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Practical case of measures to reduce the stray current impact on a 40 km long natural gas pipeline caused by intersecting High Voltage transmission lines

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Abstract

A natural gas pipeline is affected by ohmic interference caused by two intersecting 400 kV transmission lines and a 130 kV transmission line. Electromagnetic coupling from the transmission lines induces currents in the sky wires which flow to ground through the towers/groundings and increase the soil potential gradients around the high voltage power lines. The current passing through the ground, in combination with high resistivity soil, results in potential gradients in the soil that occur across a wide area.

By introducing several insulating joints into the 40 km long section of the natural gas pipeline, the permanent AC level has been reduced on the entire pipeline route. 95 % of the entire pipeline route is now below the criterion of 10 VAC.

Resumée

Une canalisation de gaz naturel est affectée par des interférences galvaniques générées au croisement de deux lignes de transport de 400 kV et d'une ligne de 130 kV. Les courants induits dans les lignes aériennes augmentent les gradients de potentiel du sol autour de lignes haute tension via les pylônes/mises à la terre. Le courant traversant le sol, combiné à une résistivité élevée, fera que les gradients de potentiel dans le sol s'étendront aussi très largement.

En introduisant plusieurs joints isolants dans la section de canalisation de gaz naturel de 40 km de long, le niveau de courant alternatif permanent a été réduit sur tout l'itinéraire de la canalisation. Nonante-cinq pour cent de tout l'itinéraire de la canalisation respecte désormais le critère de 10 V_{CA}.

Zusammenfassung

Eine Erdgasleitung wird durch ohmsche Beeinflussung beeinträchtigt, die von zwei kreuzenden 400-kV-Leitungen und einer 130-kV-Leitung verursacht wird. Induktionsströme in den Oberleitungen erhöhen die Potentialgradienten im Boden rund um Hochspannungsleitungen über die Masten/Fundamente. Der Strom, der im Boden fließt, führt in Kombination mit einem hohen Leitungswiderstand dazu, dass die Potentialgradienten im Boden ebenfalls sehr groß werden.

Durch den Einbau mehrerer Isolierstücke in die 40 km lange Erdgasleitung konnte die Größe des ständigen Wechselstroms an der gesamten Leitungstrasse vermindert werden. 95 % der gesamten Gasleitungstrasse liegen jetzt unter dem Schwellenwert von 10 VAC.

INTRODUCTION

AC Voltage produced on gas pipelines can, in spite of cathodic protection, cause corrosion. Laboratory and field studies of AC corrosion have been made for a long time in many countries.

The Technical Specification CEN/TS 15280 “Evaluation of a.c corrosion likelihood of buried pipelines – Application to cathodic protection pipelines” recommends the following limits:

- 10 VAC where the local soil resistivity is higher than 25 ohm.m
- 4 VAC where the local soil resistivity is less than 25 ohm.m

These guidelines provide the context for the steps taken to minimize the risk of AC corrosion on a natural gas pipeline in southwestern Sweden between Getinge and Mosshult. AC voltages between pipe / soil have varied along the pipeline and in some places have come close to 30 VAC. The source of the AC interference is obtained from the local transmission lines. Figure 1 shows a map of the pipeline route and the 130 kV and 400 kV power lines crossing the pipeline.

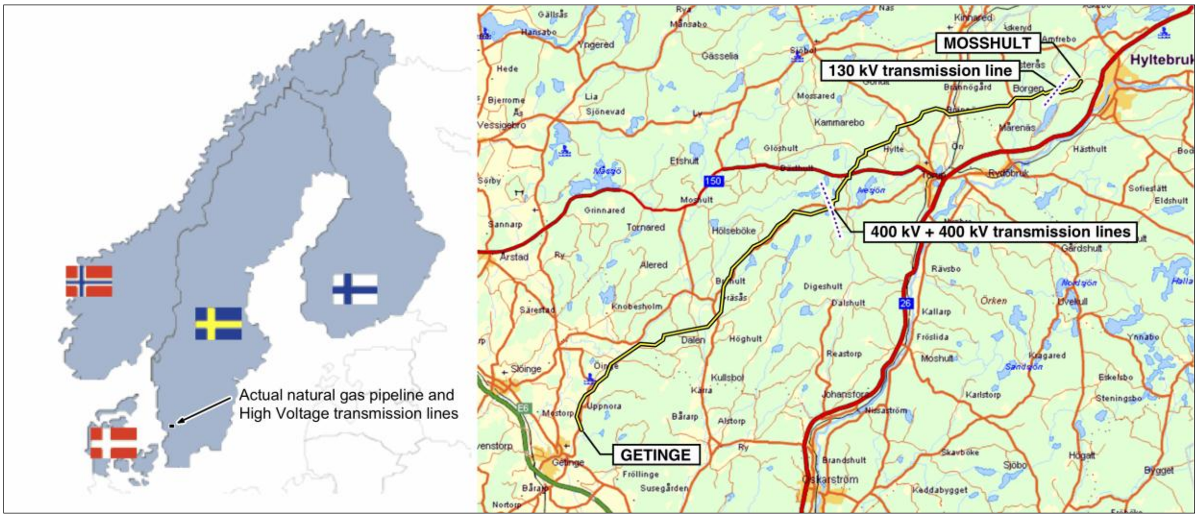

Figure1. Overview of gas pipeline

<u>Data and description of the pipeline</u>

Design pressure: 80 bar

Pipe length: 38,2 km

Diameter: 406,4 mm

Coatings: 2,2 mm PE (+10 mm Fiber concrete on 31 km pipe length)

Cathodic protection*: Impressed current, one rectifier and anode installation

Current demand*: 7,5 mA

Current Density*: < 0,15 μA/m^2

(* = before measures)

DESCRIPTION OF MEASUREMENTS

The pipeline was constructed in 1991 and during the following years, in connection with the control measurement of the cathodic protection, it was noticed that AC voltages occurred. In 1995, a new 400 kV transmission line was installed (parallel with the earlier line) which increased the impact of AC on the pipeline.

An investigation was made in which the AC voltage impact was calculated along the pipeline route. This investigation showed that the levels should be significantly lower than those measured in the field. The calculations were made with respect to induced voltages. This indicated that the main source of the measured voltage does not come from the induction.

In order to rectify the alternating voltage impact a series of measurements with direct earthing and earth via diodes were conducted. Very briefly, these tests indicated that only a local voltage reduction was obtained at the location of the earthing while it increased in other locations. This showed that the AC voltage in the pipeline was obtained from the ground. Since any types of earthing only caused circulating currents in the pipeline and no general reduction was obtained in this case this was not a practical approach.

