IMPACT OF GLOBAL EARTHING SYSTEMS ON THE INDUCTIVE INTERFERENCE ON BURIED ISOLATED METALLIC PIPELINES

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ABSTRACT

In this paper the authors present the impact of global earthing systems on the calculation and measurement of pipeline interference voltages. Due to bundled energy routes, high voltage energy systems are located near buried isolated metallic pipelines with the consequence of a high inductive coupling. This can produce hazardous pipeline voltages and therefore the calculation of the inductive interference is very important. However, pipeline voltage calculations show significant higher values than conducted measurements on pipelines in the same locations.

Investigations show that global earthing systems have a reduction effect on pipeline voltages because of their similar characteristics. Thus, in this paper voltage calculations are done with and without consideration of the global earthing system voltage model to show that with the correct model it is possible to get nearly the same voltage characteristic as measurements show. Thereby it is possible to estimate the pipeline voltage levels more exactly and to prevent unnecessary and expensive measures against harmful interference voltages.

INTRODUCTION

Due to bundled energy routes, high voltage energy systems (HVESs), e.g. AC overhead lines or AC traction power supply, are located near buried isolated metallic pipelines. Consequently, the calculation of the inductive interference is important because the possible high inductive interference from electric energy systems may produce hazardous pipeline AC voltages. High AC voltage levels can cause personal injuries (touch voltages) and material damages (AC corrosion).

Within Europe and Austria standards and guidelines (EN 50443 [1], EN 15280 [2]) exist which limit the maximum voltage for long term and short term interference. For touch voltages, 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 given limits no further measures, e.g. AC earthing systems, special working methods or additional isolating joints along the pipeline are required and no further costs are generated.

For this reason it is necessary to calculate the induced pipeline voltages already in the planning stage or in the case of significant changes in the pipeline or HVESs to specify necessary protection measures. Even if all calculations are done very carefully by established and generally agreed calculation methods, conducted measurements on pipelines show lower pipeline voltage levels up to a factor of 5, than have been calculated for the same pipelines and pipeline locations. It is essential to investigate these differences by analysing the parameters for the calculation of induced voltages like load currents or the soil resistivity and other ambience factors.

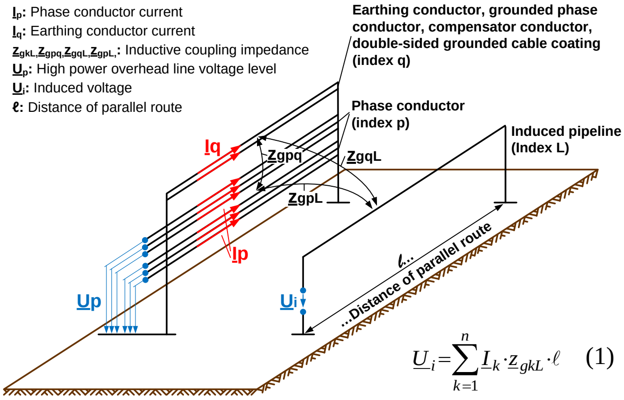
METHODOLOGY

Inductive interference on pipelines

Inductive coupling appears when a magnetic field between an interfered buried isolated metallic pipeline system and an interfering HVES exists. The essential parameter for a high inductive interference is a strong inductive coupling. This occurs when a geographical closeness between a pipeline and an energy system over a longer distance exists and results in a high pipeline interference voltage.

However, there exist other important parameters. First, the HVES parameters like the load current and the phase conductor arrangement. These are major factors because the value of the load current is a direct impact factor in the voltage calculation 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 third parameter, which basically cannot be controlled through technical equipment, is the ambience soil resistivity which varies within a large spectrum, depending on location, material, weather and the time of the year. The fourth and final important parameter is the influence of several known and unknown grounded conductors, located near influenced or influencing systems. These conductors produce a voltage reduction on the induced pipeline and can be e.g. the PEN conductor of low voltage power lines, metal rails and compensation conductors of AC traction power supplies, conducting pipelines, foundation earth electrodes and global earthing systems.

