IMPACT OF HIGH VOLTAGE OVERHEAD LINE DESIGN ON PIPELINE SECURITY

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Abstract: The changing focus of energy politics to renewable energy and the constantly rising demand for energy has been leading to the development of existing high voltage stations, overhead power lines and cables as well as to the construction of new equipment for the transportation of additional current load. Therefore, the conductive and inductive interference near buried isolated metallic pipelines is rising which causes an increase in AC pipeline interference potential. This has an impact on the operation of pipelines. Increased voltages on a pipeline are a danger to people and pipeline system components. In addition, the higher inductive interference may raise the AC corrosion risk on the pipeline itself. In this case higher inspection and maintenance costs arise because of material corrosion and, in a worst case scenario, it may cause an additional threat to the environment.

Within Austria and Europe exist standards and guidelines (EN 50443 [1], EN 15280 [2]) which limit the maximum voltage for long term and short term interference. If the pipeline interference voltage is within the limits no further actions are required and no further costs are generated.

With newly built or extended high voltage overhead lines the maximum current for normal operations and short-circuit-situations can increase fundamentally. A precise method is needed to calculate the inference potential of a pipeline to find (only) the necessary measures for pipeline protection to avoid endangering people and material. It can be shown that the positioning and, for long term interference, the overhead line phase conductor arrangement are decisive factors when calculating the inference potential. Current mathematical models and software simulations show that varying pipeline coating and the ambience specific soil resistivity may cause a big fluctuation in the pipeline interference voltage.

Classification: Inductive interference, AC corrosion, pipeline safety

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1 Introduction

Due to the increasing overlap of traffic and energy routes, high voltage stations, overhead power lines and cables are located in the vicinity of buried isolated metallic pipelines. Consequently, the calculation of the inductive interference is becoming increasingly important since high conductive and inductive interference produces high pipeline interference voltages.

As a result of the changing focus of energy politics to renewable energy and the constantly rising need for energy, existing high voltage stations, overhead power lines and cables are being updated and new equipment is being constructed for the transportation of additional current load. Therefore, the conductive and inductive interference near buried isolated metallic pipelines is rising which leads to increased pipeline interference voltages. Higher voltages may pose a danger to people and pipeline system components. In addition, the higher inductive interference pipeline voltage may cause AC corrosion. This increased risk of material corrosion has an impact on the operation of pipelines. The inspection and maintenance costs rise to prevent leakage, which represents the worst case scenario.

Within Austria and Europe exist standards and guidelines (EN 50443 [1], EN 15280 [2]) which limit the maximum voltage for long term and short term interference. For touch voltage, the limit is 60 Volt in normal operations and 1500 Volt in short-circuit-situations while the limit for AC corrosion is 15 Volt. If the pipeline interference voltage is within the limit no further actions, e.g. AC earthing systems or additional isolating joints, are required and no further costs are generated.

With newly built or extended high voltage overhead lines the maximum current for normal operations and short-circuit-situations can increase fundamentally. Also, the positioning and, for long term interference, the overhead line phase conductor arrangement are major factors. Therefore the danger of exceeding the touch voltage and AC corrosion risk limits rises. This poses a danger to pipelines, especially in areas where the interference voltage is already near the given limit.

However, the development of existing and new overhead lines has different effects on pipelines. The reason is that the value of the pipeline coating changes with time due to surface defects. Also, the ambience specific soil resistivity varies within a large spectrum, depending on location, weather and the time of the year. With current mathematical models and software simulations it can be shown that these two parameters may cause a notable fluctuation in the calculated pipeline interference voltage.

Software simulations and the identification of proper mitigation measures can decrease the AC corrosion risk and help optimize further measures for pipeline and high voltage equipment. This reduces unacceptable pipeline voltages and their costs.