Since the problem could not easily be solved, new tests were initiated and investigations made to find the cause of the AC voltage occurring in the pipeline. The measurements showed that AC gradients increased close to the two parallel 400 kV transmission lines and towards the east end of the pipeline.

The investigations found that the high voltage power line produced induced currents in the sky wires which flow to the earth via the local earthing electrodes connections to the power line towers producing AC voltage gradients in the earth. Approximately 2 km at right angles from the high voltage power lines there was a voltage gradient with a field strength of about 0,1 VAC/m. Closer to the transmission lines the voltage gradient was much steeper. Due to the high soil resistivity and short depth to bedrock the potential gradients along the electric power transmission systems may be widely spread.

To deal with the large current flows in the sky wires (estimated to be over 100 A) the sky wires were isolated on one of the two 400 kV transmission lines at a distance of 4 km from the intersection with the pipeline. On the second 400 kV power line the sky wires could not be isolated because an optical cable was connected to one of the sky wires. In combination with these measures on the sky wires, even the earth wires were isolated in the vicinity of intersection point of pipeline.

Outside the area 4 km on each side of the intersection with the pipeline, both high voltage power lines are connected together to the same towers and sky wires which means that isolation of one of the sky wires mainly gives a reallocation of current

flow in the sky wires. The result of the isolation measures was therefore only a marginal reduction of soil voltage potential in the area of the crossing.

As the power flow on the high voltage lines increased with time, the impact on the pipeline also increased proportionally. This made it necessary to take protective measures. The focus became henceforth to investigate the possibility of making changes in the pipeline system.

During annual surveys measurements were made of the AC voltages between the pipeline/soil. See figure 2 below.

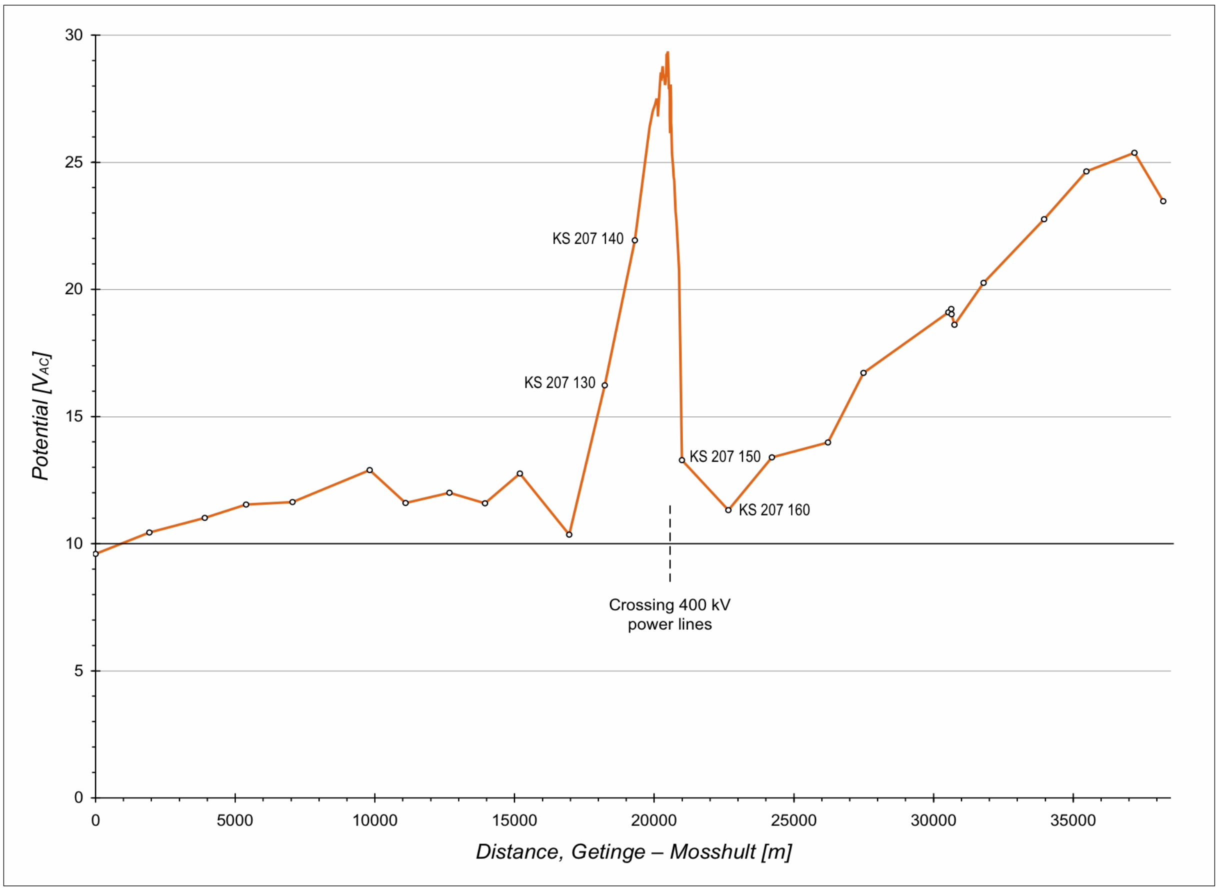

Figure 2. Measuring of AC potential on pipeline

The figure shows a typical graph of the alternating voltage between the gas pipe/soil over the whole distance between Getinge - Mosshult. Test posts along the pipeline are represented by the round points. Between the test posts closest to the high voltage power line (KS 207 140 – KS 207 150) an additional intensive measurement was made.

The currents in the high voltage power lines vary from day to day and the ground potentials vary proportionately. In the figure shown above measured values have been recalculated so that they each correspond to the voltage of a power output of 1.5 GW on the high voltage power line.

In order to allow easy recalculations of measurements a separate installation was installed consisting of two electrodes in the ground separated by a distance of 100 m, positioned at right angles out from the high voltage power lines approximately 200 m from the outer phase conductor. Voltage gradient could then be easily measured between the two installed electrodes and be compared with the power flow in the transmission line. The measured value was calibrated to the power flow in the high voltage lines which meant that it was then not necessary to obtain this information from the power company for each measurement.

Figure 3 shows an example of how the power flow in the transmission line varies over 24 hours.

