A.C. INTERFERENCE FROM A POWER LINE ON A BURIED PIPELINE: EVALUATION OF THE CURRENT DENSITY

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Abstract: The paper considers two examples of electromagnetic interference between a buried pipeline and an A.C. power line in normal operating conditions; due to the inductive coupling, an A.C. current density is exchanged between the pipeline and the soil through the holidays present in the insulating coating with the consequent risk of corrosion; the examples are based on real cases: the first one considers a power line which is, for the moment, only at the design stage whilst the object of the second one are two plants already existing and operating.

1. INTRODUCTION

It is well known that when a pipeline or a metallic duct is under the electromagnetic influence of an A.C. power or electrified railway line, induced voltages and currents appear on it; depending on the level of those quantities, we may have problems of safety for personnel or damages or malfunctioning of apparatuses installed along the pipeline. For such a reason, in many countries suitable standards have been published with the indication of limits to be respected in order to ensure safety for people and correct functioning of apparatuses; nevertheless in the last decades, starting from the field experience, a new problem, again originating from the electromagnetic induction on the pipeline, has been recognized: the A.C. corrosion even on cathodically protected pipelines.

Within the community of pipelines corrosion experts, it is commonly accepted that the A.C. current density exchanged between a pipeline and soil through the holidays present in the insulating coating is a meaningful parameter in order to assess the risk of A.C. corrosion; in particular the value of $30A/m^2$ is considered a threshold that, if exceeded leads, to corrosive effects for any type of soil [1]. Thus, from this point of view, especially at the design stage of new plants, one can realize the usefulness of predicting the level of current density in different point along the pipeline so that the risk of A.C. corrosion could be assessed. Moreover, also in case of already existing plants, the use of simulation programs can be a complementary tool to be used besides the field measurements.

The algorithms on which such simulation tools are based, are strictly related to the ones, succesfully adopted since a long time, to calculate voltages and currents induced on telecommunication cables and pipelines under the influence of power or electrified railway lines [2], [3], [4]; it is worthwhile to mention that such simulation tools have also been validated by specific field measurements [5], [6].

Before presenting the examples of application, which are the core of our paper, we shall devote the next paragraph to sketch the basic theory needed to model the pipeline under the influence of power or electrified railway lines.

2. SHORT DESCRIPTION OF THE MODEL

2.1 Basic electric circuit modelling the pipeline

According to [2], [3], when dealing with electromagnetic interference problems produced by power lines or electrified railway lines on pipelines or telecommunication cables, the induced plant may be suitably modelled, from the electric point of view, by means of a chain of an adequate number of elementary circuits (cells) as shown in Fig. 1.