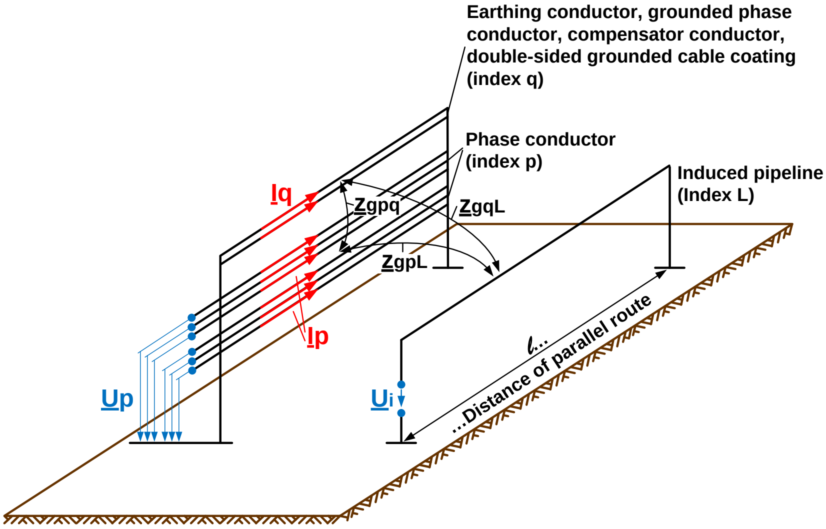
2 Methodology

2.1 Inductive interference

Inductive coupling appears when a magnetic field between an interfered buried isolated metallic pipeline system and an interfering high power overhead line or cable exists. A high pipeline interference voltage occurs when the inductive interference has a high value. The essential parameter for high inductive interference is a geographical closeness between a pipeline and an overhead line over a longer distance.

There exist other important parameters. First, the high power overhead line parameters like the current load or the phase conductor arrangement. These are major factors because the value of the current load is a direct impact factor in the formula (see Figure 1). A poor phase conductor arrangement produces an inhomogeneous inductive rotating field which can increase the inductive interference significantly. Second, certain pipeline parameters like the pipeline diameter, material or coating are also important. The last major factor, which basically cannot be controlled through technical equipment, is the soil resistivity which varies as mentioned above.

Figure 1: Complex example of inductive interference between pipeline and two-system overhead line



$\underline{I}_p$: Phase conductor current

$\underline{I}_q$: Earthing conductor current

$\underline{z}_{xxx}$: Inductive coupling impedance

$\underline{U}_p$: High power overhead line voltage level

$\underline{U}_i$: Induced voltage

ℓ: Distance of parallel route

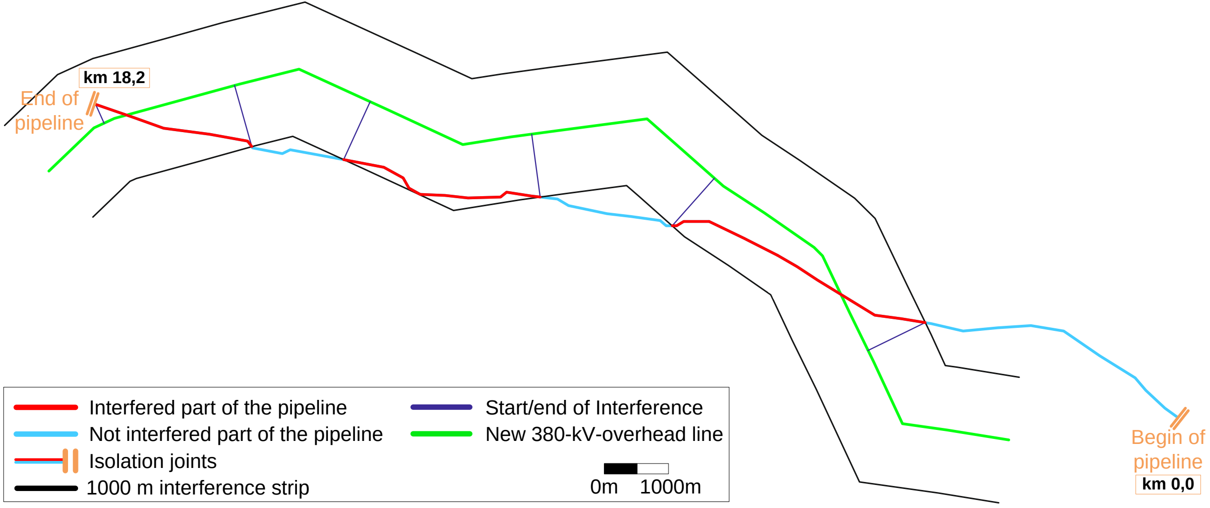
$$\underline{U}_I = \sum_{k=1}^{n} \underline{I}_k \cdot \underline{z}_{gkL} \cdot \ell$$

Figure 1 shows the inductive interference between an interfered pipeline and an interfering two-system high power overhead line. Each conductor is shown as a system of parallel line cables. The phase conductor current I_p is set by the current for normal operations and short-circuit-situations, all other currents I_p flow through other conductors and cable coatings. If all currents and inductive coupling impedances are known, the induced pipeline interference voltage can be calculated. Inductive coupling impedances are calculated with the formula of Dubanton [3].