The inductive coupling impedances $\underline{z}_{gkL}$ are affected by all of the above-described parameters and can be calculated with e.g. the formula of Dubanton [3].



$$\underline{U}_i=\sum_{k=1}^{n}\underline{I}_k\cdot\underline{z}_{gkL}\cdot\ell \qquad (1)$$

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

Figure 1 shows the inductive interference between an interfered pipeline and an interfering two-circuit high voltage overhead line. The phase conductor current $\underline{I}_p$ is set by the current for normal operations and short-circuit-situations, all other currents $\underline{I}_q$ flow through other conductors and cable coatings. The following matrix (2) leads to the currents $\underline{I}_q$ (3).

$$\left\|\begin{matrix}\underline{U}_p\\ 0\end{matrix}\right\| = \left\|\begin{matrix}\underline{z}_{pp} & \underline{z}_{pq}\\ \underline{z}_{qp} & \underline{z}_{qq}\end{matrix}\right\|\cdot\left\|\begin{matrix}\underline{I}_p\\ \underline{I}_q\end{matrix}\right\| \qquad (2)$$

$$\underline{I}_q = -\underline{z}_{qq}^{-1}\cdot\underline{z}_{qp}\underline{I}_p \qquad (3)$$

If all currents and inductive coupling impedances $\underline{z}_{gkL}$ for one section are known, the induced voltage $\underline{U}_i$ can be calculated for a segment. Segmenting is needed because of the fact that the geographical closeness and other parameters are not constant over the whole interfering distance and therefore the value of $\underline{z}_{gkL}$ is always changing as depicted in Figure 2. Also, other segments are not influenced as can be seen in Figure 2. When all induced voltages $\underline{U}_i$ have been calculated, the induced pipeline interference voltage over the whole interfering distance is calculated with the lattice network model. As a requirement for using this model, all parameters must be (approximately) homogenous within one segment.

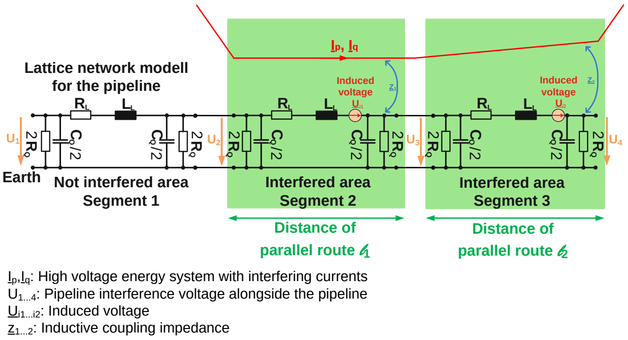


Figure 2: Pipeline subdivided into segments because of changing parameters

In this network model, the parameters represent the longitudinal impedance (R_L, $\underline{L}_L$), which stands for the pipeline material characteristics and the shunt admittance ($\underline{C}_Q$, R_Q), which is a combination of the pipeline coating value, ambience soil resistivity and possible existing AC earthing systems. Finally, the pipeline interference voltage alongside the pipeline is calculated with an admittance matrix [4].

Impact of global earthing systems

As mentioned above, conducted measurements on pipelines show much lower voltage levels, than have been calculated for the same pipelines and pipeline locations. One possible explanation is the voltage reducing effect of global earthing systems (GESs). In short, GESs consist of linked foundation electrodes and other conductive material buried in the soil within a (sub-)urban area. The advantage of GESs is that nearly no dangerous potential differences exist inside the soil within its area.

Normally, bigger pipelines are constructed over longer distances which means that they are unavoidably built near (sub-)urban areas because of route optimization and cost control. Additionally, those pipelines are similar to GESs, because they are also made of a conducting material (e.g. steel) and are buried inside the ground. If also a HVES is located near a pipeline and a GES, a configuration arises depicted in Figure 3. In these cases, pipeline and GES are more or less parallel metallic conductors and the inductive coupling impedances $\underline{z}_{gkL}$ from the energy system turn into a parallel connection of the pipeline coupling $\underline{z}_{pipe}$ and the GES coupling $\underline{z}_{earth}$.

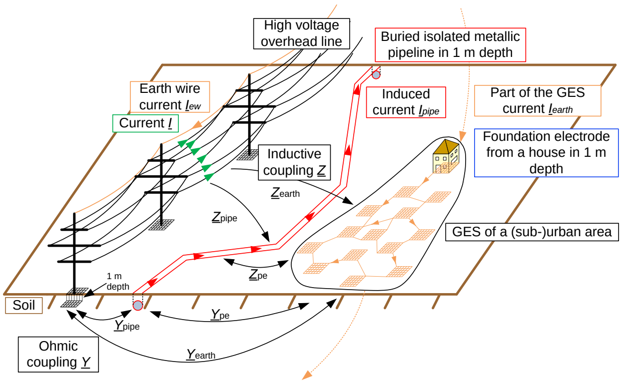


Figure 3: The complex interference and reduction situation between high voltage power line, GES and pipeline system

