SIMULATION AND OPTIMISED REDUCTION OF INDUCED PIPELINE VOLTAGES CAUSED BY HIGH-VOLTAGE LINES ON INDUCTIVELY INTERFERED PIPELINES

Ernst SCHMAUTZER
Graz University of Technology
Austria
schmautzer@tugraz.at

René Braunstein
Graz University of Technology
Austria
rene.braunstein@tugraz.at

Mario OELZ
Graz University of Technology
Austria
mario.oelz@tugraz.at

ABSTRACT

Electrical power supply systems are expanding concerning spatial dimensions as well as ranges of short-circuit and operation currents. These circumstances lead to increasing inductive interferences of buried oil- , gas- , district heating- or water- pipelines, caused by high-voltage lines.
Due to normal operating and short-circuit currents of high-voltage lines, voltages are induced in isolated buried metallic pipelines by the magnetic field. These harmful voltages can be mitigated either with a.c. earthing systems in combination with kirk-cells or power capacities as well as with galvanic separations by insulating joints. From the risk of hazard induced pipeline voltages among 65 V in normal operation mode and induced pipeline voltages among 500 V in short-circuit mode have to be observed. For reasons of a.c. corrosions only some 4-10 V, depending on the specific soil resistivity, are accepted. The values regarding a.c. corrosion are based on practical experiences of electro-chemistries, material-scientists as well as pipeline-operators.

In this paper the often common and usually concerned discussed measures to reduce induced pipeline voltages as there are a.c. earthing systems and isolating joints, are mentioned.
The main part of this paper deals with the impact of additional important measures that also have to be regarded - different phase positions, which are investigated for two selected species of overhead pylons.

INTRODUCTION

When calculating and evaluating parallel energy corridors and approaches of high-voltage lines with pipelines, in a first step the mutual impedances, depending on pipe- and high-voltage – localizations are calculated by the infinite series approximations of Carson and Pollaczek. In a next step pipeline direct-axis-impedance per unit length and quadrature-axis-admittance per unit length can be determined by the formulas of Michailow and Rasumov.
To act with the assumption of a homogenous pipeline the well-known equivalent electric- line circuit with a direct-axis-impedance and a quadrature-axis-admittance can be formed into an equivalent ladder network [1].
In a next step the induced pipe voltages along the interfered pipeline can be calculated with the help of the nodal admittance matrix. Potential mitigating measures like a.c. earthing systems have to be considered in the main diagonal of the nodal-admittance matrix. Calculations cover with the experiences of the authors, that potential mitigating a.c. earthing systems have to be, due to the low impedance of the pipeline itself, very low impedant in the range of 1 Ω [2].
The electromagnetic fields of the high-voltage transmission systems for different phase positions types are calculated with the programme WinField/EFC-400® to show the

- Equivalence between induced interfering voltage U_i and the magnetic field strength H
- Impact of the earth wire(s)
- Spatial relations and approximations

A.C EARTHING SYSTEMS AND ISOLATING JOINTS

The impact of the well-established mitigating measures a.c. earthing systems and isolating joints are often and well discussed [3], [4], [5].
The following figure 1 summarizes the principal impact of earthing systems to inductively interfered pipelines.

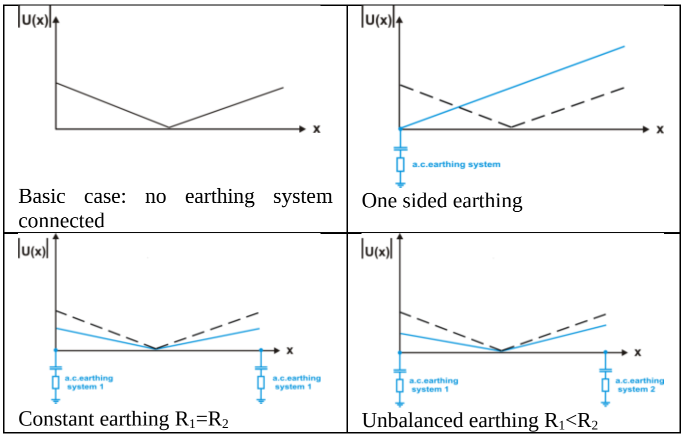

Figure 1: Summarization – Impact of earthing systems [2]

In the first subfigure the basic case, without a connected earthing system is plotted in black. In the second subfigure the basic case is black dotted, the ***one sided earthing effect*** is shown in light blue. The third subfigure shows the ***constant earthing effect*** in light blue. The ***unbalanced earthing effect*** is shown in light blue in the fourth subfigure [2].