2.2 Inductive interference and calculation example

When the geographical distance between a pipeline and a high power overhead line is less than 1000 meters, norms and guidelines say that significant inductive couplings between both systems can be expected and have to be investigated by calculation. Figure 2 shows an example of such a case and all following calculations will refer to this example. It investigates, whether the varying soil resistivity or the varying pipeline coating resistance has the bigger influence on the pipeline influence potential. The example also investigates if these two parameters influence each other.

Figure 2: Example of an approach between a pipeline and a high power overhead line



Specific soil resistivity parameter:

The specific soil resistivity along a pipeline is usually not constant because the different types of soil along the route of the pipeline have a different soil resistivity. However, this is not the only factor because weather and time of the year also influence the soil resistivity by changing the soil moisture and the soil temperature. The soil resistivity is lower when the soil moisture is high (e.g. due to high precipitation) and/or the soil temperature is high (e.g. during the summer). Therefore it is difficult to find the correct value of the soil resistivity along a pipeline.

In this paper, the specific soil resistivity varies between 25 Ωm and 10000 Ωm with the following steps: 25, 50, 100, 250, 500, 1000, 2500, 5000, 10000 Ωm.

Pipeline parameters:

The interference is calculated for an 18.2 km buried isolated steel pipeline with a diameter of 1200 mm. The coating resistance value varies. This value changes during the simulation for two reasons. On one hand, the material has been changed from bitumen, with a low coating resistance, to polyethylene, with a high coating resistance. On the other hand, the pipeline coating resistance decreases over time due to increasing coating holidays, which result in a direct contact between the steel pipeline and the soil. Coating holidays occur due to material defects or disadvantageous environmental conditions (e.g. sharp stones, construction sites). AC corrosion may occur when the pipeline interference voltage is high enough and the current density at the holiday exceeds a certain value.

In this paper, the specific pipeline coating resistance varies between 5 kΩm² and 1 MΩm² with following steps: 5 k, 15 k, 30 k, 100 k, 500 k, 1 MΩm²

High power overhead lines parameters:

All calculations use a 380-kV-overhead line which is a standard voltage level for the backbone high voltage power transmission network in Austria. Figure 3 shows the standard electricity pylon for such systems. For a two-system overhead line the phase conductor arrangement in Figure 3 is one of the best options for low inductive interference.

The load current is 1 kA, which is a realistic value for long term load current in such high power systems.

Figure 3: Electricity pylon

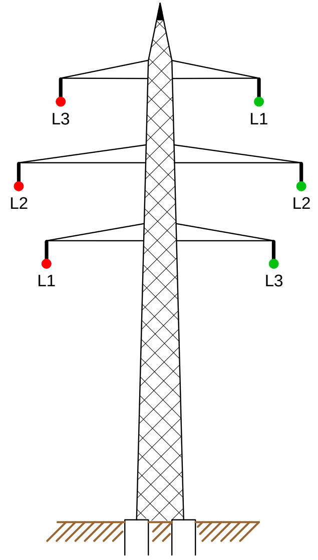
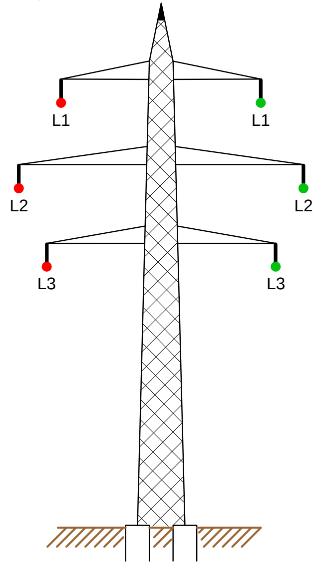


Figure 4 shows the above 380-kV-overhead line with a different phase conductor arrangement. This is a bad arrangement because the inductive rotating field is inhomogeneous and amplifies the inductive inference tremendously.

