3-DIMENSIONAL MODELLING IN EVALUATING ELF FIELDS EXPOSURE

COMELLI M.[(1)], COLONNA N.[(2)], LICCIARDELLO C.[(2)], LICITRA G.[(2)]

(1) IFAC-CNR ("Nello Carrara" Institute for Applied Physics, of the National Research Council),

comelli@ifac.cnr.it

(2) ARPAT (Regional Environment Protection Agency of Tuscany),

n.colonna@arpat.toscana.it, c.licciardello@arpat.toscana.it, g.licitra@arpat.toscana.it

Abstract

In the last years the Regional Environment Protection Agency of Tuscany (ARPAT) has made an evaluation of the ELF (Extremely Low Frequencies) exposure of population trough the means of an integrated system which includes the implementation of the Regional Power Lines Archive (CERT)[1] as a data source for the calculation software.

The storage of 380 and 220 kV lines has been possible entering the lines routes, the profiles and the technical diagrams of high and very high-tension power lines — obtained from the lines operators after an agreement with Tuscany Region — in the CERT archive. Differently from the 380 and the 220 lines, the storage of 132 kV is still in progress. The PLEIA calculation software — developed in a IFAC-ARPAT agreement — allows the 3-dimensional calculation of magnetic field values in proximity of power lines.

A control procedure has been developed to guarantee the quality of theoretical valuations obtained by using the data of the CERT archive. The controls concerned the geometrical features of pylons and buildings got from the numeric cartography.

DGPS (Differential GPS) measures have allowed to improve the precision of the pylons coordinates; all the geometric features stored in the archive have been verified (straddles amplitude, lower wire height, span catenary constant) for each pylon using a laser telemeter. The same tool has been used to measure the distances of closest buildings to power lines and their height.

In conclusion, some 3-dimensional visualization environments (ESRI ArcScene and GoogleEarth) have been tested as further support by the technicians involved in the controls.

Introduction: the archive development

During these years, the collaboration between ARPAT and IFAC has been orientated to the power lines regional archive (CERT) development and to realize a set of applications (among which a software called PLEIA - Power Line Electromagnetic Impact Assessment) which use CERT data to evaluate the distribution of magnetic field in the environment.

CERT is a computerized archive of electric and magnetic fields sources connected with electric energy production, transmission and distribution, operating at a work voltage equal or higher to 132 kV in the territory of Tuscany Region. For each source, it is possible to know:

- the placement on territory;
- the mechanical structure, for pylons;
- the electric features of wires.

Restricting the analysis to the most significant data for magnetic field calculation, CERT allows to save the following information:

- for each pylon:
  - ✓ the position, with Gauss-Boaga coordinates and the altitude above sea-level;
  - ✓ orientation, referring to the North;
  - ✓ height of lower wire suspension point from ground level;
  - ✓ the position of the suspension points of wires;
- for each line:
  - ✓ the sequence of pylons;
  - ✓ the features of every wire (starting and final pylons and relative suspension points, catenary constant, diameter, phase, fraction of total current);
  - ✓ voltage and current values.

[1] The CERT financed by Tuscany Region and developed in collaboration with "Nello Carrara Institute for Applied Physics", IFAC, of the National Research Council (CNR).

Referring to what provided by Italian law, CERT allows to record also power stations data.

Population exposure

PLEIA software is part of a kit in Windows environment, including tools for CERT archive management, for magnetic field generated by one ore more power lines calculation, for archive objects and calculation output visualization, and for other additional functions. To go into details, the calculation module is targeted to evaluate the magnetic induction generated by one or more power lines, which data are recorded in CERT, in georeferred points in Tuscany Region territory.

During the last years, PLEIA calculation model has been tested with a series of validations in complex cases of several lines too, characterized by currents that vary in time in an uncorrelated way, with significant differences in level between pylons, and so on. Such tests gave positive results, as revealed in previous works [2, 4]

Tension	Number of lines	Number of spans	Total length
132 kV	307	11234	2989 km
220 kV	13	1255	454 km
380 kV	20	2306	1072 km
Any	340	14795	4515 km

Table 1 – Power lines in CERT: number of lines, of spans and total length.