The following figure 2 summarizes the principal impact of isolating joints to inductively interfered pipelines

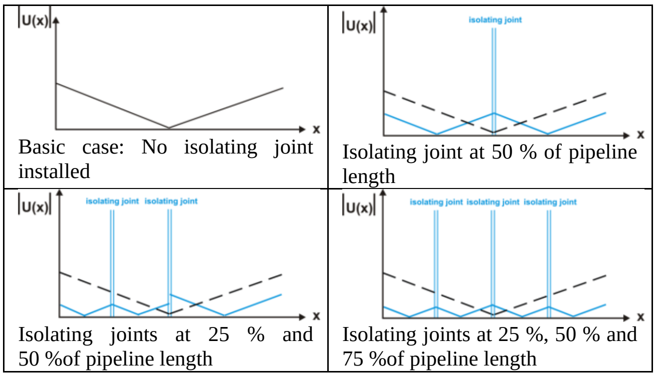

Figure 2: Summarization – Impact of isolating joints to pipeline interference voltages [2]

In the first subfigure the basic case, without an installed isolating joint, is plotted in black. The second subfigure shows the basic case in dotted black, the effect of an isolating joint in the middle of the pipeline is shown in light blue. The third subfigure shows the effect of two isolating joints at 25 % and 50 % of the pipeline length. The effect of 3 balanced isolating joints at 25 %, 50 % and 75 % are shown in the fourth subfigure [2].

INVESTIGATED INTERFERENCE SITUATION AND PARAMETERS

Approach

In the investigated characterising case a 10-km parallel section between the pipeline and the interfering high-voltage line is selected. The horizontal distance between the pipeline and the interfering system is 250 m. The pipeline is buried in a depth of 1m. The specific soil resistivity ρ_E is defined with 200 Ωm. The assumed specific coating resistance of the pipeline amounts to 100000 Ωm^2. The pipeline radius is defined with 500 mm. In the characterising cases the phase positions are not changed over the investigated 10 km.

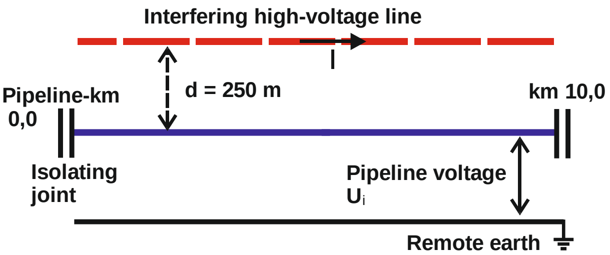

Figure 3: Approach between the pipeline and the interfering high-voltage line for the investigated case.

High-voltage systems

The simulation is performed for two types of high-voltage pylons, as they are an in Austria common 3-level pylon called “Tonne” and an in Austria common 2-level pylon called “Donau”. The different impact of one or/and two earth wires on the induced voltages and electromagnetic fields is also part of this paper. The following figures show a scheme of the selected high-voltage overhead pylons.

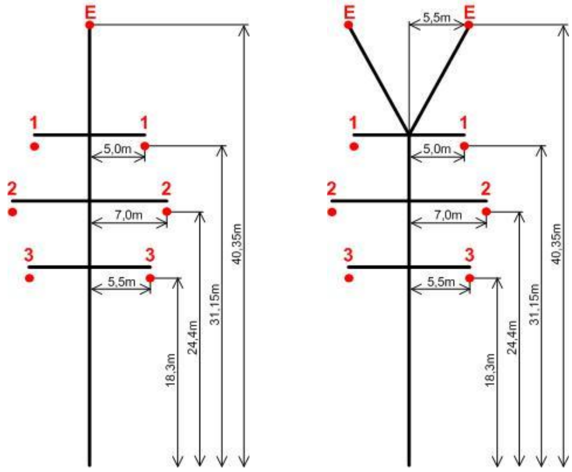

Figure 4: Geometry of the selected 3-level pylons with one and two earth wires, (Tonne)

