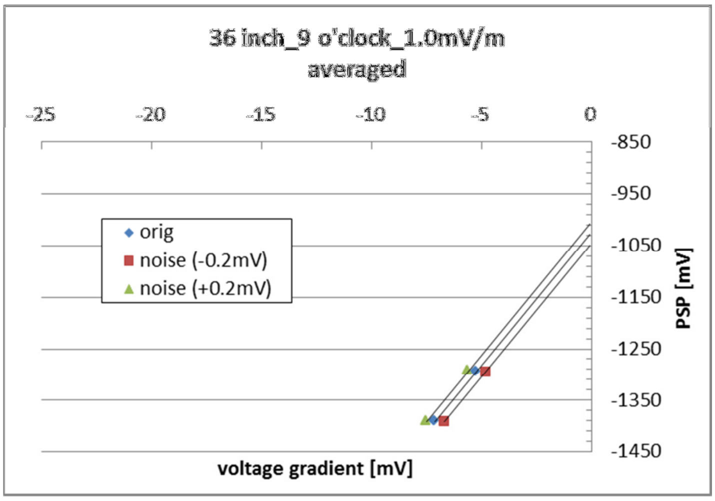


Figure 12 – averaged voltage gradients obtained from both sides of an 36 inch pipe

By decreasing the distance of the remote the reference cell from the pipeline center the effect of the stray current in the measurement can be decreased but the gradient sharply decreases and therefore the uncertainty of the measurement increases as shown in figure 13 to 15.

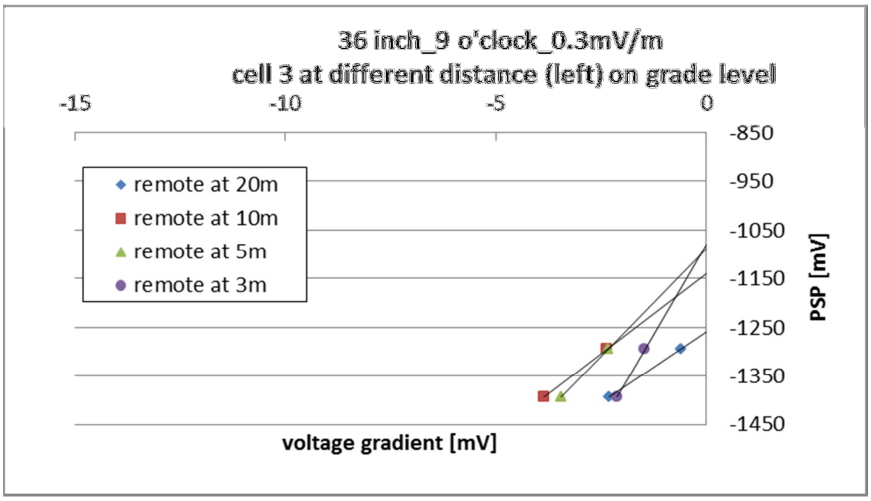


Figure 13 – effect of position of ref cell 3 on left side (36" pipe, moderate stray current, defect on the left side)

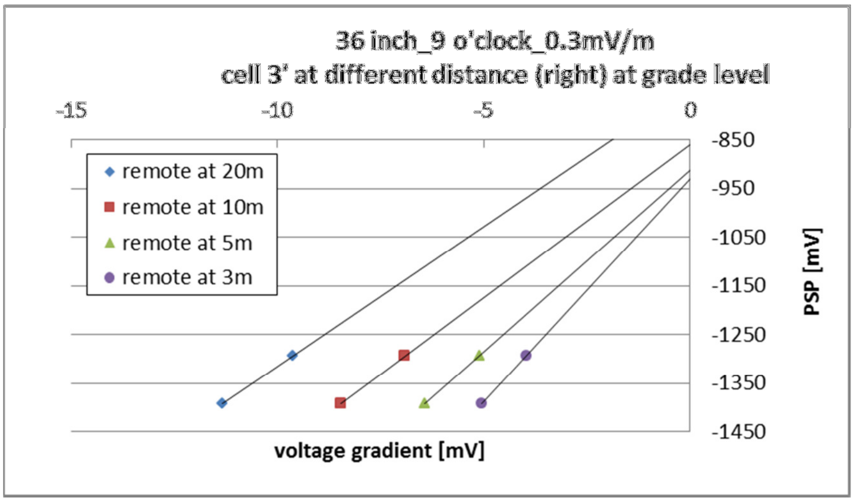


Figure 14 – effect of position of ref cell 3 on right side (36" pipe, moderate stray current, defect on the left side)

