# IMPACTS OF INDUCTIVE AND CONDUCTIVE INTERFERENCE DUE TO HIGH-VOLTAGE LINES ON COATING HOLIDAYS OF ISOLATED METALLIC PIPELINES

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## ABSTRACT

*Inductive and conductive interferences of isolated metallic oil-, gas-, water- and district-heating pipelines due to short-circuit and operation currents of high-voltage lines are a well-known problem since the early 1960ies. In these times the first big so called energy routes, where high-voltage lines, electric railways and pipelines are located in the same close corridor, developed.*

*The electromagnetic coupling between high-voltage lines and the pipeline lead to nameable induced voltages causing the risk of hazard as well as a.c. corrosion. When speaking about conductive interference, currents flow, mostly through the electric flow field in earth, from the high-voltage line to the pipeline. Conductive interference plays a role, assuming that influencing and influenced systems are close together in the same potential gradient area, either in short-circuit modes, or in normal operation modes, where currents enter through coating holidays[1] of the isolated influenced pipeline due to potential differences between the metallic pipeline and local earth. In the area of the possible coating holiday dangerous touch voltages can be picked off. In normal operation modes for example in the vicinity of transposition towers as well as electric railways, currents also can enter through coating holidays. In case of inductive interference already small induced voltages in the range of some 4-10 V lead to high current densities (above 100 A/m$^2$) at small coating holidays (for example diameters < 10 mm). Referring to European Technical Specifications very high a.c. corrosion likelihood is given from current densities higher than 100 A/m$^2$. Inductively as well as conductively coupled a.c. currents flowing over coating holidays lead to extensive material removal.*

## INTRODUCTION

Pipeline isolation defects can develop very easily, for instance during construction work. From an electrical point of view, coating holidays can be seen as a small, high-impedant pipeline a.c. earthing system connected to the pipeline. If the coating holiday size for example exceeds a certain dimension, corrosion risk likelihood neutralizes according to the relevant current density. In this paper the coating holiday is described mathematically and the effects on pipeline voltages and current densities are shown. In addition to that the potential distribution along a pipeline in the potential gradient area of an electrical power system is shown in dependency of the distance to the coating holiday.

## MATHEMATICAL DESCRIBTION AND MODELLING COATING HOLIDAYS

There exist several publications and technical reports for example [1], [2], [3] in which the model of a coating holiday is discussed. Generally speaking the total resistivity of a coating holiday is the sum of the polarisation resistance of the bare steel, the resistance of the medium inside the coating defect and the leakage resistance in the soil. Assuming homogenous soil conditions inside and outside the coating defect, the coating holiday can be simplified as a circular plate earthing system. The amount of the polarisation resistance plays an underpart and is not taken into account in this paper. This can be done aware of the fact that for example the determination of the soil resistivity is always an assumption, if we think about long pipelines over several kilometres.

Nevertheless the following calculation results and figures provide practicable reference values.

The resistivity of a circular coating holiday $r_{ch}$ can be calculated with the following formula [11].

$$r_{ch} = \frac{\rho_E}{4 \cdot d}\left(1 + \frac{2}{\pi} \cdot \arctan \frac{r}{2 \cdot H}\right) \qquad (1)$$

| | |
|---|---|
| $\rho_E$ | specific soil resistivity |
| d | diameter of circular coating holiday |
| r | radius of circular coating holiday |
| H | Vertical Distance from earth's surface to coating holiday |

The following figure 1 shows the correlation between the resistivity of the coating holiday $r_{ch}$, the specific soil resistivity $\rho_E$ and the diameter of the coating holiday d.

1 Small defects of isolating pipeline coating

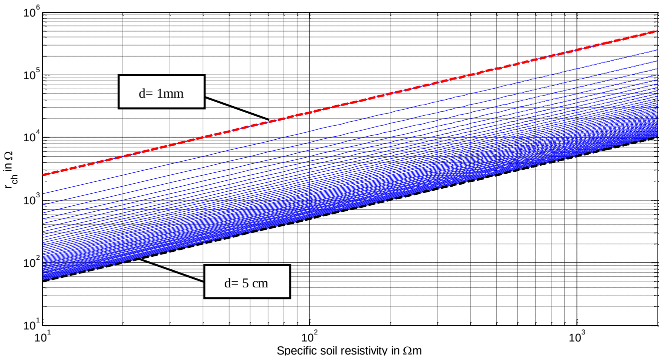


Figure 1: $r_{ch}$ plotted against $\rho_E$ for variable coating holiday diameters

The Figure 1 shows how the resistance of the coating holiday rises with increasing soil resistivity. The specific soil resistivity $\rho_E$ is varied from 10 Ωm to 2000 Ωm in steps of 10 Ωm. The diameter of the coating holiday is varied from 1 mm to 5 cm in steps of 1 mm. The d = 1 mm series is dotted in red, the d = 5 cm series is dotted in black.