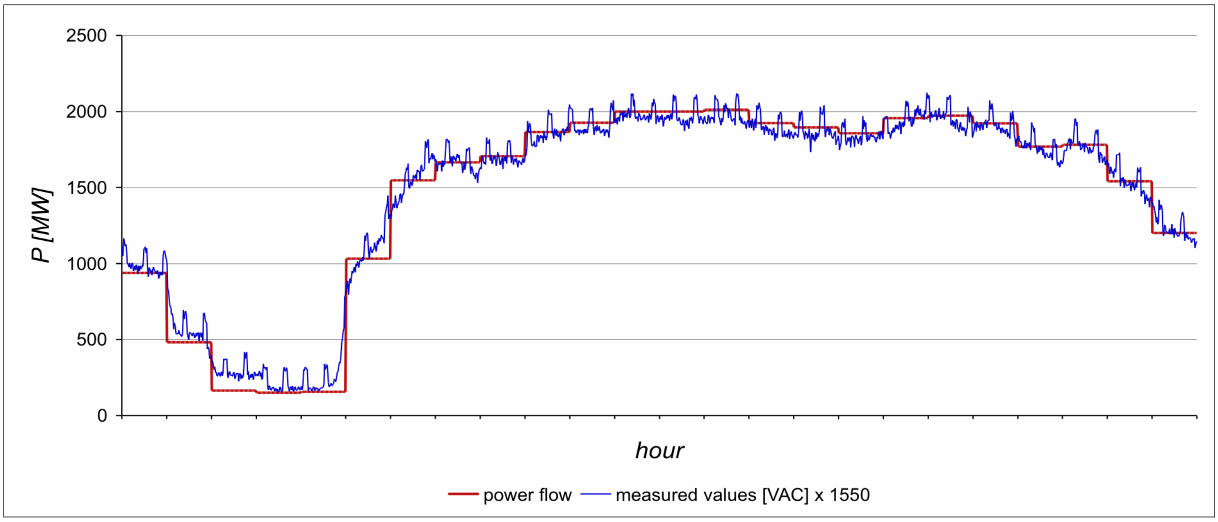

Figure 3.

In figure 3, the red curve shows the high voltage power flow (hourly average values), the blue curve show measured values during the same period on the installed earthing electrodes.

Based on these measurements (collected over a longer period), the ratio between the power flow and the measured potential gradient in the soil between the earthing electrodes is determined. Figure 4 illustrates this relationship

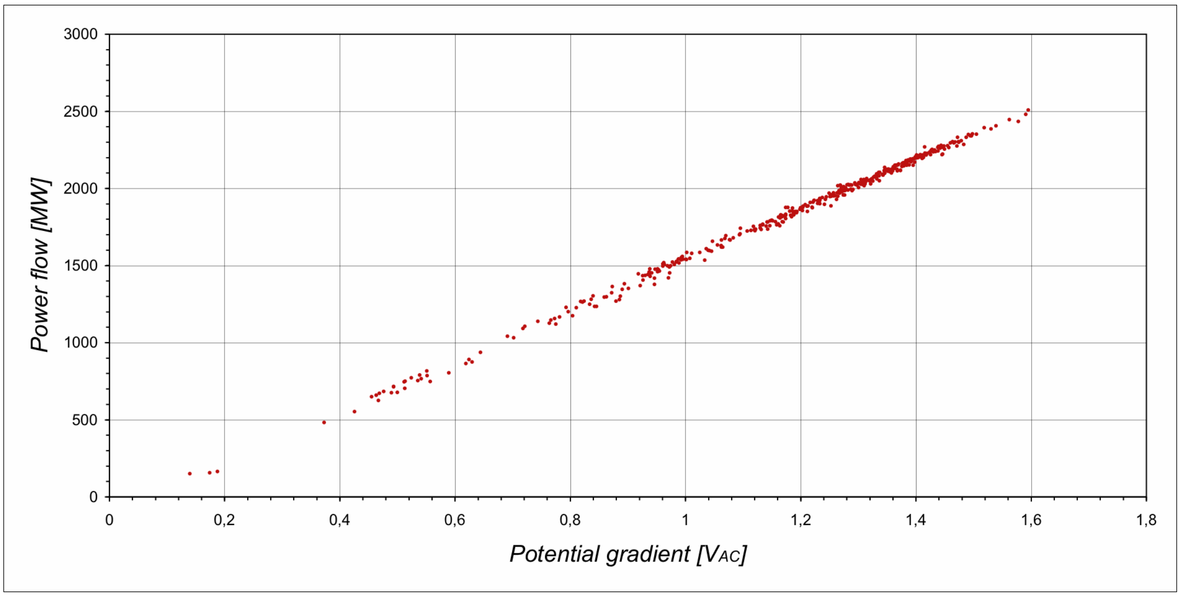

Figure 4.

The figure shows the obtained hourly average values for the power flow on the power lines and the corresponding average value for the measured potential gradient in the soil. The measurements show that the measured voltages between the earthing electrode are directly proportional to the power flow on the transmission line.

LABORATORY MODEL

In order to increase understanding of the phenomena of how AC voltage occurs on the pipeline, in 2006 a couple of laboratory models were made to conduct simulations in various steps. The figure below shows one of the models where we could recreate voltage impact similar to that recorded in the pipeline.