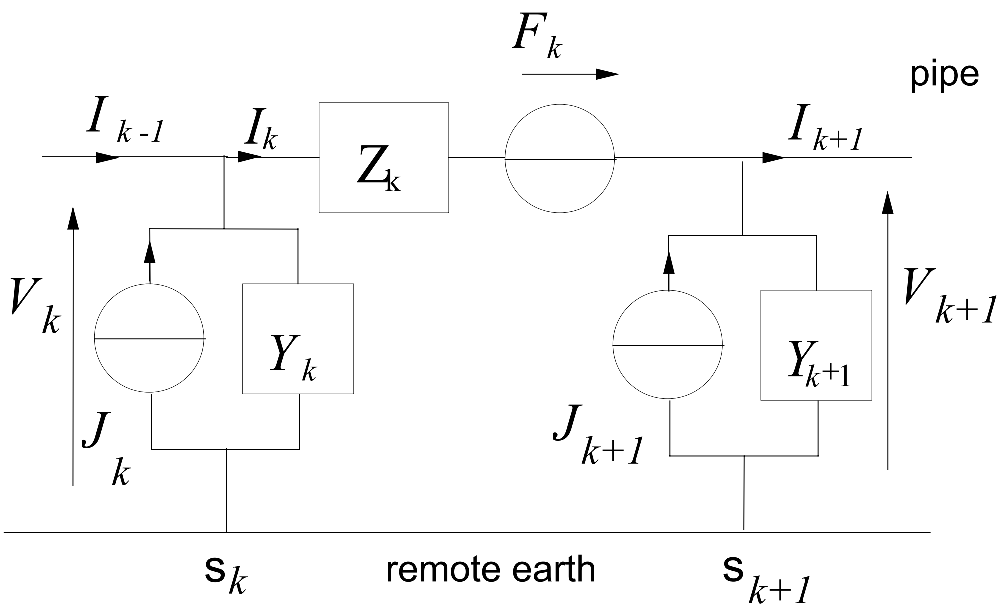

Fig.1: k-th cell of the circuit pipeline with earth return

We can see that the generic k-th cell, located between abscissas s_k and s_{k+1}[1], is described by means of the following electric parameters:

- Z_k : the impedance of the circuit formed by the pipeline with earth return;
- Y_k , Y_{k+1} : the admittances to remote earth of the pipeline;
- F_k : the ideal longitudinal voltage generator describing the inductive influence of the inducing line on the pipeline;
- J_k , J_{k+1} : the ideal transversal current generators describing the conductive influence of the inducing line on the pipeline.

By adopting this model, we can realize that, when dealing with the exchange of current between soil and pipe, a very important role is played by the admittance to earth (or, equivalently, transversal impedance to earth); for such a reason, the next paragraph will be devoted to the description of such a parameter together with some formulas for evaluating it when holidays are present in the coating.

2.2 Earth resistance of a coating holiday

Let us consider a pipeline buried at depth h, having a diameter 2b and covered by a coating of thickness d; moreover, let us suppose that a single holiday is present on the coating at a given location of the pipeline. The holiday is represented by a small cylindrical vacancy of the coating, having a cross section A and the same height d as the coating thickness (see Fig.2), filled with soil.

[1] The lay-out of the pipeline is represented by means of a broken line and s is the curvilinear abscissa defined on it.