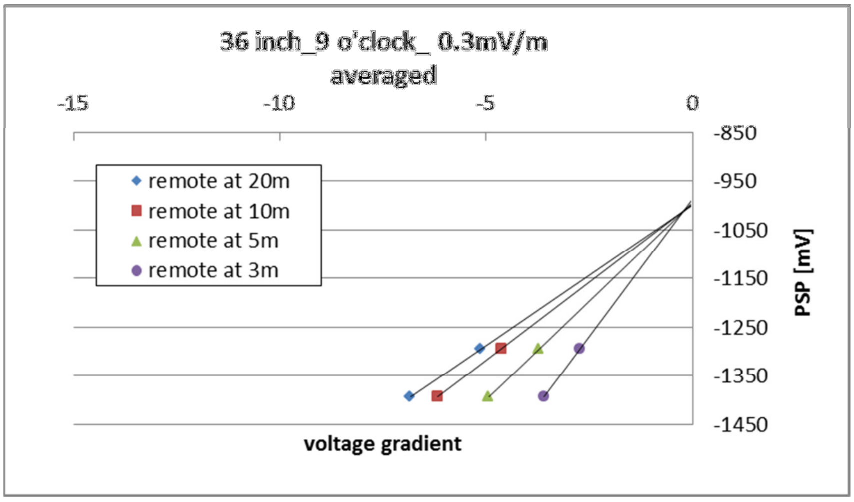


Figure 15 – effect of position of ref cell 3 on right side (36" pipe, moderate stray current, defect on the left side)

4. Vertical alignment

In order to minimize the effect of stray currents and to maintain sufficient voltage gradient, a vertical alignment of the central and remote reference cell through the epicenter is investigated. The center reference cell is now placed closer to the defect, and the remote reference cell is put perpendicular above the center reference cell (0.25 m below grade level to avoid noise). By putting the central reference cell deeper in the borehole, the potential gradient can be increased again. The gradient can thereby be significantly larger than the original setup (central reference cell at the epicenter and the remote reference cell at 20 m distance). An example for a 36 inch pipe with a defect at 9 o'clock is given in figure 16.

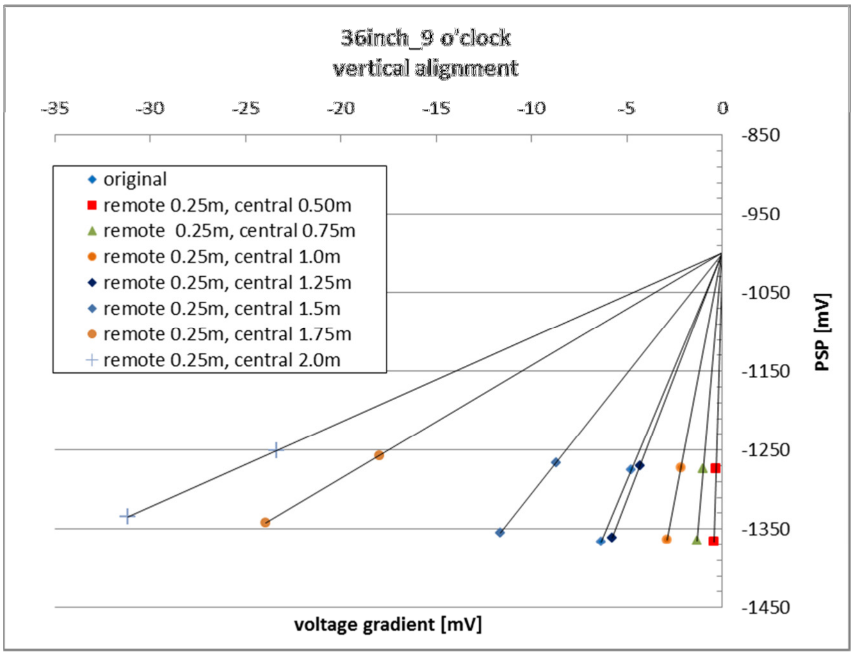


Figure 16 – vertical alignment of reference cell for 36" pipe with defect at 9 o'clock

