Electric Power Systems Research 110 (2014) 55–63

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Active shielding of overhead line magnetic field: Design and applications

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ARTICLE INFO

Article history:
Received 12 March 2013
Received in revised form 2 January 2014
Accepted 6 January 2014
Available online 1 February 2014

Keywords:
Magnetic fields
Magnetic shielding
Power transmission lines
Active shielding

ABSTRACT

The paper presents the successful field application of active shielding of the magnetic field of HV overhead lines. Two plants have been deployed and are being operated since some years on a 132-kV and a 400-kV line. The solutions adopted minimize the impact on the line structure. Also the configuration of the control systems has been studied in order to avoid any impact on the normal operation of the line. Two different solutions were used; the first is based on a current sensor and a radio transmitter–receiver system, the second relies on the mutual effect between the line and the shield wires thus not requiring any device installed on the power conductors.

Both systems have been continuously operated for some years and have assured to keep the magnetic field at the sensitive targets below the desired limits.

1. Introduction

In recent times, the concern for the effect on health of the exposure to magnetic fields led to a growing opposition not only to projects for new transmission lines [1,2], needed for a better utilization of the present generation asset [3,4], but also to the full exploitation of already existing lines [5] and to possible upgrade of their capacity [6,7].

In several countries, the law has defined limits to be respected when planning the possible use of the areas close to an overhead line. In case of existing buildings near a line, the limits on magnetic field become a limit on the line capability. It is worth noticing that, usually, only a very small length of any line is really close to "sensitive targets", which means that there is no need for reducing the magnetic field throughout the whole line length. An approach to the problem which considers this characteristic might give an effective solution on both technical and economical side.

The principle for shielding the lines is well known and is based on the compensation effect that a current in additional wires has on the magnetic field generated by the current in the power conductors [8]. Although well known and widely studied worldwide, this principle had not been applied on overhead lines yet.

In the past decades, passive solutions had been studied, since, in principle, they simply need properly designed wires, to be installed without any supplying system [9–14]. The electromotive force induced in the shield wires generates a current which, in turns, gives a magnetic field that partly compensates the effect of the power wires. The large values of the wire cross section needed for achieving high enough currents in the shield or the position where the shield should be located for being effective [12,13] made these solutions practically unfeasible. Even in the theoretical condition of making a shielding circuit with zero resistance, the result would be to have a null value of the flux linked to the shield circuit itself. It does not mean that the magnetic field is properly reduced at the interesting points outside the loop.

In other cases, the possibility to supply the shield wires through transformers directly connected to the line conductors has been studied. Several transformer configurations have been conceived to supply a current which depends on the line current itself [15]. In this way, the effect is to reduce the magnetic field to a given fraction of the unshielded value. These solutions need an expensive transformer directly connected to the high voltage wires for supplying the shield. Besides the technical difficulties of building a transformer with a proper insulation level, a possible fault on the shielding system might compromise the operation of the power line.

A more effective shielding can be obtained through an active strategy where the current in the shield wires is supplied through an external supply system [16]. Different criteria can be adopted to define the right current value. Some solutions tried to adopt a field

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http://dx.doi.org/10.1016/j.epsr.2014.01.005

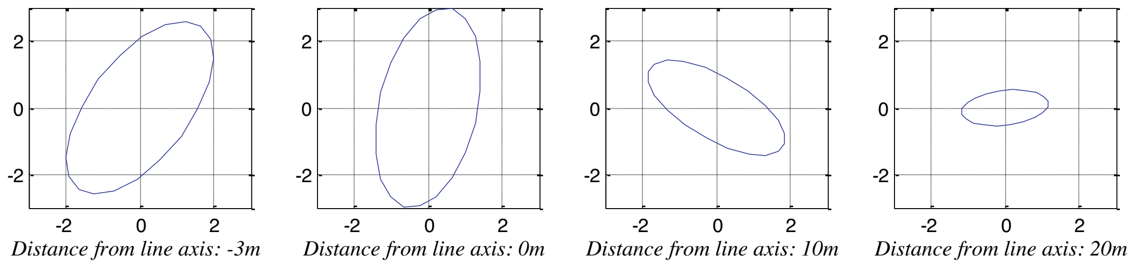

Fig. 1. Ellipses described by the rotating fields on a plane perpendicular to the line in the delta configuration (values in μT).

sensor near the target for controlling the shield current, although it is difficult to distinguish between the shares due to the power and the shield currents [17,18].

