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# Currents Identification in Overhead Lines from Radiated Magnetic Field Knowledge

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**Abstract** — Electric currents are the source of overhead lines magnetic fields. Once these fields are known, it is possible to recover all information about the circuit's current which can be used to monitor distribution networks. It should discriminate the interference of land and pole structures on magnetic field measurements to build a correct model that draws these currents. This paper presents a study about these inaccuracies as well as a procedure to recover the currents of overhead lines from strayed magnetic field knowledge.

## I. INTRODUCTION

High-voltage power lines generate electric and magnetic fields in their neighborhood. The sources of the magnetic field are the currents in the lines conductors. The electric field is caused by the potential of the conductors. Therefore, periodic field measurements can be used to monitor the energy quality or to indicate faults on networks [1]. However, overhead line geometry (pole structure and conductors outlook) and land effects (ground currents appear when faults happen) make not obvious the identification of fields distribution.

Many studies have been presented to elucidate the stray fields from overhead electric lines; among them we can quote the IEEE's boards [2]-[3]. There are a lot of measurement precautions and interference elements to take into account to study magnetic field with accuracy. Usually, the most important are:

- The ground current influence – we do not discuss if it exists, but where it rolls;
- The presence of ferromagnetic and/or conductor materials around the line modify the magnetic field. It means for example the concrete pole which supports the circuit lines.

In this paper we quantify the influence of these two elements on the magnetic field distribution. The interest is to determinate how much interference they caused and if we can neglect them or not in an on-time monitoring action. Having the field measurements, the goal is to recover all currents information to identify possible problems in the system.

Thinking about the magnetic field computation, it can be done by Biot & Savart law if the currents are known (amplitude, phase and geometry) – what we name 'direct model'. On the other hand, if the stray magnetic field is known an 'inverse approach' may be applied to compute currents. This inverse procedure can be used for monitoring overhead lines by remote current sensing.

In our study we propose a procedure to identify the currents in overhead lines from radiated magnetic field based on possible simplifications from interferences studies. Some aspects related to a correct inversion are also discussed.

## II. DIRECT MODEL

Biot-Savart law describes the magnetic field set up by a steady current density. As discussed in introduction section, some aspects can complicate it. We present two topics in this resume section: the study of ground influence and the analysis of the perturbation caused by concrete pole with metal structure. These simulations are relevant to determinate the complexity of the problem.

### A. Land Influence

To learn about the land influence, it means the return current effect, a magnetodynamic 2D FEM [4] has been used (eddy currents under ground are taken into account). The conductors are placed at a fixed distance between each other and with the same height of the soil. The land is a massif resistor [ $\Omega.m$ ] with a given skin coefficient. Fig. 1 shows the fields obtained by this simulation (air + ground) and analytical computation by Biot & Savart (just air). Many configurations of currents, geometries and ground resistance have been tested, for example different kinds of network earth faults. The difference in percentage among simulations and analytical computations decreases when moving away the measure point from soil and approaching it to the line conductors. More distant of the ground we are, less interference we have on measurements. Furthermore, when the resistance per meter (i.e. the skin coefficient) is changed, the measures are not so affected (more details in the extended version of this paper).

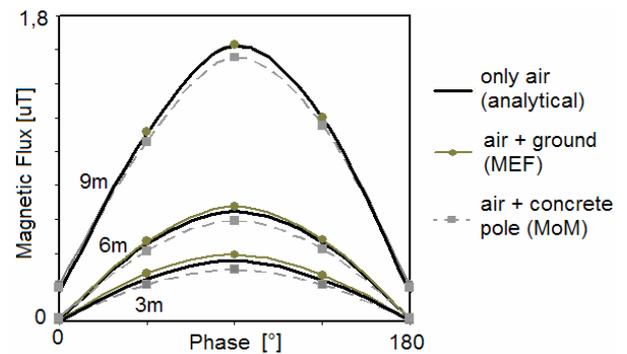


Fig. 1. Comparison between simulation and analytical computation.

### B. Concrete Pole with Conductor Structure

We use a magnetostatic 3D MoM [5] to study the interference on field measurement due to ferromagnetic structures inside concrete pole which support the overhead line (FEM is too heavy). Here, the inaccuracy is always constant in all measurements, as Fig. 1 shows. Of course, this percentage depends on how much ferromagnetic material has the concrete pole and how this material is placed inside it.