One can see that a coating holiday acts like a very high impedant earthing system (for example 1000 Ω for a coating holiday with d = 2.5 cm at 100 Ωm) to inductively interfered pipelines. As can be shown the earthing effect of such high impedant holiday earthing systems is much too low to reduce pipeline potentials of inductively interfered pipelines, because of the low pipeline self-impedance.

## CURRENTS OVER COATING HOLIDAYS

In a next step four relevant induced pipeline voltages – 1 V, 4 V, 10 V and 20 V are assumed. Due to the in figure 1 shown coating holiday resistivities and Ohm's law, the currents $I_{ch}$ flowing over the coating holidays, for the chosen values of the soil resistivity $\rho_E$ and the coating holiday diameter d can be calculated.

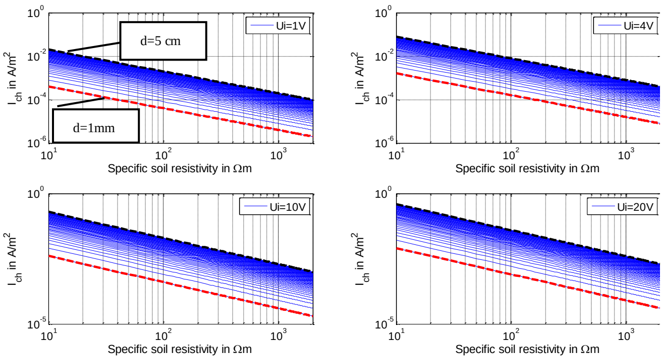


Figure 2: $I_{ch}$ plotted against $\rho_E$ for variable coating holiday diameters and selected induced pipeline voltages

The figure 2 shows how the currents over coating holidays decrease with rising soil resistivity. This corresponds to relevant European recommendations [3], that say that for very low soils resistivities ($\rho_E$ < 25), the measured pipeline voltage towards remote earth should not exceed 4 V, to reduce a.c. corrosion likelihood. For greater soil resistivities ($\rho_E$ > 25) the pipeline voltage to remote earth should not exceed 10 V. These mentioned values base on long term practical experience of European pipeline operators [3].

The diameter of the coating holiday is again varied from 1 mm to 5 cm in steps of 1 mm. The d = 1 mm series is dotted in red, the d = 5 cm series is dotted in black. The currents leaving the coating holidays are relatively small. The highest current $I_{ch}$ of approximately 0.4 A in this example can be achieved with the maximum assumed induced voltage Ui = 20 V, the maximum assumed coating holiday diameter d = 5 cm and the minimum assumed specific soil resistivity $\rho_E$ = 10 Ωm.

## CURRENT DENSITIES AT COATING HOLIDAYS

By dividing the currents over the coating holidays $I_{ch}$ (Figure 2) by the circular surfaces of the coating holidays, the current densities at the assumed coating holidays $J_{ch}$, for the assumed induced pipeline voltages can be calculated.

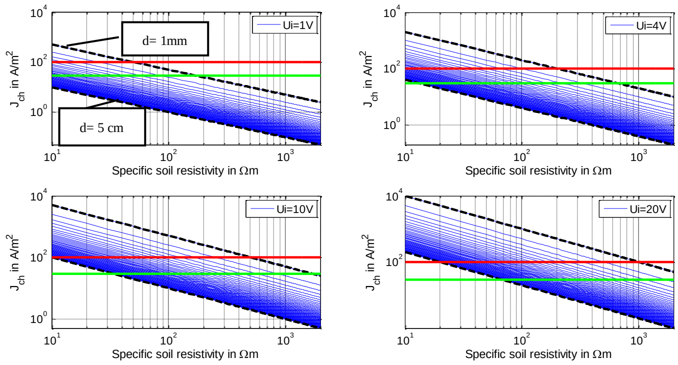


Figure 3: $J_{ch}$ plotted against $\rho_E$ for variable coating holiday diameters and selected induced pipeline voltages red line: 100 A/m$^2$ border, green line: 30 A/m$^2$ border