For a defect assumed at the 12 o'clock position is the logical to measure in the vertical setup in the the epicenter. For a defect assumed at the 9 o'clock position a vertical measurement in the epicenter is logical (see above figure 16). However for a defect assumed at the 6 o'clock position, the voltage gradient is likely to be weaker if taken at the epicenter, and therefore it is obvious to measure at a larger depth to obtain a large voltage gradient.

In Figure 17 the measurement is taken in the epicenter right above the pipeline (can not be deeper than 1.25 m because of the pipeline) while in figure 18 the vertical measurement is taken next to the pipeline in order to go deeper and to obtain greater voltage gradient at a greater depth. As can be seen a comparable signal strength is obtained with the central reference cell at approximate depth of the defect as with the original set-up with the remote reference at 20 m distance.

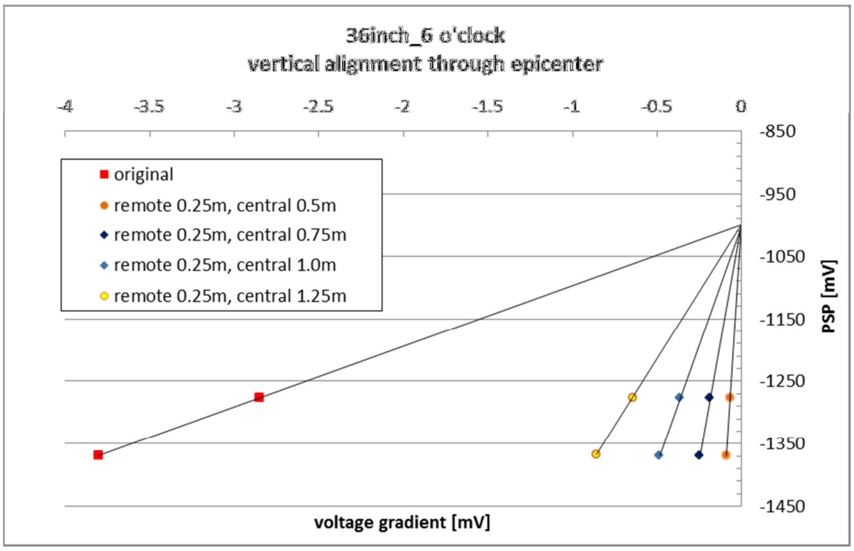


Figure 17 – vertical alignment of reference cells above 36" pipe with defect at 6 o'clock

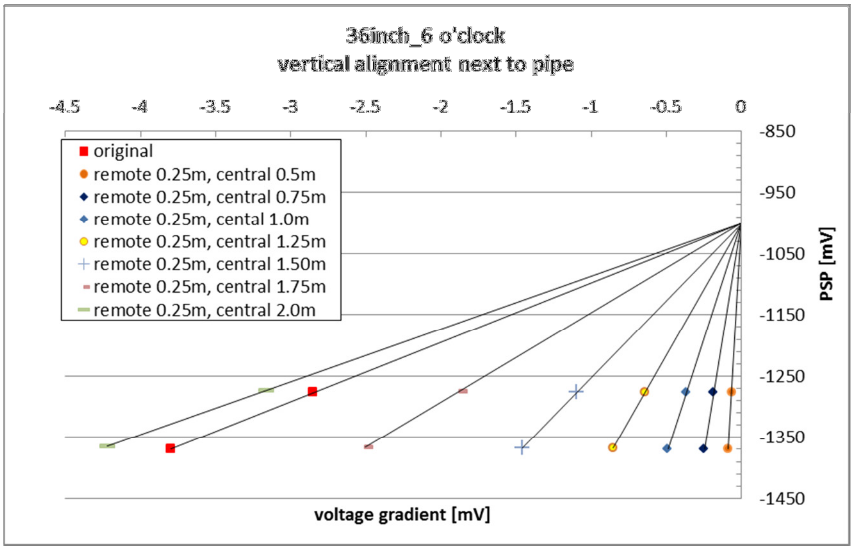


Figure 18 – vertical alignment of reference cells next to 36" pipe with defect at 6 o'clock