The disparities among all these simulations (just air, with ground and concrete pole) are around 5%. Is it negligible? If we suppose to work with ‘overhead power lines monitoring’ the answer can be yes. Consequently, the currents computation can be done from an inverse procedure of the Biot & Savart law.

### III. INVERSE MODEL

The objective is to find a matrix relation between the unknown currents and the measured field generated by them. Based on Biot & Savart law, we can write

$$[H] = [G] \times [I], \quad (1)$$

find  $[I]$  such as  $\|[G] \times [I] - [H]\|$  is minimal,

where  $G$  is the geometry matrix depending on number and position of the conductor lines and points of measurement.

The solution of this inverse problem (1) is not single, because we can have infinite current arrangements  $[I]$  which give the values of magnetic flux measured. The problem is then known as ‘ill-defined’ or ‘ill-posed’. This ill-posed nature appears basically because we have:

- Less information (measurements) than unknowns (currents and noise). Thus, some measurement points must be added in different spatial places;
- Badly conditioned problem due to uncertainty measurements. Therefore, it is difficult to distinguish a source distribution compared to another. In this way, there is also not unicity of the solution.

These are intrinsic characteristics of inverse problems, the instability of their solutions. One way to quantify this instability is the condition number of the problem ( $\xi$ ) [6]. In our case, it depends exclusively on geometry matrix  $G$

$$\frac{\|\Delta I\|}{\|I\|} \leq \xi(G) \frac{\|\Delta H\|}{\|H\|} . \quad (2)$$

To minimize the inverse problem instability, it means do not permit the amplification of the measurements inaccuracy and uncertainty by a elevated condition number of  $G$  matrix, we can use some optimization algorithm to find the best location for the measurement points [6], which are the single parameters that we can adjust (the others  $G$  parameters are fixed like the concrete pole structure and conductors position). Here, the optimization variables are the coordinates of the measurement points and the objective is to minimize the condition number of the geometry matrix.

The inversion of  $G$  can be done by several mathematical methods, but if we have a problem with quite good condition number, it is enough to use normal equation

$$[I] = ([G]^T [G])^{-1} \times [G]^T \times [H] . \quad (3)$$

### IV. SIMULATION EXAMPLE

Fig. 2(a) shows two amplitude measurements (two vector sensors) obtained from one phase short-circuit by EMTP [7]. Using the inverse model, we identified the currents with accuracy as Fig 2(b,c) shows. The currents fit with less than 2% (numerical imprecision).

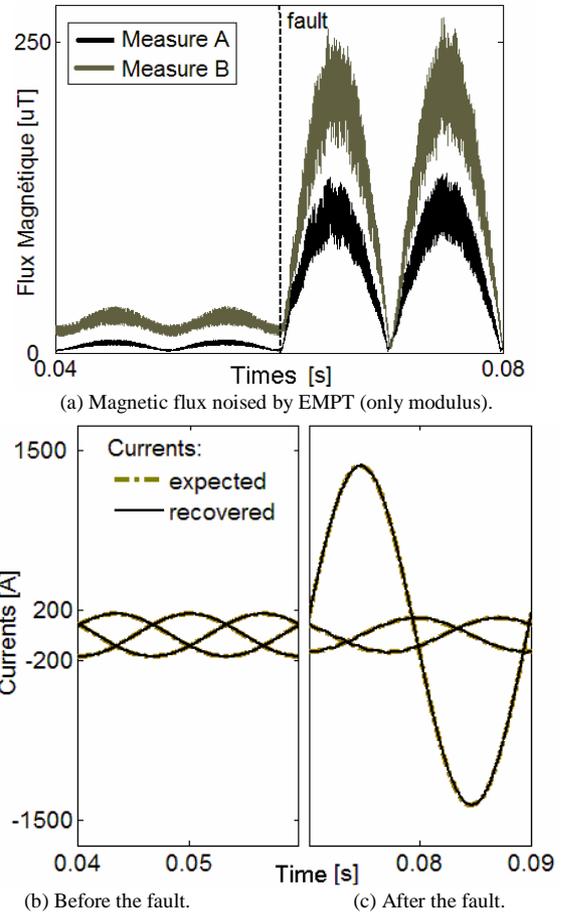


Fig. 2. Currents Identification by inverse model.

The inverse model presented here works with any configuration of currents or/and spatial geometry as far as we have a good condition number of the problem.

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