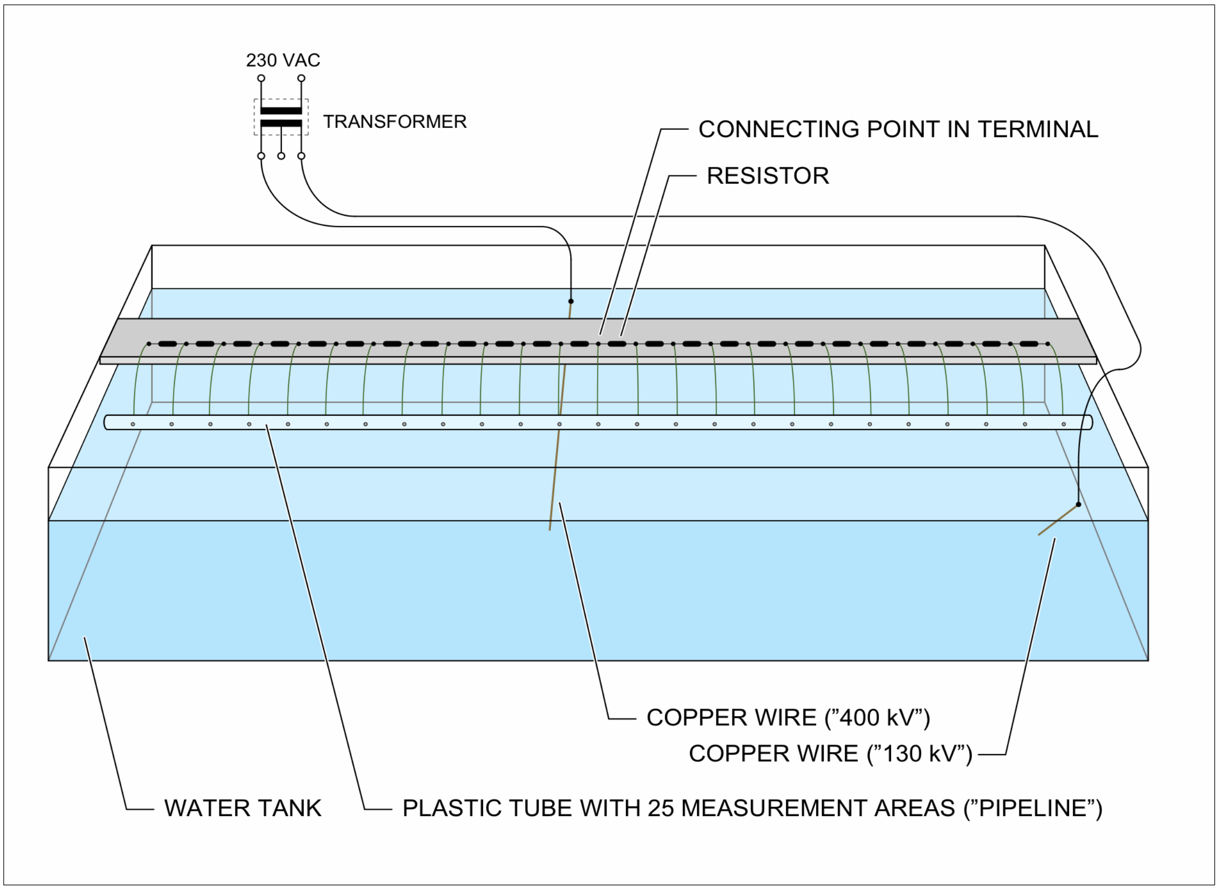

Figure 5. Model

The pipeline is simulated in the model (figure 5) by a plastic tube with 25 measurement areas. The 400 kV transmission lines were simulated by a crossing earthing wire and a small earthing plan for 130 kV network.

By trying different voltage potentials and connections to the earth wire and earthing plane we could do different simulations. Both voltage potential measured between pipe / soil (water) and potential gradients in soil (water) could be measured in this tests.

Since all the measuring surfaces were coupled together in a terminal block, it was possible to measure the current flow and current density in the measuring surfaces. In the model, it was also possible to do various experiments with sectioning the pipeline (model) at various points.

Figure 6 shows the final model used in simulations for the design of sectioning. The model was built at a scale of 1:50 000 with measuring distance corresponding to 500 meter between surfaces.

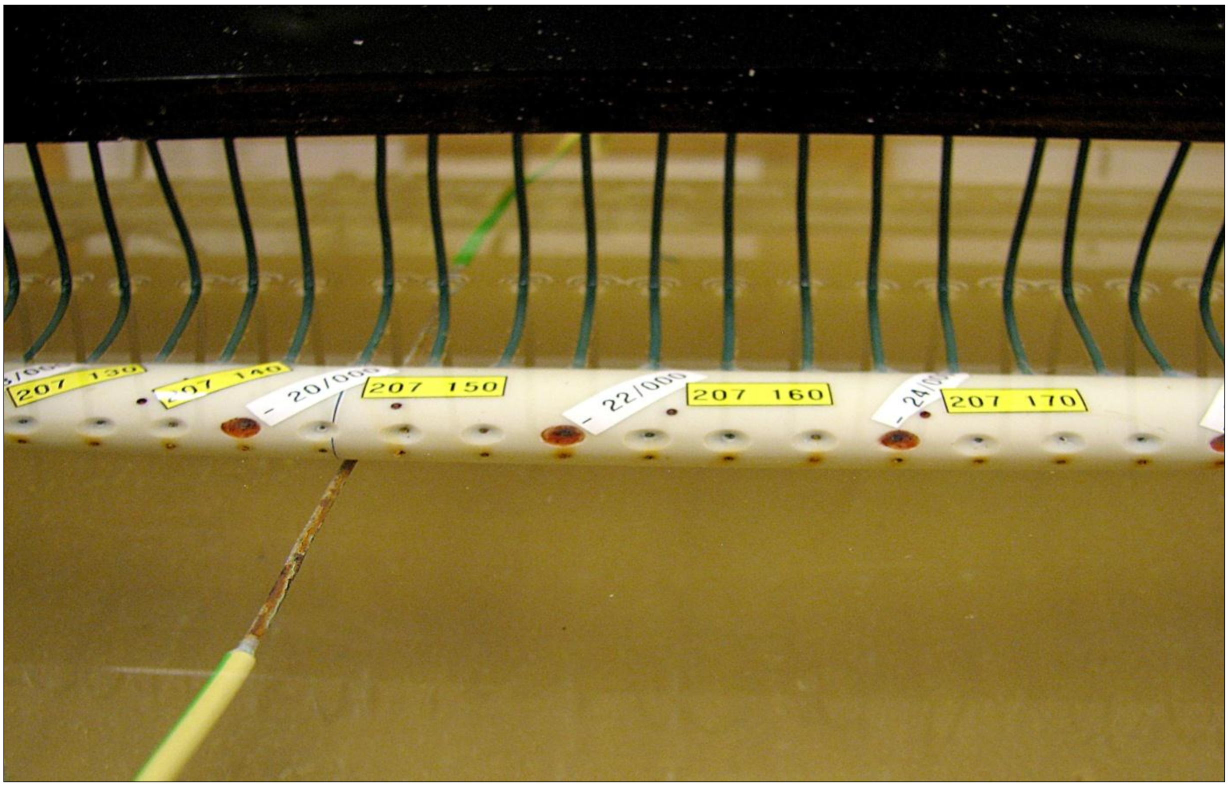

Figure 6. Picture of the Model

The photo (figure 6) shows a close up in the area of the crossing with the 400 kV power lines. The small dots are measuring surfaces with a diameter of 0.7 mm. Above these are the location points for reproducible measurement of the reference electrode.

The distances along the pipeline are marked with white labels. The yellow labels mark the location of the test post in the field (= the dots in figure 2). The crossing 400 kV power lines ground system is represented in the model by a non-insulated copper wire placed under the model of the pipeline.

Figure 7 shows one of the curves measured in the model.