In case of stray currents and a defect at 12 o'clock a vertical measurement in the epicenter will not be influenced by stray currents because of symmetry. For a defect at 9 o'clock however two vertical measurements on either side of the tube should be performed. For a defect at 6 o'clock, the vertical measurement must be made next to the pipeline as outlined above to get enough signal strength. By measuring on both sides of the pipe, one can be more confident by averaging these two measurements and theoretically compensates for any stray current effect. In the figures below, such a dual measurement at both sides of the pipeline is shown for an asymmetric defect on the 9 o'clock position.

Although the influence of asymmetry may be expected by stray current from a single vertical measurement, figures 19 and 20 taken at both side of the pipeline show the same IR-free potential value for both the individual measurements and the average of the two measurements. Measurements on a 36 inch pipeline give the same results (not shown). So it seems permissible for defects on 12 and 9 o'clock to perform just a single vertical measurement, even in the presence of stray current.

Although not modeled but in analogy with the 9 o'clock defect, it is expected that just one vertical measurement for defects at 6 o'clock is also acceptable in case of stray currents.

The theoretical exploration of the vertical measurement still needs to be performed in the case of multiple defects. If multiple defects are detected multiple measurements should normally give a better look at the defects in question.

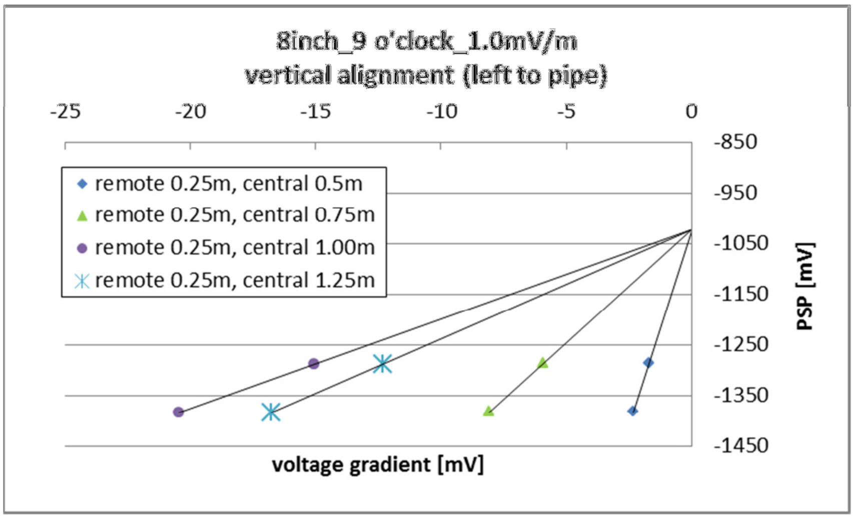


Figure 19 – vertical alignment of reference cells <u>left</u> to 8" pipe under severe stray current (defect at 9 o'clock)