Figure 4: Electricity pylon

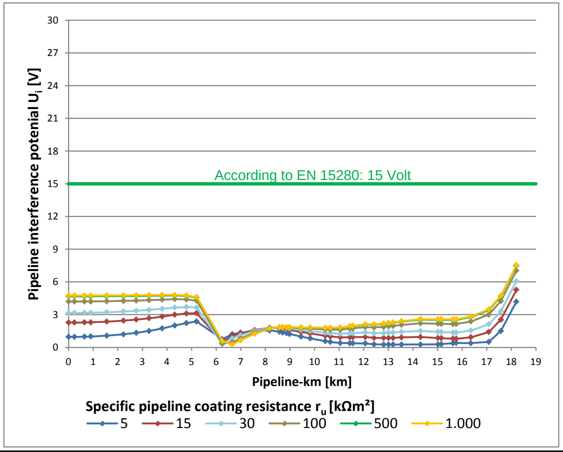
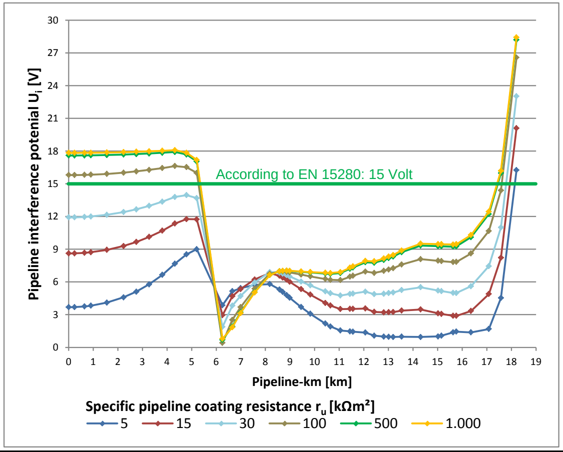
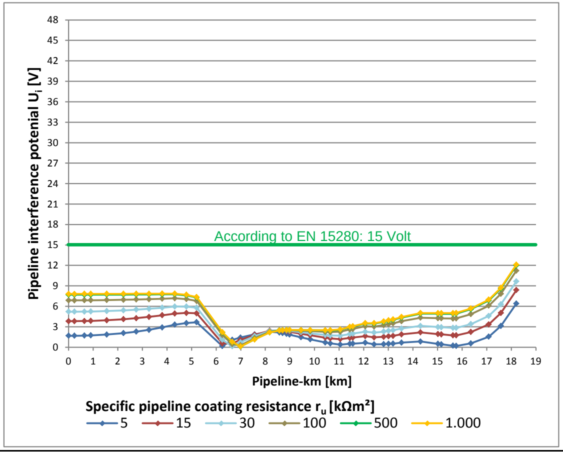
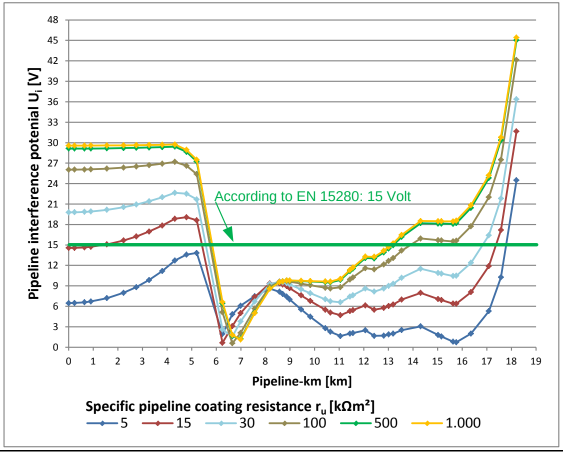
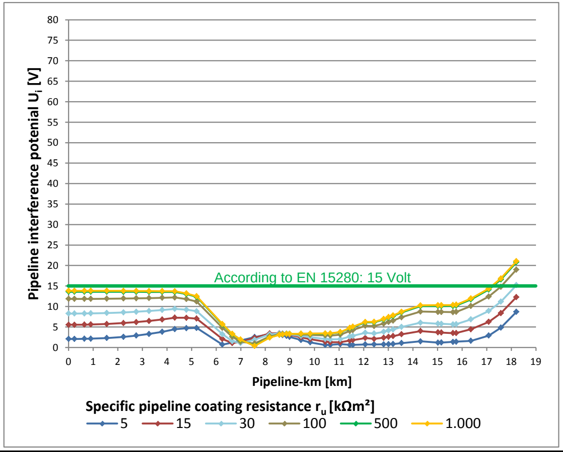
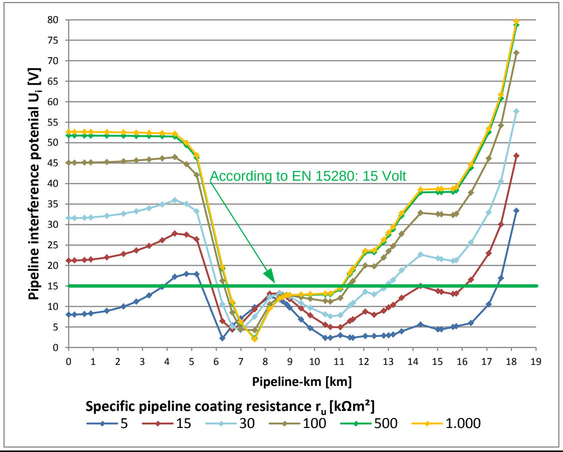


During the simulation, the phase conductor arrangement is the only high power overhead line parameter that changes, all other parameters remain unmodified.