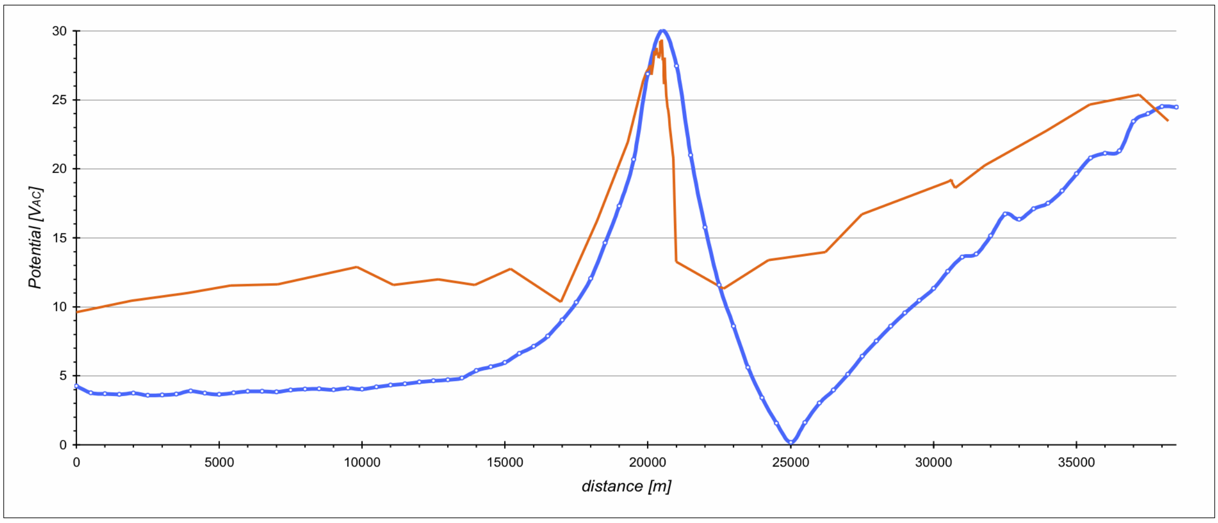

Figure 7. Potential measured in model comparison with potential on pipeline

The blue curve shows the potential measured in the model and the orange curve shows the curve measured in the field, the same curve as presented in Figure 2. In the curve from the laboratory measurements there was a clear zero-crossing at “25 000 m”. The zero-crossing has not been measured in the field. The actual gas pipeline is however also to some extent influenced by the induced voltage which makes the situation more complex.

In the model, a number of simulations and measurements were made to obtain results of different sections, test with earth pipelines, and more. Figure 8 below shows one of the simulations to see the effect of sections with a number of insulating joints.

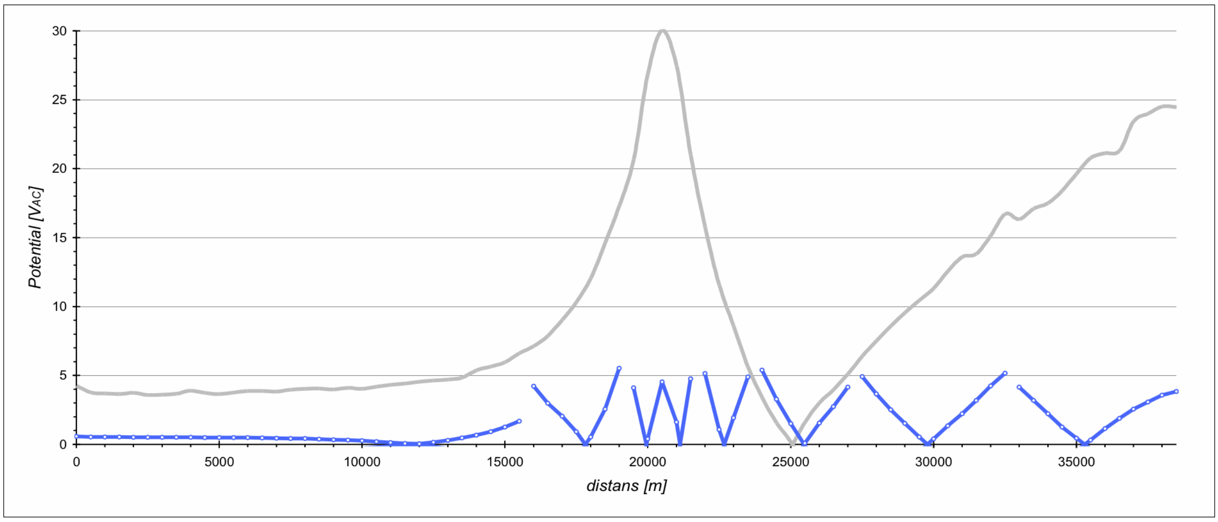

Figure 8. Simulation of seven sectionings by six insulation points of the pipeline in the Model

The simulations of the model have shown that sectioning the pipeline with insulation joints is a possible solution for obtaining the wished reduction in the voltage between the gas pipe / soil. The real appearance of voltage gradients along the entire route will be crucial in determining how many sections there need to be and where they should be placed.

PROJECT INSULATING JOINTS

To obtain a basis for the design we carried out a number of field measurements of the voltage gradients in the soil. Because of capacitive current transferred to the pipeline there will also be a certain influence of soil potential gradient in the near-by area. This means that one cannot use the measurements obtained on or near the pipeline as a basis for the design of sections. Based on this the measurement was carried out alongside the pipeline, outside the area where impacts from pipeline voltage gradients exist.

Voltage gradients in the soil were measured between two earth electrodes, one fixed and one moving along the route that was divided into stages. The obtained values were recalculated so that they were corrected for the varying power flows on the 400 kV transmission line. The various readings were then merged into a graph, which is shown in figure 9.