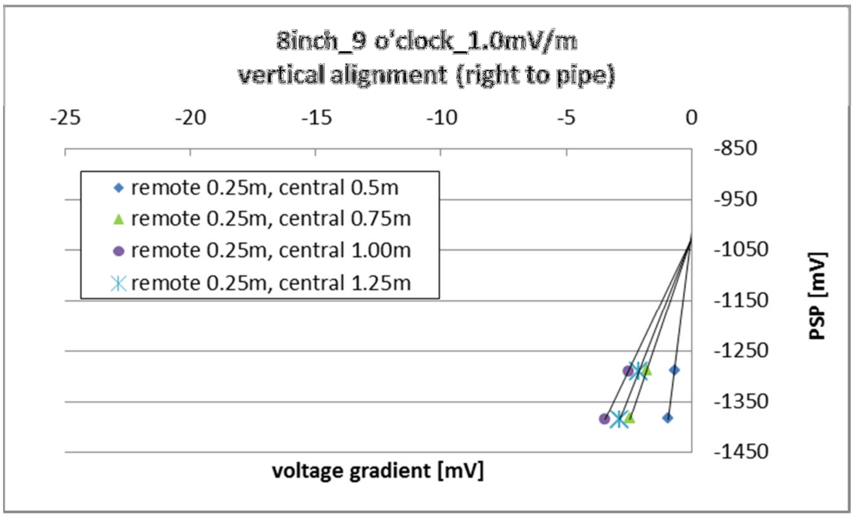


Figure 20 – vertical alignment of reference cells <u>right</u> to 8" pipe under severe stray current (defect at 9 o'clock)

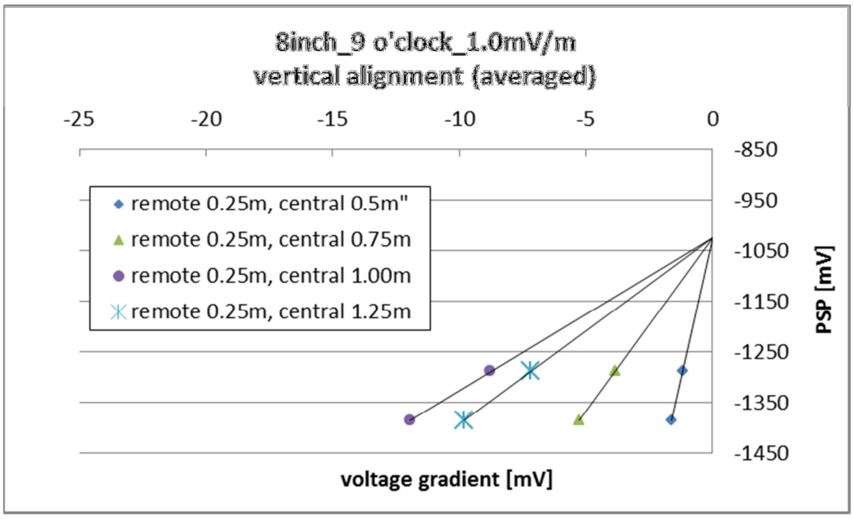


Figure 21 – averaged voltage gradients for 8" pipe under severe stray current (defect at 9 o'clock)

It is important to note that a greater gradient can be realized by using the vertical measurement set-up than in the classic measurement setup. The vertical alignment seems to be less sensitive for stray currents, which would make single vertical measurements acceptable instead of two measurements at both side of the pipeline. The vertical measurement method should be verified in the field on real cases.

Conclusions

The IR-free interpolation method requires an intensive measurement that is mostly only executed for an in-depth analysis. In order to increase the certainty of the IR-free value the measurement should be performed with care. The sensitivity of the method and its applicability was therefore investigated from a theoretical point of view through modeling.

• In case of IR-free determination at a detected coating defect it is recommended to place the reference cells directly below ground level in order to avoid noise on the reference cells.

• In case that the original set-up as described by the standard EN13509 is followed, the remote reference cells should be placed preferentially no further than five to ten meters from, and preferably left and right symmetrical to, the central reference cell located in the epicenter. This makes the measurement less sensitive to possible inhomogeneity of stray currents gradients and will give less influence from other more far away located objects. This can be seen as a possible method in city areas. In areas where less interference is expected, such as in the county, the method with the remote reference cell at 20 m is preferred. A long distance between the remote reference cell and the pipe will increase the accuracy of the measurement which is also favorable for weak signals (e.g. small defects at 6 o'clock position on large diameter pipes).

• A vertical alignment of the reference cell is proposed in this study. The vertical set-up has the benefit to generate sufficient strong signals while minimizing the effect of stray currents.
In case of suspected defects at the top and side of a pipe, it can be sufficient to perform a single vertical measurement at the epicenter. In case of suspected defects on the underside of large pipelines due to weak signals a vertical measurement on both sides of the pipe (and averaging afterwards) is recommended, however, one single vertical measurement is highly likely to be practically sufficient.

• Field experiments needs to be performed to verify the assumptions and to validate the outcomes of this modeling study.