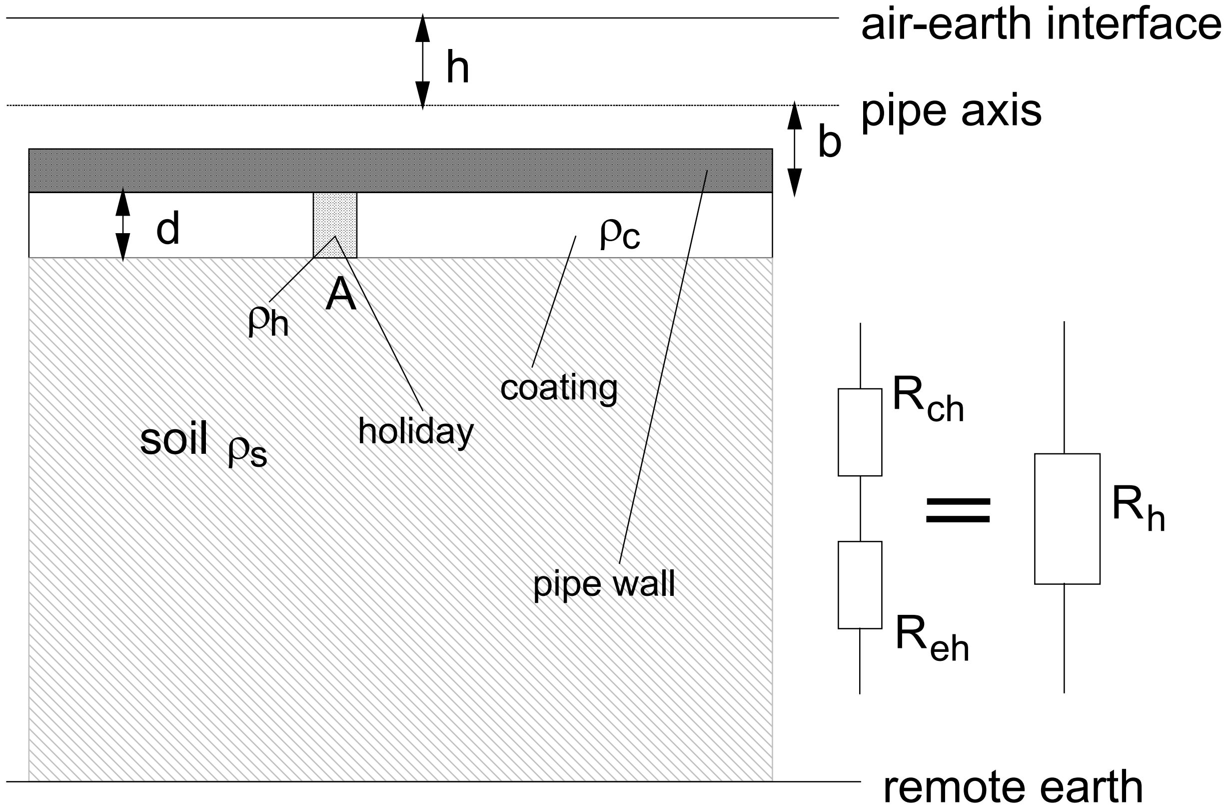

Fig.2: Coating with one single holiday.

Moreover, according to field measurements [7], the value of the soil resistivity measured in points very close to the holidays is very different with respect to the value of the soil resistivity measured at a certain distance from the pipeline; for such a reason, we shall consider two different values resistivity: ρ_h for points inside the holiday and ρ_s in all the other points[2].

The resistance to remote earth R_h of the pipeline through the holiday is given by the sum of two contributions; the first one, indicated by R_{ch} , representing the resistance relevant to the small cylinder inside the coating, is given by:

$$R_{ch} = \frac{\rho_h d}{A} \tag{1}$$

The second one, indicated by R_{eh} , represents the earth resistance (with respect to the remote earth) of the holiday; it can be evaluated as the earth resistance of a disk of area A, placed on the soil surface [2], that is:

$$R_{eh} = \frac{\rho_s}{4}\sqrt{\frac{\pi}{A}} \tag{2}$$

Thus, by adopting the term *holiday resistance* to indicate the quantity R_h we have:

$$R_h = \frac{\rho_h d}{A} + \frac{\rho_s}{4}\sqrt{\frac{\pi}{A}} \tag{3}$$

[2] On the basis of the results in [7] we have in first approximation that $\rho_h \approx \rho_s /10$.

It is useful to remark that in corrosion books and papers, R_h is generally named *spread resistance*.
Typical values of the holiday resistance versus the holiday area and for different values of soil resistivity are shown in Fig.3; we can notice that R_h assumes very high values (some hundreds of Ω) even with very large values for holiday area A and for low value of soil resistivity ρ_s.