The figure 3 shows how current densities at coating holidays $J_{ch}$ decrease with rising soil resistivities. At coating holidays with smaller diameters, the current densities are comparatively higher. Due to the relevant European recommendations [3] there exists no or a low likelihood of a.c. corrosion for current densities < 30 A/m$^2$. The 30 A/m$^2$- borderline is plotted in green. For current densities between 30 A/m$^2$ and 100 A/m$^2$ there exists medium a.c. corrosion likelihood. For current densities > 100 A/m$^2$ there exists very high a.c. corrosion likelihood. The 100 A/m$^2$- borderline is plotted in red.

One can see that there already exist high a.c. corrosion risks for an assumed induced voltage of 1 V. Knowing well that this occurs only for very low soil resistivities and very low coating holidays with diameters up to 5 mm. The small coating holidays in this investigation demonstrate a borderline case.

In the following tables 1 and 2 some significant cases are clearly represented.

| | d=1mm | d=5mm | d=1cm | d=2cm | d=5cm |
|---|---|---|---|---|---|
| | $J_{ch}$ in A/m$^2$ | | | | |
| Ui = 1V | 509.21 | 101.78 | 50.84 | 25.38 | 10.11 |
| Ui = 4V | 2036.85 | 407.11 | 203.39 | 101.54 | 40.42 |
| Ui = 10V | 5092.14 | 1017.78 | 508.49 | 253.84 | 101.06 |
| Ui = 20V | 1018.42 | 2035.56 | 1016.97 | 507.68 | 202.11 |

Table 1: $J_{ch}$ for selected induced pipeline voltages, selected coating holiday diameters and $\rho_E$ = 10 Ωm

The cases of low or no a.c. corrosion likelihood are marked in green. The medium a.c. corrosion likelihood is marked yellow. Cases of high a.c. corrosion likelihood are marked red. The bigger the coating holiday diameter gets, the lower the a.c. corrosion likelihood.

| | d=1mm | d=5mm | d=1cm | d=2cm | d=5cm |
|---|---|---|---|---|---|
| | $J_{ch}$ in A/m$^2$ | | | | |
| Ui = 1V | 50.92 | 10.18 | 5.08 | 2.54 | 1.01 |
| Ui = 4V | 203.69 | 40.71 | 20.34 | 10.15 | 4.04 |
| Ui = 10V | 509.21 | 101.78 | 50.84 | 25.38 | 10.11 |
| Ui = 20V | 1018.42 | 203.56 | 101.70 | 50.77 | 20.21 |

Table 2: $J_{ch}$ for selected induced pipeline voltages, selected coating holiday diameters and $\rho_E$ = 100 Ωm

| | d=1mm | d=5mm | d=1cm | d=2cm | d=5cm |
|---|---|---|---|---|---|
| | $J_{ch}$ in A/m$^2$ | | | | |
| Ui = 1V | 5.09 | 1.02 | 0.51 | 0.25 | 0.10 |
| Ui = 4V | 20.37 | 4.07 | 2.03 | 1.02 | 0.40 |
| Ui = 10V | 50.92 | 10.18 | 5.08 | 2.54 | 1.01 |
| Ui = 20V | 101.84 | 20.36 | 10.17 | 5.08 | 2.02 |

Table 3: $J_{ch}$ for selected induced pipeline voltages, selected coating holiday diameters and $\rho_E$ = 1000 Ωm

When comparing Table 1,Table 2 and Table 3 one can recognize that a.c. corrosion likelihood decreases with raising specific soil resistivity $\rho_E$. Mutual impedances and consequently induced pipeline voltages in direct axis get higher with higher soil resistivities according to Carson [4] and Pollaczek [5].

A.c. corrosion likelihood decreases with raising soil resistivities, because the currents are more constraint to stay inside the metal.

Of course the impact of changing specific soil resistivities is in reality not as linear as shown in the Tables above. The linearity in the mentioned tables comes from disregarding the nonlinear [6] polarisation resistance.

Nevertheless the values are practicable reference values, if we think about uncertain variables like the prevailing specific soil resistivity, the seasonal changes of the specific soil resistivity, or the geometry of the coating holiday [7].