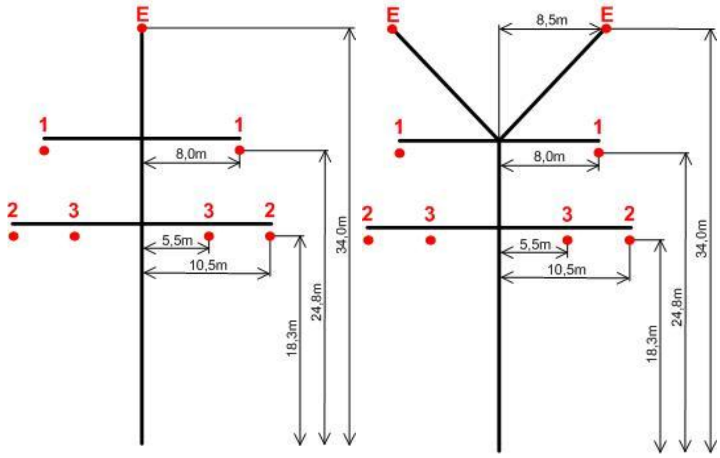

Figure 5: Geometry of the selected, 2-level pylons with one and two earth wires, (Donau)

To have the possibility to compare the impacts of the 2-level pylon and the 3-level pylon, the lowermost conductors are assumed at the same height.

The following figure 6 shows the 6 investigated kinds of phase positioning [6]. The chosen phase currents are 1000 A per conductor.

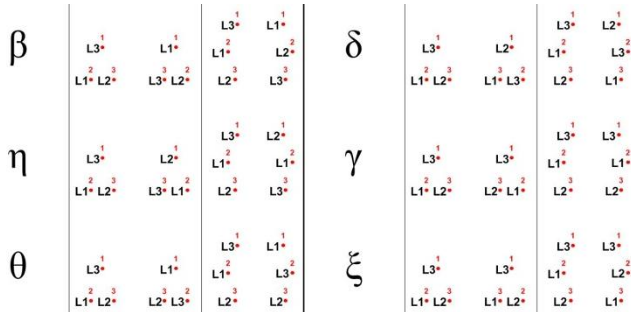

Figure 6: Investigated kinds of phase positions [6]

SIMULATION RESULTS

3-Level Pylons

In the following figures 7 and 8 the interference voltage to remote earth in the pipeline, for the investigated phase positions and 3-level pylons with one and two earth wires are shown.

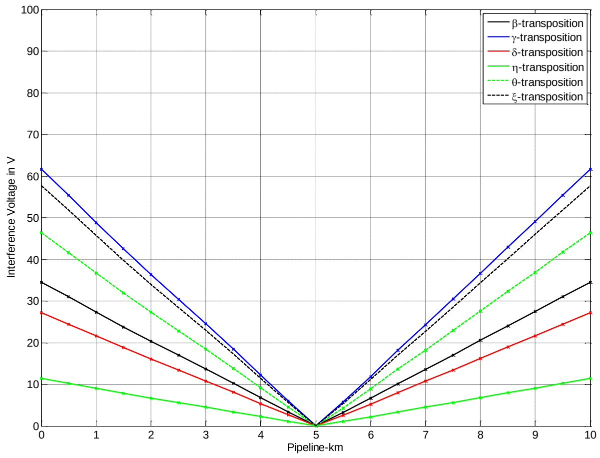

Figure 7: Interference pipeline voltage for different phase positions, 3-level pylons with **one earth wire**