3 Results

3.1 Varying the specific soil resistivity

The following figures show only selected specific soil resistivity values depending on the specific pipeline coating resistances. All other soil resistivity has the same curve progression but different values. The maximum pipeline interference potential value in this example is always at the end of the pipeline at km 18.2.

With good phase conductor arrangement	With bad phase conductor arrangement
Figure 5: Soil resistivity 25 Ωm  	**Figure 6: Soil resistivity 25 Ωm** 
Figure 7: Soil resistivity 100 Ωm  	**Figure 8: Soil resistivity 100 Ωm** 
Figure 9: Soil resistivity 1000 Ωm  	**Figure 10: Soil resistivity 1000 Ωm** 

Even with an optimal phase conductor arrangement, it is not possible to find a general solution for all cases since the pipeline interference voltage is not always below the AC corrosion limit. A specific solution depends on the value of the soil resistivity and the specific pipeline coating resistance. As a general rule, increasing both of these factors increases the pipeline interference voltage. With a low soil resistivity, any pipeline coating may be used, as the pipeline interference voltage is always below 15 Volt and therefore below the AC corrosion limit. However, when the soil resistivity rises, in this example above 100 Ωm (Figure 9), then pipelines with a high coating resistance can exceed the limit and therefore increase the corrosion risk. In this case, constructional or operative actions need to be taken. Figure 9 also shows that a low pipeline coating resistance can prevent AC corrosion due to lower pipeline interference voltages. In addition, Figure 9 depicts how the pipeline interference voltage rises with a rising soil resistivity. If this value is too high (> 1000 Ωm), then a lower coating resistance is needed in order to not exceed the AC corrosion limit.

The Figures 5 to 9 also show that the pipeline interference voltage rises with a rising coating resistance. However, a rising coating resistance slows down the increase in voltage, until it almost comes to a stop at a coating resistance of 500 kΩm². Therefore, in the case of high coating resistances the pipeline interference voltage only depends on soil resistivity.

Irrespective of the rising pipeline interference voltage and the specific pipeline coating resistance, the maximum voltage for the bad phase conductor arrangement is always higher between the factors of 3.7 and 3.8. With this bad phase conductor arrangement, it is in this example impossible to be below the AC corrosion limit of 15 Volt (see Figure 6, Figure 8 and Figure 10). Therefore, if the high power overhead line design chooses a bad arrangement, further constructional measures, e.g. AC earthing systems and/or additional isolating joints, or operative measures, e.g. more (real-time)-measurement and/or more maintenance, are always necessary.

3.2 Varying the specific pipeline coating resistance

The following figures show only selected specific pipeline coating resistance values depending on different specific soil resistivities. All other coating resistances have the same curve progression but different values. The maximum pipeline interference potential value in this example is always at the end of the pipeline at km 18.2.