As a result of this inductive coupling, the current $\underline{I}_{pipe}$ (4) flows alongside the pipeline and $\underline{I}_{earth}$ alongside the GES ((4), $\underline{z}_{earth}$ instead of $\underline{z}_{pipe}$).

$$\underline{I}_{pipe} = \frac{\underline{U}_i}{R_L+L_L} = \frac{\sum_{k=1}^{n}\underline{I}_k\cdot\underline{z}_{pipe}\cdot\ell}{R_L+L_L} \qquad (4)$$

This results in the effect of an additional inductive coupling $\underline{z}_{pe}$ between pipeline and GES. The coupling $\underline{z}_{pe}$ exists because for the respective system, the other system is an active energy system with his own magnetic field due to the additional current ($\underline{I}_{pipe}$ or $\underline{I}_{earth}$). Depending on the current flow direction, the current in the GES can additional amplify or reduce the current in the pipeline and thus the pipeline interference voltage.

An ohmic coupling $\underline{Y}$ exists between all interfered and interfering systems due to their grounding systems. In normal and fault operation conditions of HVESs, earth currents can flow through their own grounding systems e.g. pylons or transformer stations) into their ambience soil and in case of the vicinity of a GES, the GES can catch these currents and spread them to other regions. This results in a higher $\underline{I}_{earth}$ component with the effect of a higher influence on the current $\underline{I}_{pipe}$ and the resulting pipeline voltage. This effect is an ohmic-inductive coupling and is not considered in the calculation for this paper.

Practical impact of global earthing systems

Is the geographical distance between interfered and interfering systems less than 1000 (suburban and rural) or 300 meters (urban), respectively, for long term interference, standards and guidelines say that a significant inductive coupling between both systems can be expected and has to be investigated by calculation [1]. Figure 4 shows a simplified example of such interference between a HVES, two pipeline sections and three differently sized GESs with a 1000 m wide interference range parallel on both sides of the HVES.

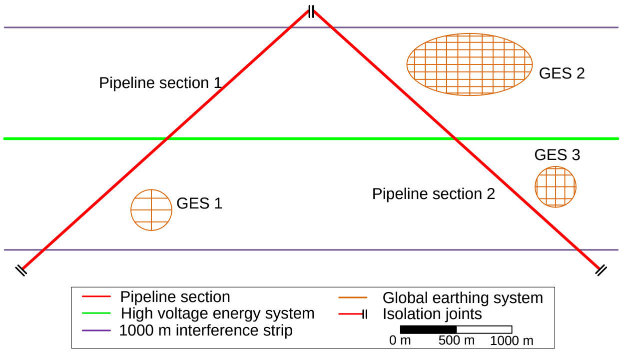


Figure 4: Two pipeline segments with different GES-impacts

GES 1 represents a small village with a low, GES 2 a small town with a high and GES 3 a village with a medium density of conducting grounded material. The size and the amount of buried conducted metal leads to an accordingly high voltage reduction effect. Unfortunately, it is not this simple to calculate the reduction effect because often the material and structure of the GES is unknown. Today, even with expert knowledge it is only possible to make a rough estimate.

But there exist other important known parameters. One of these is the general geographical alignment of the GES. In case of parallelism to energy systems and pipelines, the impact of the GES is much higher. The other parameter is the geographical closeness to energy systems und pipelines with the effect of higher inductive and ohmic coupling and therefore of a higher impact on the pipeline interference voltages.

The example in Figure 4 shows the small GES 1 next to the pipeline segment 1. The result of the calculation is depicted in Figure 5 and shows a small voltage reduction effect while the pipeline interference voltage remains almost unchanged.

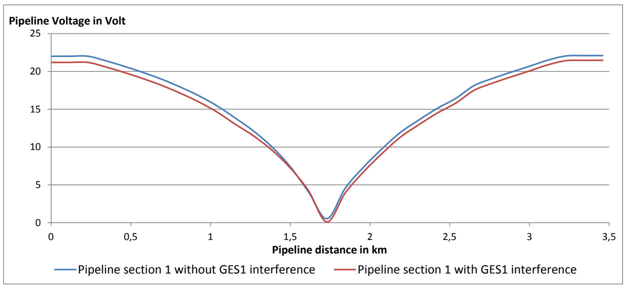


Figure 5: Pipeline voltage from the segment 1

As can be seen in Figure 6, the pipeline voltage calculations in the pipeline segment 2 show considerably lower values with both, GES 2 and 3. In detail, GES 2 has a higher impact due to the bigger geographical dimension and higher conducted grounded material density. Very interesting is the effect of GES 3. With a smaller suburban extension but a close vicinity between HVES and pipeline, it has a notable reduction effect in the end of this pipeline segment 2. It is important to understand that this knowledge is very crucial in cases when pipeline voltages are calculated higher than the given national limits without considering the voltage reducing effect of the GES. With consideration of these reduction factors in calculations, pipeline voltages may not be exceeding the given national limits anymore.