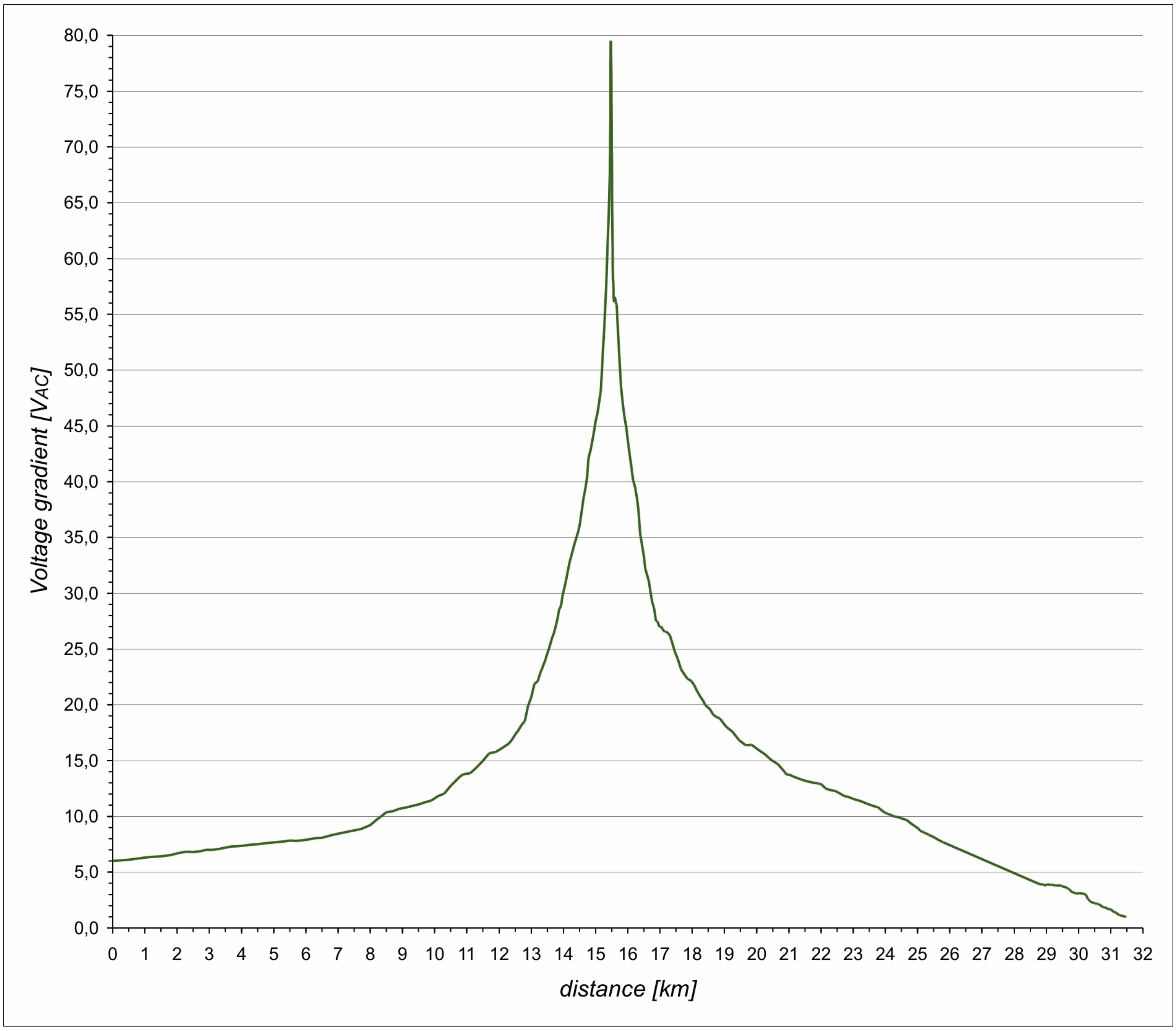

Figure 9. Measured voltage gradients at 1.5 GW power of 400 kV transmission lines.

The displayed scale is relative and it is assumed that neutral earth roughly corresponding to 5 VAC in the graph.

At one of the stages in the east area that passed the crossing 130 kV transmission line, there was measured a 180° phase-shifted AC voltage gradient around the grounding system of the 130 kV transmission line.

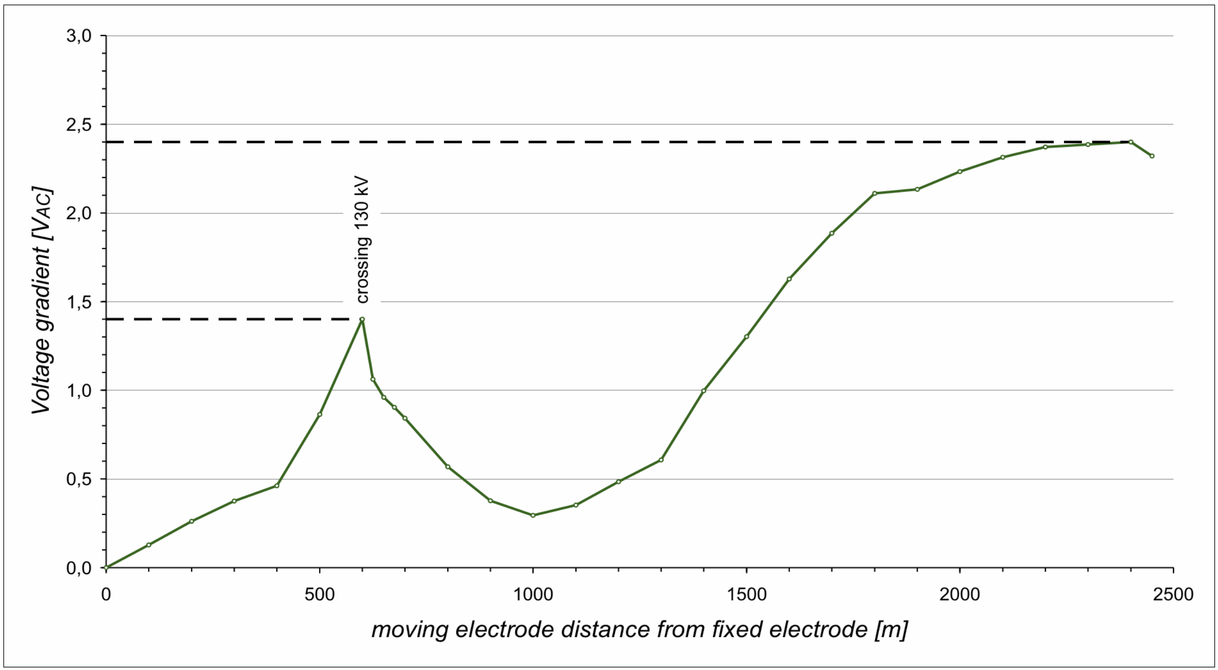

Figure 10. Diagram of the measurement where the 180° phase-shift of AC voltage was measured.

The difference between the two peaks, one at 1.4 VAC and one at 2.4 VAC was measured, not to be 1.0 VAC, but to be 3.8 VAC since they were out of phase. This measurement verifies the conclusions that were made based on the laboratory model in figure 7 concerning the shift in phase.

After all the measurements were performed and the voltage gradient appearance established, work was started to determine the number and placement of insulating joints required. The design was based on power flows of 1.5 GW on the 400 kV transmission line. As a design criterion for the AC voltage levels we used 7 VAC to obtain a certain margin to the limit value of 10 VAC.

According to the results of the field measurements, the chosen design criteria and calculations it was established that the pipeline route has to be divided into nine segments, thus requiring the installation of eight insulating joints.