The 0.4 μT 1st level bands (corresponding to the ground projection of the volume containing field values higher to 0.4 μT) have been determined from CERT data (the archive is fulfilled at 91%, having power line distribution as shown in Table 1), by using mean values of currents, to define a territory part where verify the population yearly mean exposure.

A first exposure evaluation has been carried out in correspondence of the centroids of the buildings (from numeric cartography) present in these bands (see Figure 1).

Figure 1 - 1st level bands visualization and extraction of inner buildings.

The number of people living in the houses near the power lines has been extrapolated from the 2001 Italian census, using a proportion which considers each building surface.

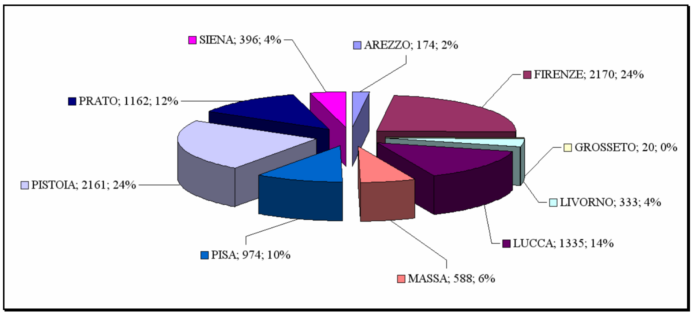


Figure 2 – District people distribution (9314 in total) in the 0.4 μT 1st level bands calculated using the mean current of power lines.

Output data, referring to district people distribution, are described in Figure 2.
The field values distribution is shown in Figure 4.

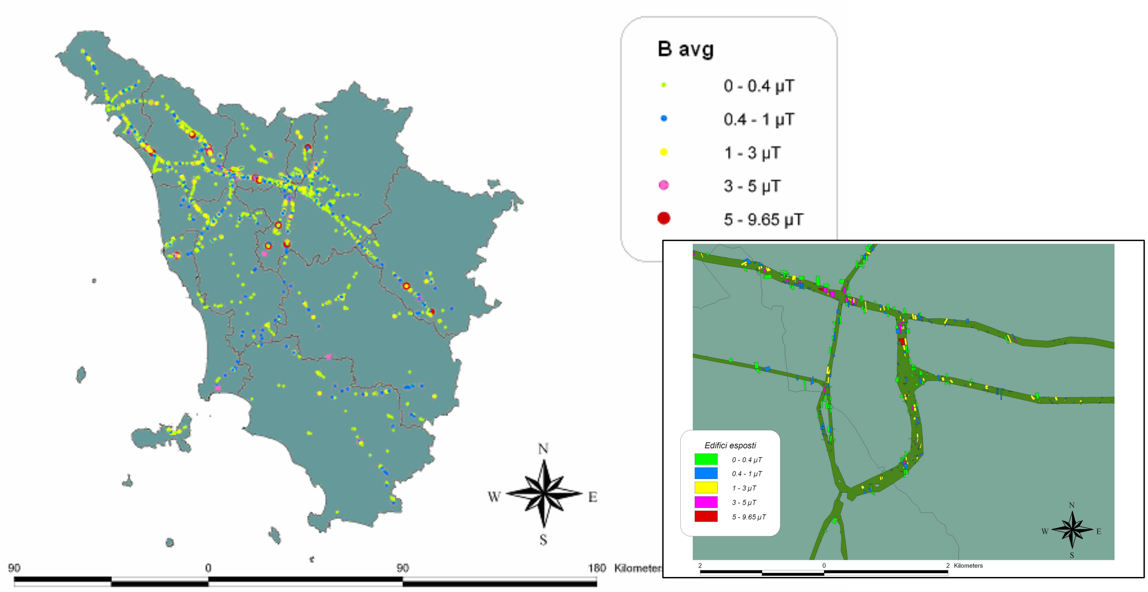


Figure 3 – Evaluated exposure in buildings inside the 0.4 μT 1st level bands.