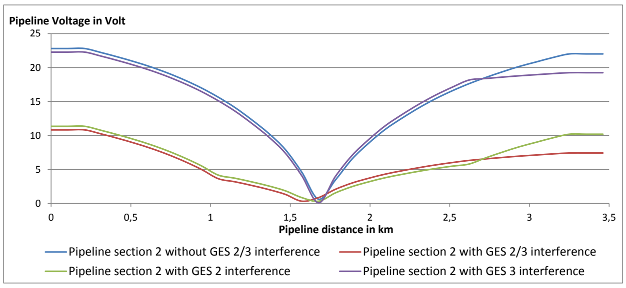


Figure 6: Pipeline voltage from the segment 2

RESULTS

Impact of using load currents

As stated above, the value of the load current is a direct impact factor in the voltage calculation formula (1). Normally it is common practice to use the maximum operational currents from the influencing systems in order to cover worst case scenarios for touch voltages or using, depending on the type of the influencing system, between 60 and 95 percent of this current for the AC corrosion.

In reality, these operational currents rarely occur because of load flow situations or safety reasons like the commonly agreed (n-1)-criteria which prevent HVES overload situations in case of a failure of other coupled systems [5]. But for the comparison of a one week lasting conducted measurement and its associated calculations on the same pipeline locations it is indispensable to use the correct actually used load currents for getting comparable results. The difference between such currents and the maximum operational currents is illustrated for two examples, for an overhead line in Figure 7and a railroad system in Figure 8.

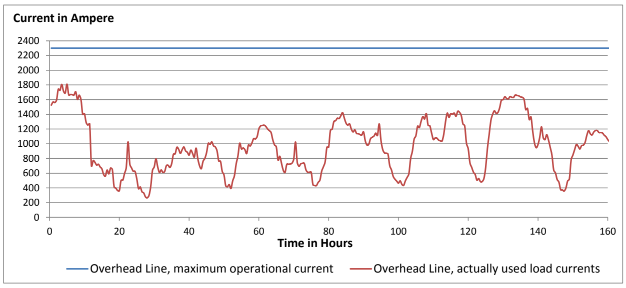


Figure 7: Difference between maximum operational currents and load currents for overhead lines

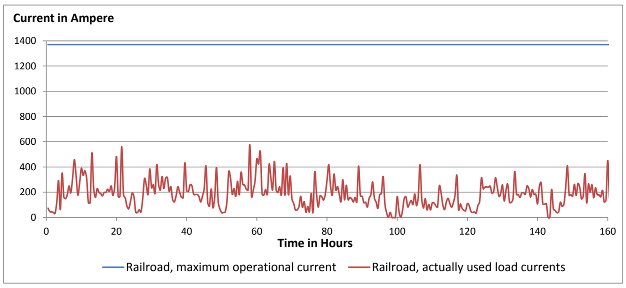


Figure 8: Difference between maximum operational currents and load currents for railroad systems

Comparison: Measurements - Calculations

The following figures show different examples of calculations using the actually used load currents, with and without GES and comparing them to measurements during a measurement period of 140 to 160 hours at different pipeline locations. In some cases, the impact of GESs on buried isolated metallic pipelines as a voltage reduction factor is comprehensible, as can be seen from Figures 9 to 11. The calculations which consider a GES result in voltages lower by a factor of 5, compared to calculations without considering the reduction effect of a GES. Especially Figures 9 and 10 show an intense voltage reduction, which are based on a geographical closeness and dimension of small towns with their well-developed GES. Also, it can be shown that the voltage characteristics of the calculations are very similar to the measurements.