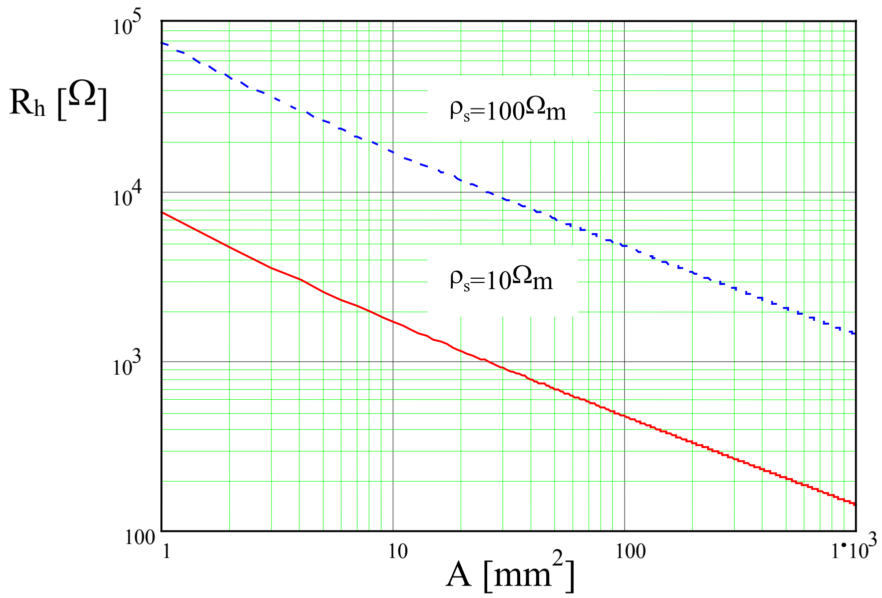

Fig.3: Holiday resistance versus holiday area for different values of soil resistivity.

Thus, *as far as the induced voltage calculation is concerned*, the main consequence of such a result is that, in most of the situations, we can neglect the presence of the holidays in the equivalent circuit of the pipeline. Hence, only the actual earthings (whose typical values lie in the range between some Ω to some tens of Ω) have to be taken into account.

2.3 Current density calculation

In order to calculate the current density through the holidays coating, it is first necessary to calculate the pipe voltage to earth under the influence of the inducing power line. This task can be achieved by means of the following three steps:

- determination of the currents on the inducing line;
- calculation of ideal electromotive force (emf) generators representing the influence of the power line on the pipeline[3];
- modelling of the pipeline under study by means of a suitable equivalent electric circuit and calculation of voltages and currents induced on it.

All the details of this calculation procedure can be found in [2], [3], [4]. If K is the number of cells choosen to properly describe the equivalent circuit of the pipeline, the results of the calculation procedure previously mentioned are the voltages to remote earth V_k calculated at boundary points s_k (k=1,2, ..., K+1) of each cell and the longitudinal currents I_k (k=1,2, .., K) relevant to each cell. The voltage at a generic abscissa s in the

[3] It is useful to remark that under normal operation conditions, except in particular situations, we have only inductive coupling between power line and pipeline; thus, with reference to the basic circuit of Fig.1, only the longitudinal electromotive force generator has to be considered.

k-th cell between s_k and s_{k+1} can be calculated by means of linear interpolation, that is:

$$V(s) = \frac{V_{k+1} - V_k}{s_{k+1} - s_k}(s - s_k) + V_k \qquad s \in [s_k, s_{k+1}] \tag{4}$$

If we suppose that an holiday of area A is placed along the pipeline in a point identified by abscissa s, by remembering (3), we have that the current density is given by:

$$J(s) = \frac{V(s)}{\rho_h d + \frac{\rho_s}{4}\sqrt{\pi A}} \tag{5}$$

Thus, the above formula allows for a straightforward calculation of the current density starting from the potential distribution along the pipeline; in particular we can notice that the shape of the function J(s) is the same of the function V(s) and they are related through the factor K given by:

$$K = \left(\rho_h d + \frac{\rho_s}{4}\sqrt{\pi A} \right)^{-1} \tag{6}$$

So, by looking at (5), we see that, for a given value of potential V(s), the smaller are the values of ρ_h and A, the higher is current density J(s).

3. EXAMPLES OF APPLICATION

3.1 Introduction

This paragraph is devoted to present two examples of calculation of current density flowing through an holiday coating[4]. The cases considered describe real situations; in particular the first one represents a case, still at the design stage, characterized by a low level of induction while the second one is relevant to two already existing plants and is characterized by an high level of induction.
On the basis of the previous remarks about the holiday resistance to remote earth, we can conclude that in the typical range of values for the soil resistivity ρ_s (10Ωm÷10000Ωm) and for the holidays area A (1mm^2÷1000mm^2), the induced voltage on the pipeline does not depend on the holidays characteristics (A, ρ_h, d) and can be calculated by considering an ideal coating (i.e. no holidays); therefore, from this point of view, the induced voltage profile V(s) along the pipeline layout is an univocal characteristic of each pair of power line and pipeline.
After a first calculation concerning the voltage, the current density may be calculated *only making some assumptions* regarding the holidays characteristics which consist in:

- assumption about the values of the parameters A and ρ_h;
- assumption about the holiday location along the pipeline; in particular, in order to consider the worst case condition, we shall suppose, in the following, that the holiday is located in the point where the induced voltage is maximum.