With good phase conductor arrangement	With bad phase conductor arrangement

Figure 11: Coating resistance 5 kΩm²

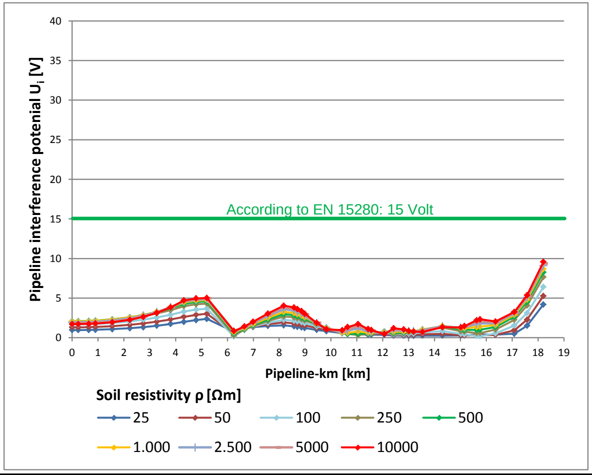


Figure 12: Coating resistance 5 kΩm²

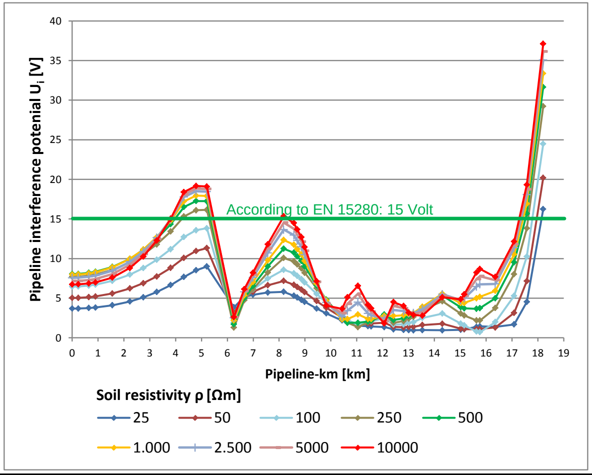


Figure 13: Coating resistance 30 kΩm²

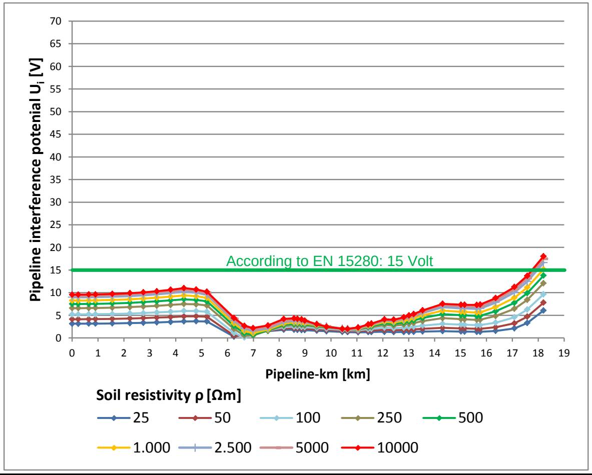


Figure 14: Coating resistance 30 kΩm²

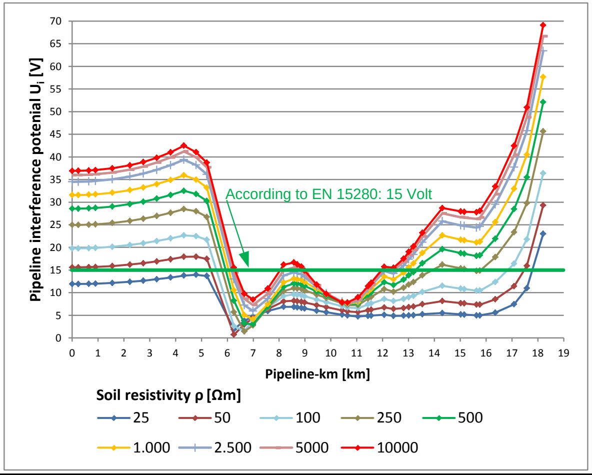


Figure 15: Coating resistance 1 MΩm²

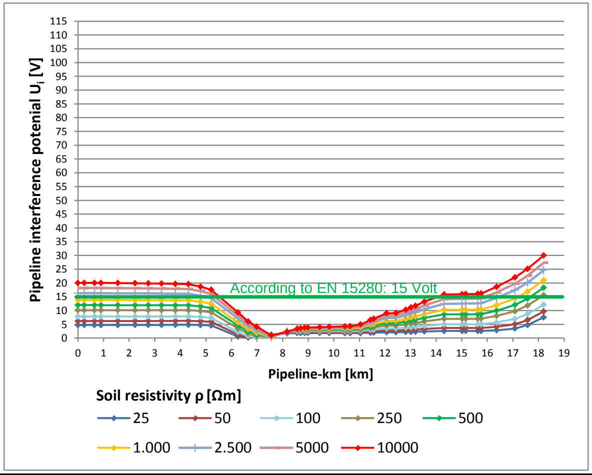
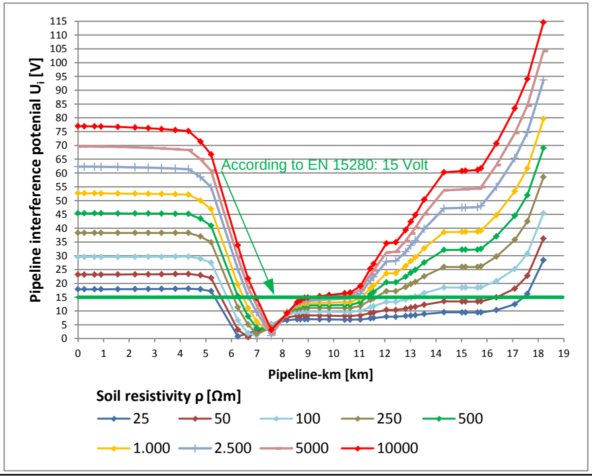