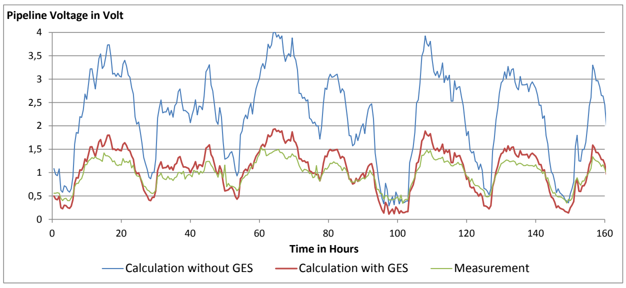


Figure 9: Pipeline voltage characteristic calculation versus measurement on the pipeline, location 1

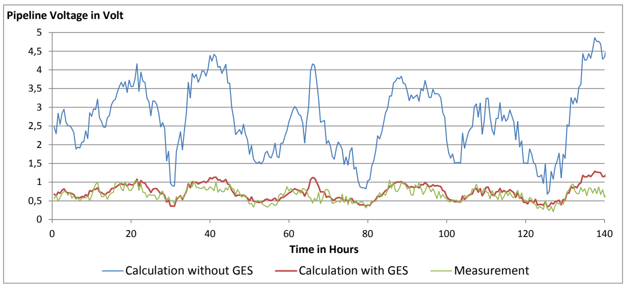


Figure 10: Pipeline voltage characteristic calculation versus measurement on the pipeline, location 2

Figure 11 shows that the calculation including GES still differs from the measurements in some cases but the peak values lie almost in the same range and the voltage characteristic is similar. Possible reasons for the deviation can be an inadequate soil resistivity, imprecise pipeline parameters or even unknown metallic systems in the vicinity of the influenced and influencing systems. What is very interesting in this measurement location is the small GES reduction factor. Therefore, the calculation with GES is only 50 % lower than calculations without considering the GES. The reason for this is that only small GESs exist in the vicinity of this pipeline section.

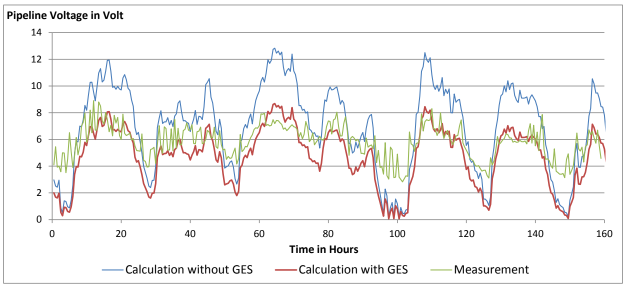


Figure 11: Pipeline voltage characteristic calculation versus measurement on the pipeline, location 3

Unfortunately, the voltage characteristics of calculations can still differ significantly from measurements. Figure 12 illustrates a case with a similar, but too high voltage characteristic. Possible causes near the measurement location could be unknown metallic systems in the soil, e.g. PEN conductor of low voltage power lines, metal rails and compensation conductors of AC traction systems, conducting pipelines and foundation earth electrodes. All these often unknown metallic systems reduce the soil resistivity within its area with the result of reduced measured pipeline interference voltages [6].

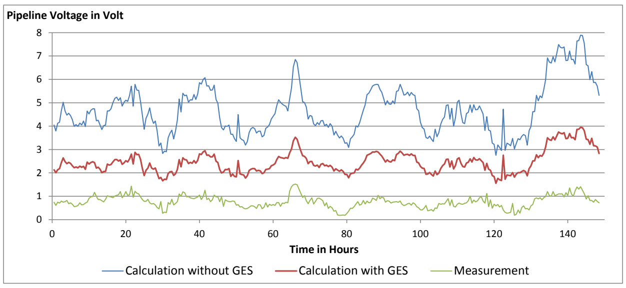


Figure 12: Pipeline voltage characteristic calculation versus measurement on the pipeline, location 4

CONCLUSION

Even if all calculations are done very carefully with established and generally agreed calculation methods, conducted measurements on pipelines show lower voltage levels than the calculated ones for the same pipelines and pipeline locations. With the consideration of global earthing systems, an added voltage reduction factor is presented which partly provides an explanation for this discrepancy. So it is in some cases possible that measurement and calculation voltage characteristic have nearly the same curve progression which means that the voltage levels are partly much lower than calculations which do not include the effect of global earthing systems.

Unfortunately, because of unknown metallic systems or other crucial factors, the model cannot be generalized yet since it is difficult to find appropriate data about the influencing global earthing systems. Therefore, it is difficult to find out the correct voltage reduction factor and detailed studies will still be necessary in future. But with the help of these investigations it is possible to understand, both measurement and calculation data. Measures to decrease pipeline interfered voltages can be reduced or avoided and other necessary actions, e.g. AC earthing systems, special working methods or additional isolating joints along the pipeline, can be used more effectively.

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