## CONDUCTIVE INTERFERENCE THROUGH COATING HOLIDAYS

An inductively interfered pipeline can be simulated by a series of pi-circuits [8]. The necessary formulas for pipeline impedance in direct-axes as well as for the pipeline admittance in quadrature-axes result from Michailow and Rasumow [9].

In case of conductive interference, currents can enter through the coating holiday. These influencing currents depend on the coating holiday resistance $r_{ch}$ (Figure 1).

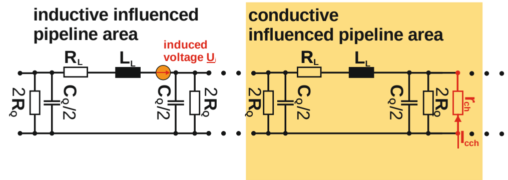


Figure 4: Pi-circuit with an inductive (left) and a conductive (right) interfered pipeline segment, conductive coupled current $I_{cch}$ over coating holiday resistance $r_{ch}$

The voltage distribution along the modelled pipeline segments can be for example calculated by nodal admittance matrix.

For the following example in figure 5 a 10-km-pipeline with a diameter of 500 mm is simulated. The assumed specific soil resistivity is 100 Ωm. The pipeline network is built with 100 pipeline pi-segments with the length of 100 m. The assumed specific coating resistance amounts to 100000 Ωm$^2$. In the simulated case the pipeline has 10 coating holidays in a distance of 100 m. The locations of the coating holidays are marked as red spots in the plot of figure 4. The diameters of the coating holidays are assumed with 10 mm (blue line), and with 20 mm (green line). The maximum potential gradient at each coating holiday to remote earth, due to conductive interference at the pipeline surfaces is assumed with 1000 V.

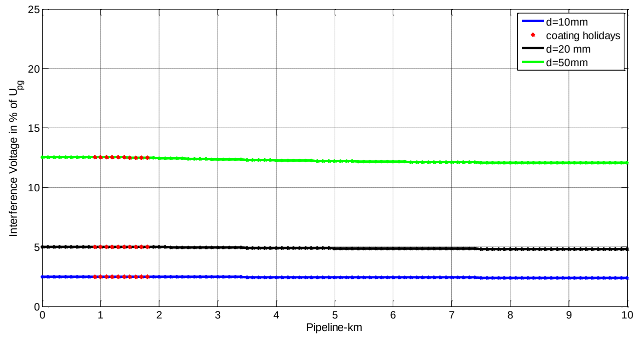


Figure 4: Interference voltage in % of the potential gradient along the pipeline due to 10 similar potential-gradients at coating holidays

The calculations in Figure 4 show an extreme example with 10 coating holidays and 10 influencing potential gradient areas. As it can be seen in this case the interfering voltages amount between 2.5 % (for d=10 mm) and 12.5 % of the interfering potential gradients. The higher interference of coating holidays with greater diameters is also pointed out in figure 4.

High potential gradients or transients may damage pipeline coatings. If they are damaged once, they are put out to the risk of a.c. corrosion.
Conductive currents through coating holidays are above all a topic in short-circuit cases. Generally in short-circuit cases, the fault it's switched off very quickly, so a.c. corrosion would not be a topic.
In compensated grids the influencing currents are very low, so a.c. corrosion due to compensating currents seems very unlikely.
Electric railways that lead their return currents partially through earth may bring some additional interfering voltages through coating holidays or earthing systems.
Other interesting cases for conductive interference are pipelines in the vicinity of transposition poles as well as in the vicinity of unbalanced high-voltage transmission systems.
Nevertheless conductive interference of pipelines has always to be considered in the vicinity of electrical power systems.

## SUMMARY

This paper describes the correlation between specific soil resistivity, coating holiday diameter, interfering voltage and current density on coating holidays. The conductive and inductive interference is in the interest of pipeline operators and the influencing high-voltage grid or railway operator.

The interference of metallic pipelines will always be the whole effect of the interplay between inductive and conductive interference.

In general mitigating measures are low-impedant a.c.-earthing systems, galvanic separations by insolating joints or realizing an improved pipeline-insulation.

The planning and optimisation of measures decreasing pipe potentials by experts also minimize recurring operating and measuring costs and ensure personal safety. Some of these mitigating measures would not be necessary, if planning processes regarding pipe routeing, avoiding narrow corridors as well as crosses with high-voltage lines would be better coordinated.

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