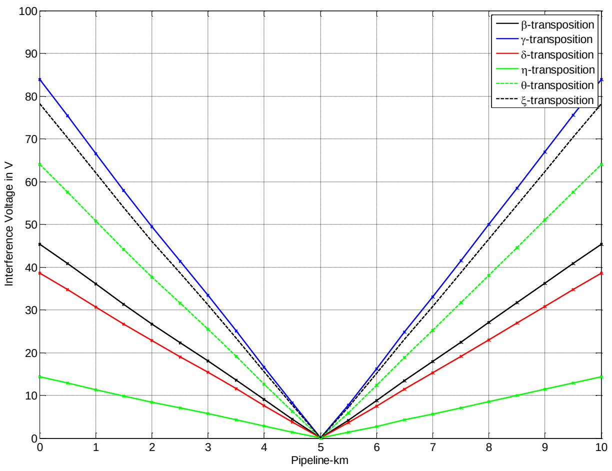

Figure 8: Interference pipeline voltage for different phase positions, 3-level pylons with **two earth wires**

3-Level pylons	Interference voltage

"Tonne"	U_{imax} in V	
	One earth wire	Two earth wires
Transp. = β	34.52	45.43
Transp. = χ	61.61	83.95
Transp. = δ	27.21	38.65
Transp. = η	11.43	14.35
Transp. = θ	46.39	64.02
Transp. = ξ	57.70	78.22

Table 1: Summary table of the results for 3-level pylons with one and **two earth wires**

As it can be seen in the results of Table 1, a second earth wire as shown in figure 4 worsens the interference situation for a horizontal distance of 250 m between the pipeline and the interfering high-voltage line. The big impact of the phase positions to pipeline interference voltage is also shown.

2-Level Pylons

In the following figures 9 and 10 the interference voltage to remote earth, for the investigated phase positions and 2-level pylons with one and two earth wires are shown.

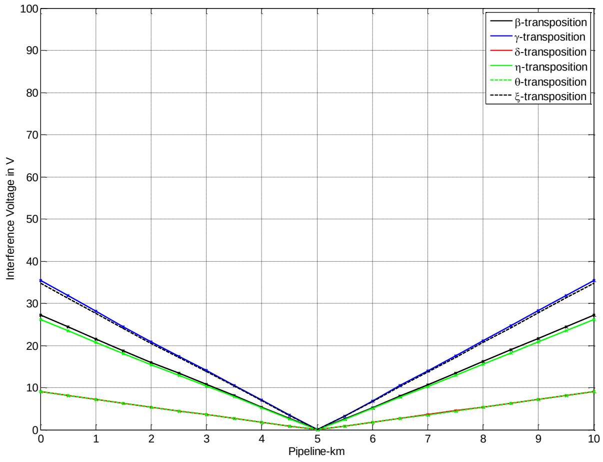

Figure 9: Interference voltage for different phase positions, 2-level pylons with **one earth wire**

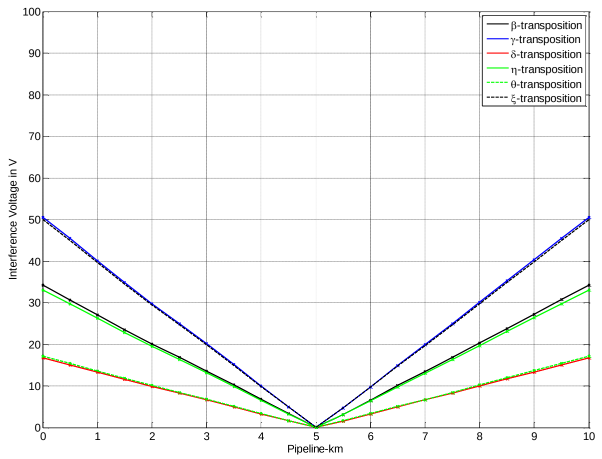

Figure 10: Interference voltage for different phase positions, 2-level pylons with **two earth wires**

2-Level pylons "Donau"	Interference voltage U_{imax} in V	
	One earth wire	Two earth wires
Transp. = β	27.22	34.21
Transp. = χ	35.41	50.54
Transp. = δ	9.03	16.72
Transp. = η	26.15	33.10
Transp. = θ	9.12	17.16
Transp. = ξ	34.78	50.03

Table 2: Summary table of the results for 2-level pylons with one and two earth wires

Also for 2-level pylons, there exists a big influence of the phase positions to the pipeline interfering voltage.