Figure 16: Coating resistance 1 MΩm²



Even when using an optimal phase conductor arrangement, it is not possible to find a general solution for all cases since the pipeline interference voltage is not always below the AC corrosion limit (Figure 13, Figure 15). Finding a specific solution depends on the value of the soil resistivity and the specific pipeline coating resistance. As a general rule, increasing both of these factors increases the pipeline interference voltage. Clearly, as depicted in Figure 11, all pipeline interference voltages are below the AC corrosion limit even if there is a high soil resistivity as long as there is a low coating resistance. When the coating resistance rises, Figure 13 shows that the value of the soil resistivity becomes increasingly important. Figure 15 indicates that this trend is a continuing one and that the value of the soil resistivity is a fundamental factor. This means that with a high soil resistivity in the area and a high pipeline interference voltage, a rise in pipeline coating resistance increases the AC corrosion risk.

In contrast to chapter 3.1, there exists an upper limit for the interference voltage but this limit cannot be reached using real values of soil resistivity. Still, the pipeline interference voltage rises with a higher soil resistivity. This can be shown in Figures 12, 14 und 16, where a bad phase conductor arrangement creates increased pipeline interference voltages. In between two levels of soil resistivity there is always a jump in the pipeline interference voltage. The voltages are always above the AC corrosion limit. Therefore further constructional measures, e.g. AC earthing systems and/or additional isolating joints, or operative measures, e.g. more (real-time)-measurement, are necessary.

3.3 Results summary

All above figures are shown with logarithmic x-axes to improve the visibility of the graphics, since the distances between the calculation points increase with higher values (e.g. 5.000 to 15.000 Ωm² vs. 500.000 to 1.000.000 Ωm²). The numbers above the graphics show the calculation points as defined in chapter 2.2.

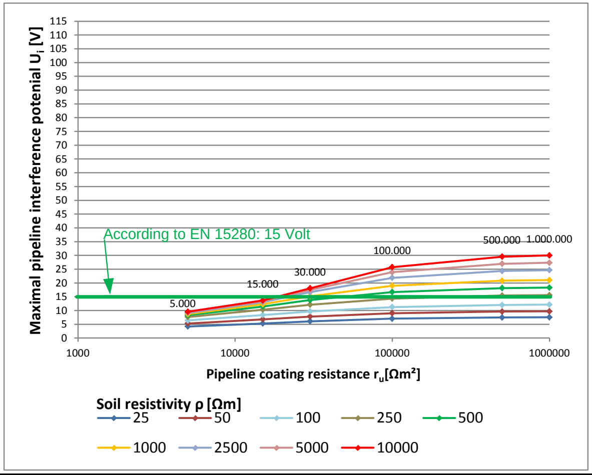
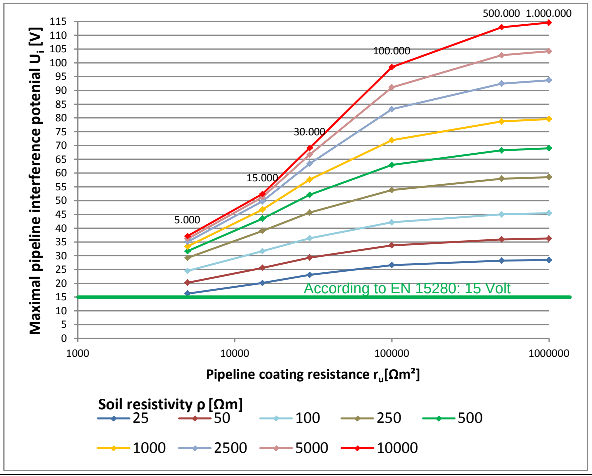
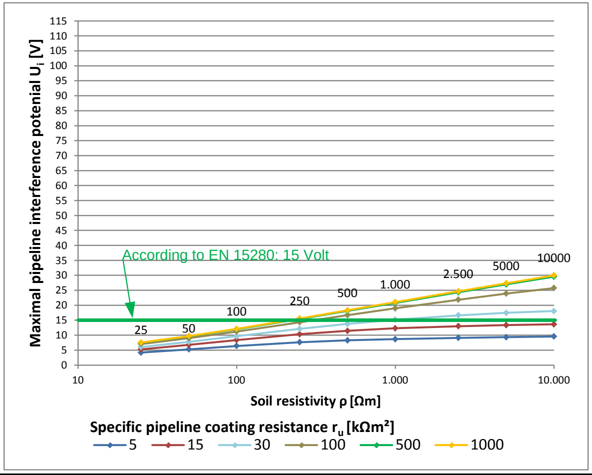
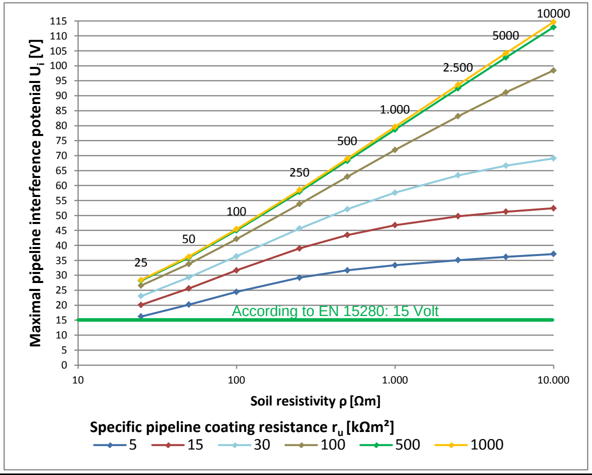
With good phase conductor arrangement	With bad phase conductor arrangement
Figure 17: Varying coating resistance  	**Figure 18: Varying coating resistance** 
Figure 19: Varying soil resistivity  	**Figure 20: Varying soil resistivity** 