3.2 Case I (Low induction)

The pipeline whose length is about 24km is laid down close to a single circuit power line (feeded 150kV-50Hz) for most of its length; the currents are unbalanced and their values (expressed in A) are: I_1=0, I_2=142, I_3=-142. A meaningful quantity characterizing the level inductive influence from the power line is

[4] For simplicity we shall consider the presence of only one holiday for all the pipeline route.

represented by the induced electromotive force f per unit length versus the pipeline route described by the abscissa s; such a quantity is shown in Fig.4.

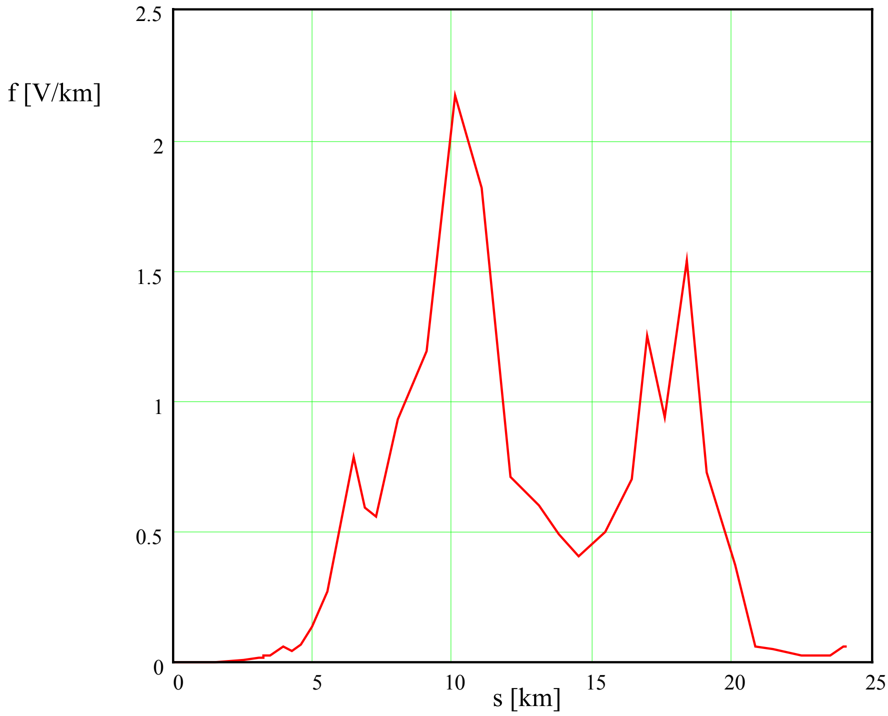

Fig.4: Induced emf per unit length versus pipeline abscissa.

The main data relevant to the pipeline are:

- burial depth h=1.5m;
- diameter 2b=1200mm;
- coating thickness d=5mm;
- earthings in eleven points with values of the earth resistance given by nearly 7Ω at the extremities and 20Ω at the inner points;
- one insulating joint is installed at point corresponding to abscissa s=4.235km;

The soil resistivity ρ_s is 200Ωm.
The induced voltage along the pipeline route is shown in Fig.5.