LOW FREQUENCY ELECTROMAGNETIC FIELDS

In the following figure 11 the magnetic fields of the investigated 220-kV pylons (1000 A phase currents) are compared to each other. The calculations corresponds to the induced voltages which due to Carson and Polaczeks infinite series [1] and show the advantageous magnetic field distribution of the 2-level pylon (Donau), causing lower magnetic fields and lower induced voltages in a distance of 250 m. The effectiveness of compensation conductors as earth wires to induced pipeline voltages is a function of the horizontal distance between interfering and interfered system.

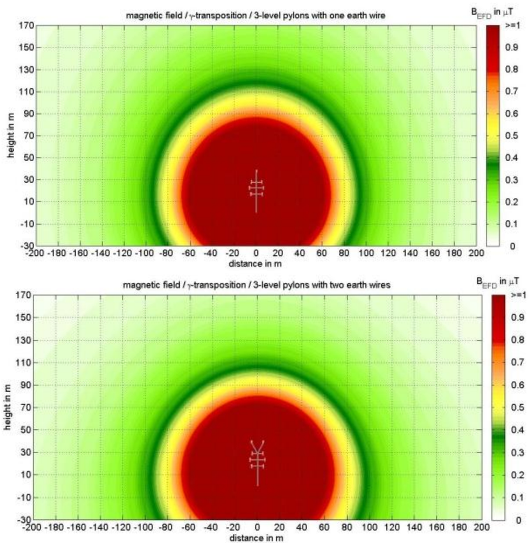

Figure 11: Comparison of magnetic fields of 220kV 3-level pylons with **one and two earth wires**

CONCLUSION

There are a lot of possibilities to reduce induced voltages in metallic pipelines. The most common are a.c. earthing systems and isolating joints.
In this paper the possibility to reduced induced voltages by optimising the phase positions is investigated. In the investigated case (10 km parallel routes, 250 m horizontal distance) can be shown that the phase positions have a big influence.
When configuring the phase positions also interests of the grid operator regarding the reduction of electromagnetic fields in certain areas (close area, in direct vicinity of the pylon or far area) have to be covered [7].
It can be shown that the configurations with one and two earth wires have different impacts to the magnetic fields in the close and the far area.
Induced voltages in metallic pipelines depend to a lot of parameters. An optimised reduction can be achieved by combining the potential mitigating measures a.c earthing systems, isolating joints compensation conductors as well as the phase positions and the transposition (twisting the phase positions).

REFERENCES

[1] E. Schmautzer, "*Ein Beitrag zur Berechnung der niederfrequenten induktiven Beeinflussung von Rohrleitungsnetzen*", Dissertation, Institute of Electrical Power Systems, Graz University of Technology, 1990.

[2] R. Braunstein, " *Technical and economical optimisation of measures decreasing inductive interference of metallic pipelines* ", Dissertation, Institute of Electrical Power Systems, Graz University of Technology, work in progress.

[3] W. Friedl, " *Berechnung niederfrequenter Beeinflussung von Rohrleitungen* ", Master-thesis, Institute of Electrical Power Systems, Graz University of Technology, 2004.

[4] R. Braunstein, E. Schmautzer, G. Propst " Comparison and discussion on potential mitigating measures regarding inductive interference of metallic pipelines", *Electrical Systems for Aircraft, Railway and Ship Propulsion (ESARS)*, Bologna, Italy,

[5] E. Schmautzer, R. Braunstein " *Lösungsansätze zur Reduktion der Wechselstromkorrosions-wahrscheinlichkeit von induktiv beeinflussten Rohrleitungen durch Traktionsströme elektrischer Bahnanlagen*", e&i-journal, vol. 6, 2009.

[6] P. Bauhofer, "*Handbuch für Hoch-spannungsleitungen – Niederfrequente Elektro-magnetische Felder und deren wirksame Reduktion*", published by VEÖ – Verband der Elektrizitätswerke Österreich, ISBN 3-9014-1100-3, 1994.

[7] K. Friedl, E. Schmautzer "Impact of the Phase Positions on the Electric and Magnetic Field of High-Voltage Overhead Lines ", *Cired Conference, Prague*, June 2009.