INSTALLATION

Based on the results from the design the eight Insulating joints were installed. The entire pipeline was now divided into nine sections that were electrically separated. Each of them requires cathodic protection. Instead of making eight new CP-installations, a different solution was done.

The low current demand made it possible to use a common CP-system by linking some sections via chokes. Specially adapted chokes were made for this purpose with an impedance of 2000 ohm at 50 Hz and a low DC resistance, less than 5 ohm. Cathodic protection current could then be passed across insulating joints while blocking the AC that remains. This meant that the pipeline route only needed to be complemented with two rectifiers. See figure 11.

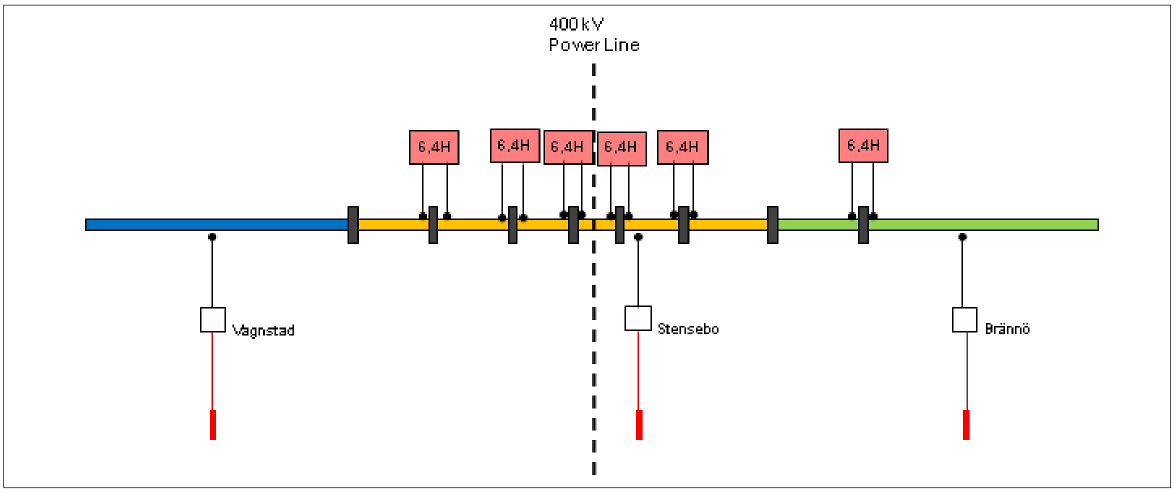

Figure 11. Overview of the pipeline, the nine sections and division of the CP-system.

Since the pipeline is located in areas where electricity is only possible at great cost, we decided to install solar-powered rectifiers. An added advantage of installing solar panels was that we were more free to choose an optimal location for the installation.

With this design the CP-system only needs to be complemented by two new rectifiers (solar powered rectifier and anodes) and comprehensive cathodic protection could be obtained. It may also be noted that the cathodic protection current total demand, after sectioning of the pipeline also decreased by about 20 %.

Each insulating joint was installed underground and next to each location there was also installed an electrical cabinet and a testpost. In the electrical cabinet were installed the chokes that let the CP-current pass and surge protection to local earthing. The test post contains functions for control of cathodic protection, Insulating joints, chokes and earthing function. Directly above the insulating joints a concrete well was placed containing a surge protection. The installation is shown in figure 12.

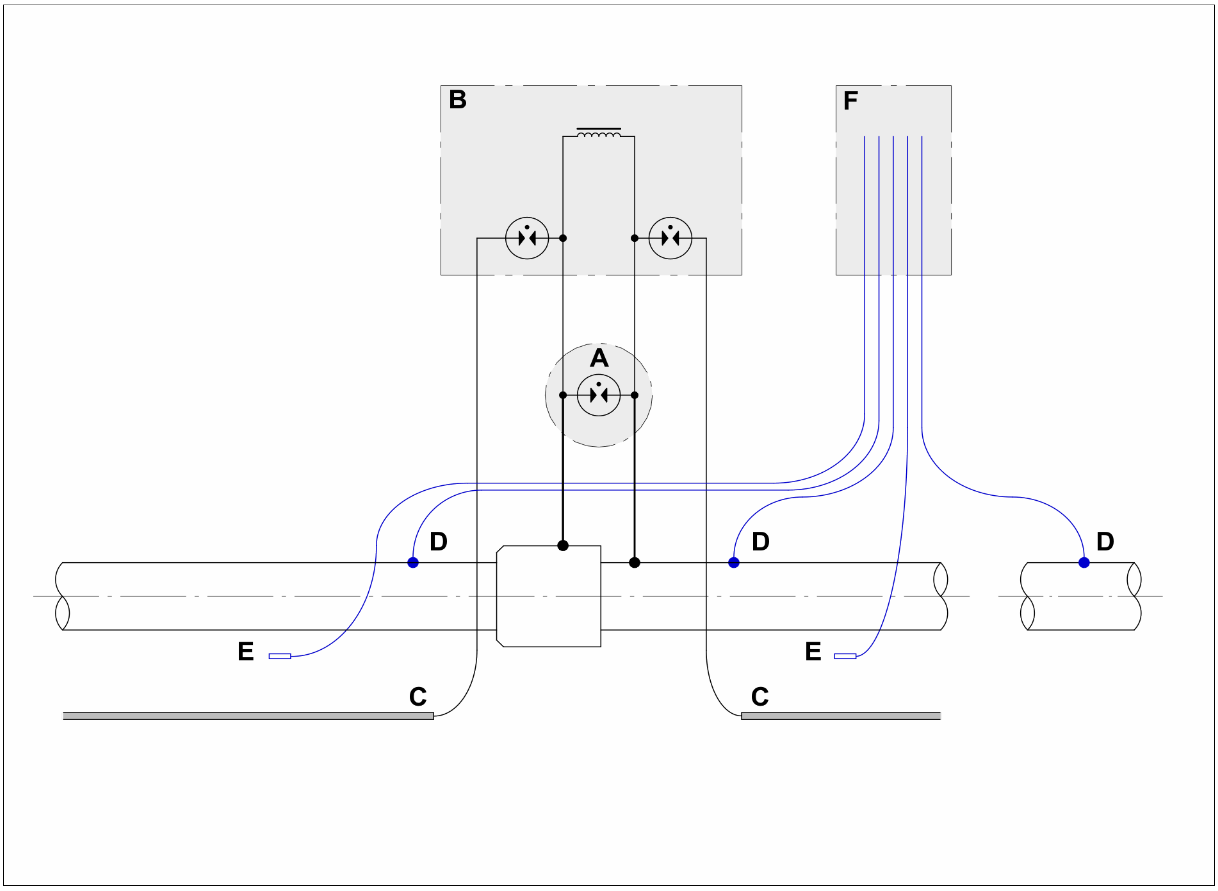

Figure 12. Principle of installations at the insulating joints.