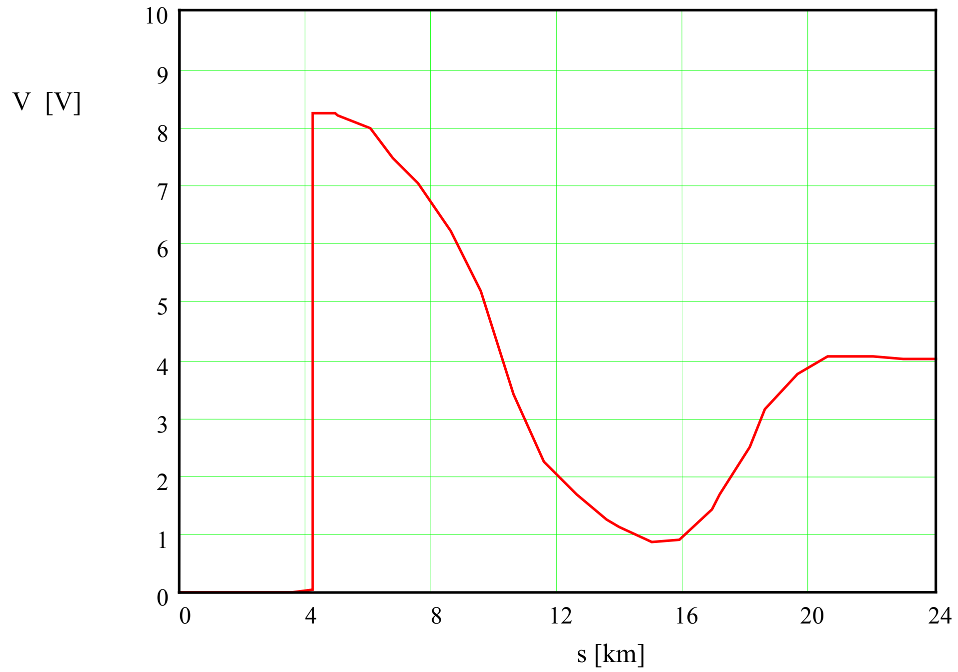

Fig.5: Induced voltage along the pipeline route.

We can notice that the induced voltage in the interval [0km, 4km] is practically nihil; this is due to the presence of the insulating joint and to the low values of the induced emf in same interval (see Fig.4).
As previously outlined, we can now calculate the current density through the holiday in the pipeline coating: in order to consider the worst case, let us assume that the holiday is just located where the induced voltage is maximum V=8.2V at s=4.95km.
In Fig.6 the current density J is shown versus the holiday area A for different values of the resistivity ρ_h of the electrolite inside the holiday.

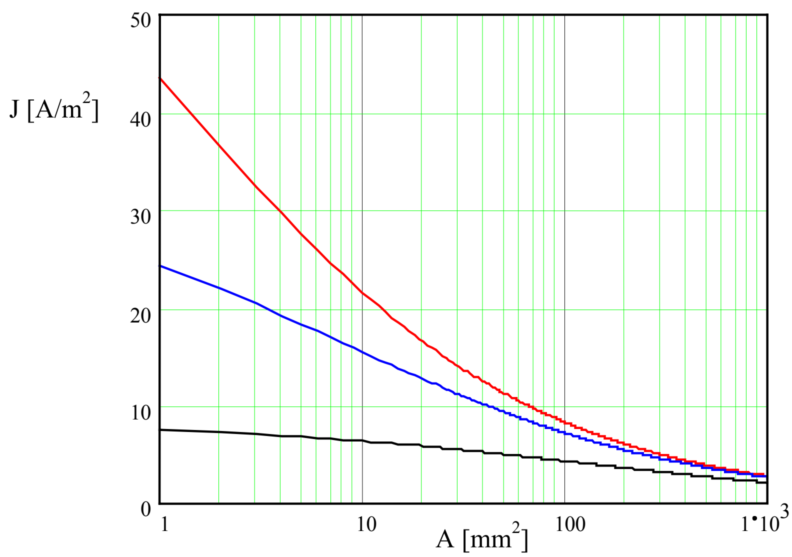

Fig.6: Current density versus the holiday area A for different values of ρ_h; (from top to bottom ρ_h= 20Ωm, 50Ωm, 200Ωm)

Fig.6 shows that in case of very small holidays and with low values for ρ_h, the value of 30A/m^2 for the current density is exceeded; the main indication we can get is that, under particular and unfavourable conditions, even low levels of induced voltages can lead to an A.C. corrosion risk.