Other studies aimed to find the optimal geometry of both passive and active shielding systems, as well as the optimal shielding current through various optimization algorithms [11,19,20]. Only numerical and simulation results are presented in the literature.

As a matter of fact, there are no actual applications of these studies on operating overhead lines. Also the international survey published in 2009 [9] stated that "the practicality of this option needs however to be demonstrated".

Two other solutions can be then adopted for defining the right current to be injected in the shield wires: either using a current sensor installed on one line conductor, for then transmitting the value to some receiver, or considering the mutual coupling between the shield loop and the line conductors, without installing any sensor on the high voltage wires.

These two solutions have been developed in sequence and are currently being operated on two HV lines in Italy [21]. Both systems, and the various technical solutions adopted for their implementation, are patented by Zerotesla scarl and 3E Ingegneria srl.[1]

2. Active shielding principle

The current flowing in a three-phase power line generates a magnetic field nearby the line itself. The magnetic field vector at each point describes an elliptic path on a plane perpendicular to the line conductors. The relative size of the major and minor axes of the ellipse depends on the geometric position of the conductors. A delta configuration is responsible of a quasi circular ellipse (see Fig. 1, referring to the 132-kV line described in Section 6), while a flat geometry, either horizontally or vertically oriented, gives a very narrow ellipse [10].

In the first case, a good compensation can be achieved only by creating a rotating compensation field, which, in turns, needs a three-phase shield configuration and a three-phase controlled source. In the second case, an effective compensation can be achieved through a single-phase system made of two conductors roughly located on the same plane of the power wires. The supply system is a single-phase source. Papers [8,10] present comprehensive tutorials on this issue.

If the shield conductors are exactly on the plane of the line conductors, the alternating field generated by the shield at any point is oriented as the major axis of the ellipse described by the rotating field given by the power wires. In this way, with a proper choice of the amplitude and phase of the shield current, the magnetic field component across the major axis of the ellipse can be cancelled and the result field will be only made of the minor axis component (see Fig. 2, referring to the modified configuration of the 132-kV line described in Section 6, where conductors were arranged on a vertical plane. Line current: 440 A, shield current: 166 A, phase shift: $\pi/2$ with respect to the current in the central line conductor).

Each figure shows the ellipse described by the unshielded magnetic field (the large ellipse), the shielding field (which acts on the direction roughly oriented along the major axis of the ellipse) and the overall effect which remains along the minor axis of the ellipse.

The current to be circulated in the shield wires shall have amplitude and phase which make the alternating field having a peak value as large as the major axis of the ellipse and opposite phase.

Obviously, the exact compensation of the major axis component can be achieved only at one point on the plane perpendicular to the line axis. At all the other points, some small residues will remain also for the major axis component. In addition, not all the tower structures enable locating the shield wires on exactly the same plane of the power ones. This means that the axis of the alternating field will not everywhere coincide with the major axis of the ellipse, thus resulting in a less effective compensation. See again [8] and Fig. 15.

On this basis, different shielding targets can be pursued: either to achieve the lowest possible field value throughout the line pathway, or to maximize the shielding effect at a specific point where a sensitive target, such as a house, is located. In the latter case, it is worth remarking that usually only one or a few targets are really critical, while all the remaining land around the line is completely free. An asymmetrical compensation can be therefore pursued with a proper choice of the shield geometry and of the amplitude and phase of the shielding current.

In the present work, the optimal value of the current (amplitude and phase) to be injected in the shield was chosen to achieve the desired result at the sensitive targets. It is not a generalized minimization of the field in the overall area around the line. Therefore studies have been performed through punctual calculations based on the Ampere's circulation law, with the simplified hypotheses of parallel indefinite straight conductors for a first approach (see results presented in Figs. 1, 2, 9, 14 and 15). Then, detailed results (such as shown in Figs. 10 and 16) have been achieved by integrating (through custom designed software) the Biot–Savart's law and accounting for the actual geometry of the thin conductors. In all cases the choice of the optimal current is made through off-line calculations searching the vector ratio between the line current and the shield current which better compensates the major axis component of the magnetic field ellipse at the sensitive target.

At a first step, with the simplified hypotheses, a first attempt current is found. Its effect is then checked accounting for the actual geometry of the conductors.

In any case, all the optimization methods studied in the past for finding the current which assures the best result according to a minimum criterion can be applied and used to define the shield current value and phase.

We remark that we worked on mitigating the effect of existing lines, not on designing new low impact configurations of power lines. Therefore, when moving towards the practical implementa-

[1] Italian patents: 1358054, 1358055, 1358056, 1382778, 1382782.