A Surge Protection (1 kV) placed in concrete well above insulating joints.
B Electrical cabinet with surge protector (0.35 kV) to the local bonding connections and chokes (6.4 H) for the transfer of the cathodic protection current.
C Local earthing connections, galvanized flat bar 6 m.
D Measuring connections on the pipeline for control measurement of the VAC, cathodic protection and power flow in the pipeline. Distance 50 meters.
E Coupon. Measuring surface 1,0 cm^2.
F CP testpost for function control.

Surge protectors over insulating joints were installed to protect against high surges caused by fault in high voltage transmission line or by lightning. The local earthings and the surge protector were installed for drainage of overvoltage and limit distribution of high voltage in the system.

The outcome of the installation was successful and figure 13 shows the AC voltage on the pipeline after the sectioning was performed.

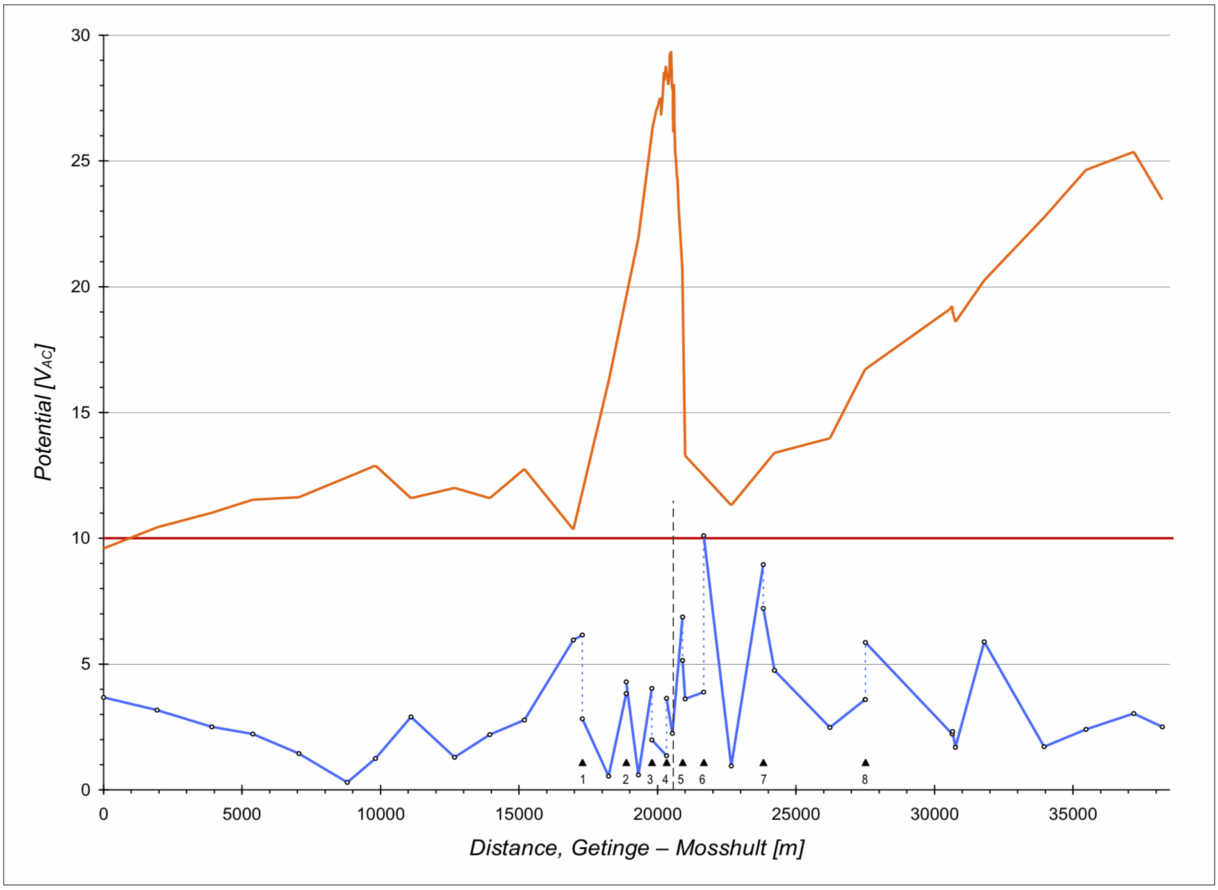

Figure 13 shows the results of sectioning,

Orange curve shows the measured VAC before sectioning,

Blue curve is measured VAC after sectioning,

Criteria of 10 VAC shows by the red line.

CONCLUSION

The source and cause of AC interference on the gas pipeline has been established through a combination of field measurements and laboratory studies.

The main problem was the widespread voltage gradient caused by two intersecting 400 kV and a 130 kV transmission line. Currents in the sky wires flow to ground through the towers/groundings and due to the high soil resistivity and shallow depth to bedrock increased the AC potential in the soil which caused relatively high AC-impact on the pipeline. By sectioning the pipeline route with insulating joints, the voltage level could be lowered to the desired level.

By installing custom chokes over the insulation joints the cathodic protection current could pass through them while the ac voltage could still be blocked.

The main experience from this event is:

- Field measurements along the whole pipeline route are a prerequisite for obtaining a comprehensive picture of the situation in cases like this.
- If the measurement of voltage gradients is made where a pipeline is already installed, it should be noted that the gradient will bend in the vicinity of the pipeline and therefore does not represent the same gradient that will exist after sectioning when the influence will decrease.
- If the measurement displays more than one increase in the AC gradient it is important to also check whether or not the two peaks in the AC potential are in phase or not.
- If the source of the voltage impact on the pipeline is obtained from the voltage in the ground, it is likely that a local earthing will only result in a local voltage reduction and a corresponding increase in another location. The risk of the increased current flow in the pipes that occur with earthing should also be considered in these cases.
- The use of insulation joints appears to be a sure way to reduce the voltage impact, whether this is obtained from the ground or through induction.
- There is a possibility to let the CP-current pass by an insulating joint with a suitable choke and have a common CP system for several sections.
- Every case is unique and will, more or less, require a special solution. If one, however, could make some kind of model where the conditions and the results from field measurements can be recreated there is also a good possibility to test different solutions and their outcomes.

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