3.3 Case II (High induction)

In this case, both the plants already exist and it is useful to mention that A.C. corrosion has been actually detected on the field; the pipeline is 28.5km long and is laid down close to single circuit power line (feeded 380kV-50Hz) for most of its length; the currents are balanced and have a value of 630A. The induced emf per unit length on the pipeline is shown in Fig.7; in this case we notice the much higher level of induction with respect to the previous one.

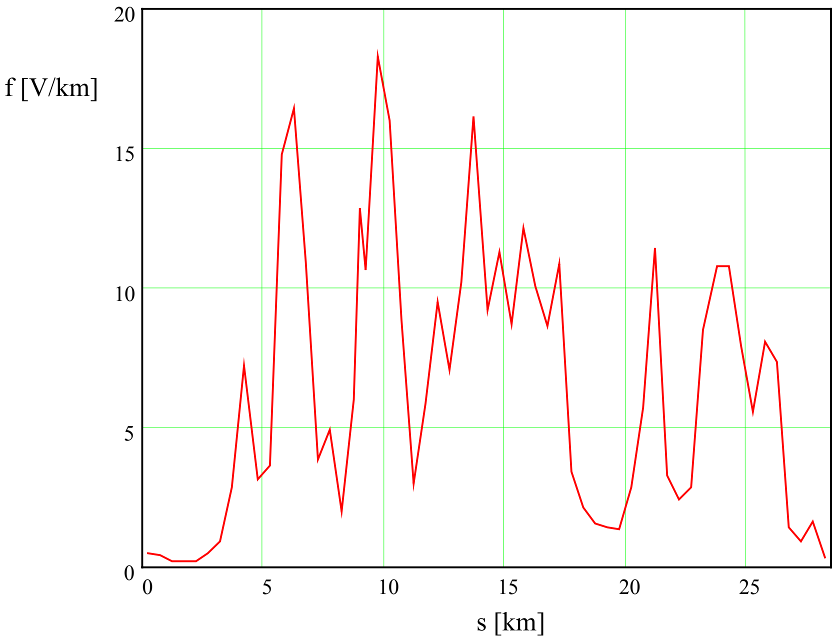

Fig.7: Induced emf per unit length versus pipeline abscissa.

The main data relevant to the pipeline are:

- burial depth h=1.5m;
- diameter 2b=1200mm;
- coating thickness d=3mm;
- earthings in eleven points with values of the earth resistance given by 5Ω at the extremities and 100Ω or few Ω at the inner points;
- two insulating joints are installed at the points corresponding to abscissa s=9km s=19km respectively;

The soil resistivity ρ_s is 100Ωm.
The induced voltage along the pipeline route is shown in Fig.8.