Figure 17 shows that the pipeline interference voltage increases with a rising specific pipeline coating resistance r_u. How much it rises depends on where the pipeline is buried. If there is a low soil resistivity along the pipeline, then the interference voltage may stay below the AC corrosion limit. In this example, if the soil resistivity stays below approximately 250 Ωm the voltage level does not exceed the limit. However, as a precondition, the high power overhead line has to have a good phase conductor arrangement, which produces a low level inductive influence. This can be illustrated by comparing Figure 17 and Figure 18: the pipeline interference voltage is on a much lower level in Figure 17.

Both figures show that the voltage increase slows down with an increasing coating resistance. It remains constant for a low soil resistivity (below approximately 1000 Ωm) and nearly constant for high soil resistivity above a resistance value of 500 kΩm².

Figure 19 shows that the maximal pipeline interference potential rises with increasing soil resistivity. How much it rises depends on the pipeline coating resistance. The difference in voltage can be significant, especially when the soil resistivity is high. If the coating resistance is low, the pipeline interference voltage might not exceed the AC corrosion limit, especially, if the soil resistivity is high.

In this example, it is possible to stay below the AC corrosion limit with any pipeline coating up to 1 MΩm² if the soil resistivity is no higher than 250 Ωm. But it is again a precondition that the high power overhead line has a good phase conductor arrangement which produces a low level inductive influence, as can be shown by comparing Figure 19 and Figure 20. These figures also indicate that for lower coating resistances, below 100 kΩm², there is a maximum level for the pipeline interference potential near the soil resistivity of 10.000 Ωm. However, for high coating resistances, there is no indicator in this example that a maximum level of pipeline interference will be reached.

4 Summary

Due to the increasing overlap of traffic and energy routes, the calculation of the inductive interference is crucial to predict necessary pipeline voltage mitigation measures. Various issues may arise. The high power overhead line can be constructed near a pipeline route with high soil resistivities. In addition, a bad phase conductor arrangement (Figure 4) can strengthen the inductive coupling. In this case, the pipeline interference voltage can increase fundamentally and it can exceed the AC corrosion limit of 15 Volt, irrespective of soil resistivity and coating resistance. Consequently, constructional measures need to be taken in order to reduce the pipeline interference potential. However, when the pipeline interference voltage is too high these measures might not be successful. Then, operative measures, e.g. real-time measurement, need to be taken.

In most cases a good phase conductor arrangement (Figure 3) is present. This means that the AC corrosion risk increases with a rising soil resistivity and a rising pipeline coating resistance. However, if a coating holiday occurs, in conjunction with a high enough pipeline interference voltage, especially at small junctions, the interference voltage can cause a high current density at the holiday which can lead to severe material corrosion.

In conclusion, the AC corrosion risk can be reduced by a low inductive coupling, a low soil resistivity and a low pipeline coating resistance.

5 Bibliography

[1] EN 50443, (2012-10-01), “Effects of electromagnetic interference on pipelines caused by high voltage a.c. electric traction systems and/or high voltage a.c. supply systems”.

[2] EN 15280, (2013-10-01), “Evaluation of a.c. corrosion likelihood of buried pipelines applicable to cathodically protected pipelines”.

[3] “Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines”, ITU-T, 1998.