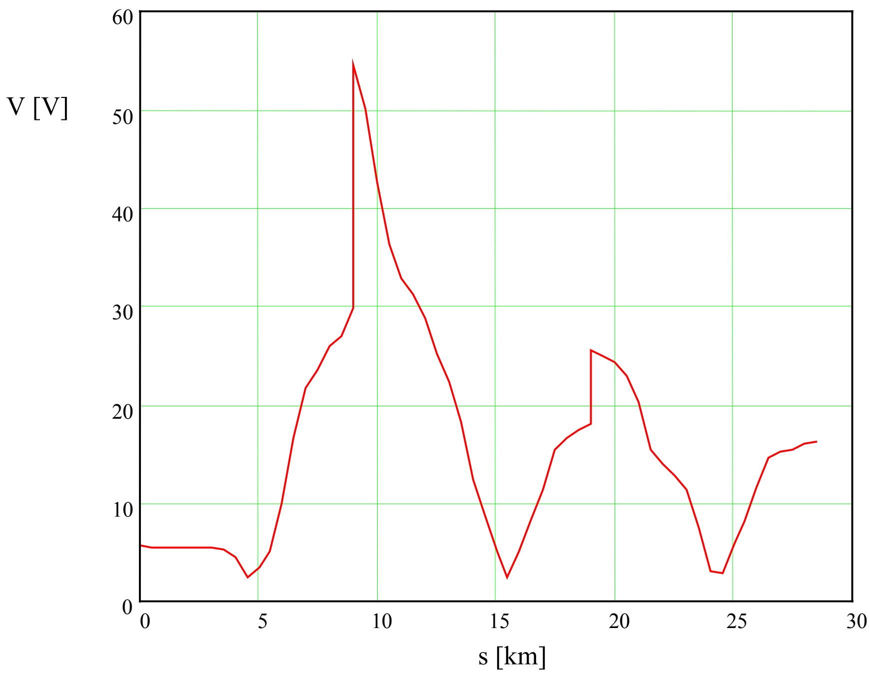

Fig.8: Induced voltage along the pipeline route.

As one could expect by looking at Fig.7, the level of induced voltage is high inspite of the presence of the two insulating joints and of the earthings; in particular the maximum is V=54.6V at s=9km. As in the previous case, we evaluate the current density by supposing the holiday just placed in the point of maximum induced voltage. In Fig.9 the current density J is shown versus the holiday area A for different values ρ_h of the resistivity of the electrolite inside the holiday.

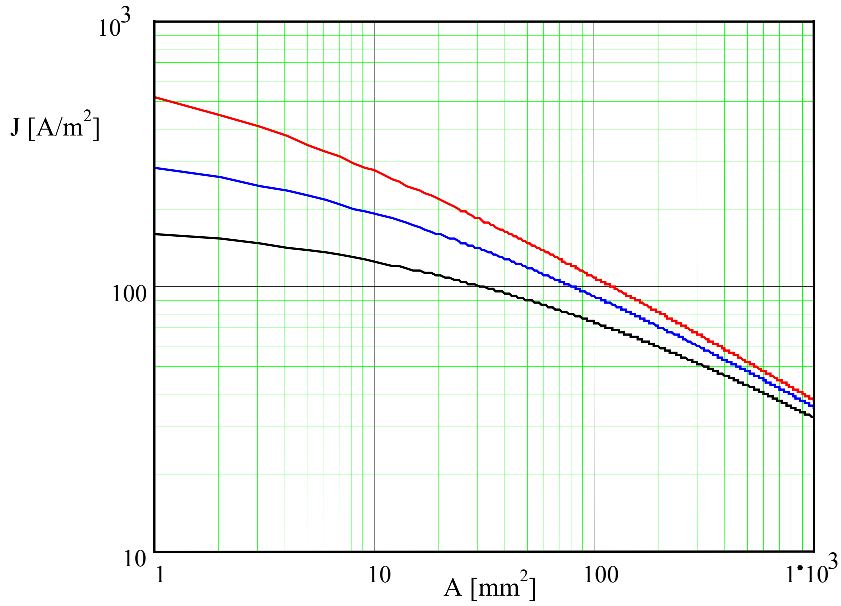

Fig.9: Current density versus the holiday area A for different values of ρ_h; (from top to bottom ρ_h= 20Ωm, 50Ωm, 100Ωm)

In this case we see that for every realistic value for the holiday area A, the value of 30A/m^2 is always exceeded independently from the resistivity ρ_h.

Although such a current density calculation has been done under conservative hypothesis, due to the high value of induced voltage along all the pipeline route, one could expect that the threshold of $30A/m^2$ for the current density is exceeded also in many other points (provided that an holiday is present); infact, as already mentioned, the presence of A.C. corrosion has been detectected in more than one point along the plant.

4. CONCLUSIONS

In this paper we have presented two real cases of electromagnetic interference from a power line on a pipeline via inductive coupling; in particular we have evaluated the current density exchanged between pipe and soil through an holiday in the insulating covering. The first example, dealing with a power line still at the design stage, shows that even in case of low induction, we can have, under particular and unfavourable conditions, the exceeding of the value of $30A/m^2$; the second example, dealing with plants already existing and operating, describes a case characterized by with an high level of induction with the possibility of exceeding the value of $30A/m^2$ not only in the worst case but also in more favourable conditions.

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