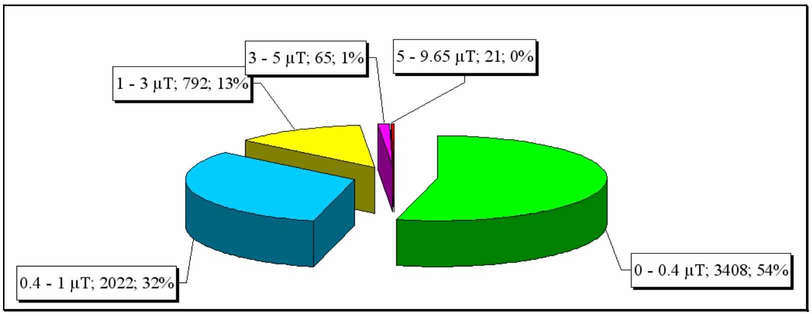


Figure 4 – Field values distribution of buildings inside the 0.4 μT 1st level bands.

Defining an impact indicator: a detailed evaluation for 314 line

A deeper analysis has been carried out for the 380 kV n. 314 power line, managed by TERNA S.p.A., which covers 89.3 km in Tuscany, touching Massa, Lucca and Pisa provinces.

The impact of the line on population, referring to the magnetic field exposure, has been quantitatively defined through a double-side analysis: theoretical evaluation of magnetic levels and their instrumental control, and check of technical data present in the archive, furnished by the power lines companies.

The theoretical evaluation makes use of GIS utilities available in ARPAT and developed to interface PLEIA system. Data used in these operations get information from CERT archive and from the Digital Terrain Model (DTM), provided by Tuscany Region.

For logistic reasons, controls cannot check out data of all the pylons stored in CERT, that's for, it's necessary to fill missing data from direct experience and verify as carefully as possible values referring to spans and buildings, where theoretical evaluations pointed out possible criticalities.

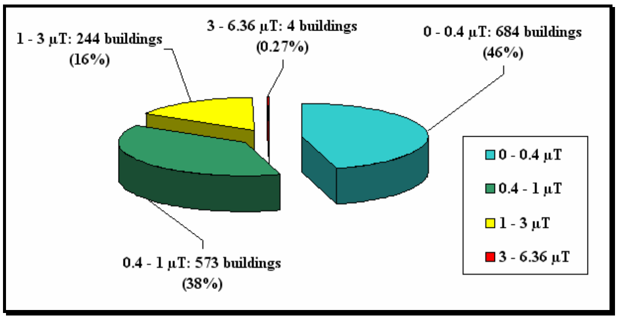


Figure 5 – Residential buildings mean exposure distribution (total: 1505 buildings).

In addition, to evidence the number of exposed people, validation with digital cartography has allowed to obtain an indicator to associate to each span. The procedure to determine this indicator associates the quantity given by the sum of the magnetic field values multiplied by the exposed people to the span:

$$Ind = \sum_i B_i N_i$$

where B_i is the calculated induction field and N_i the number of people inside the i-th building.

Data used to calculate the indicator are the historical current values (mean value, referring to previous year), and the 2001 Italian census data.

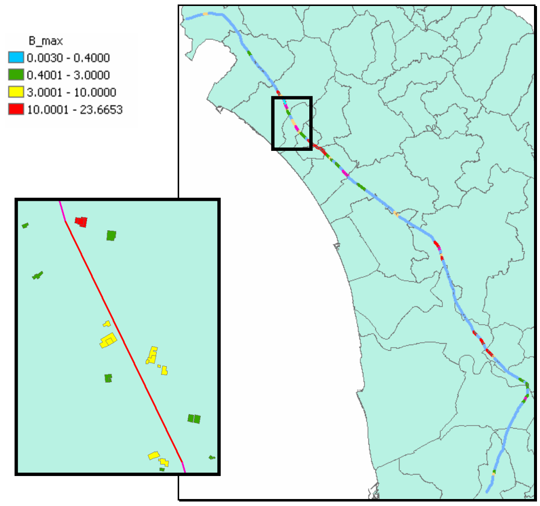


Figure 6 – Indicators and assignment of field value to each building.

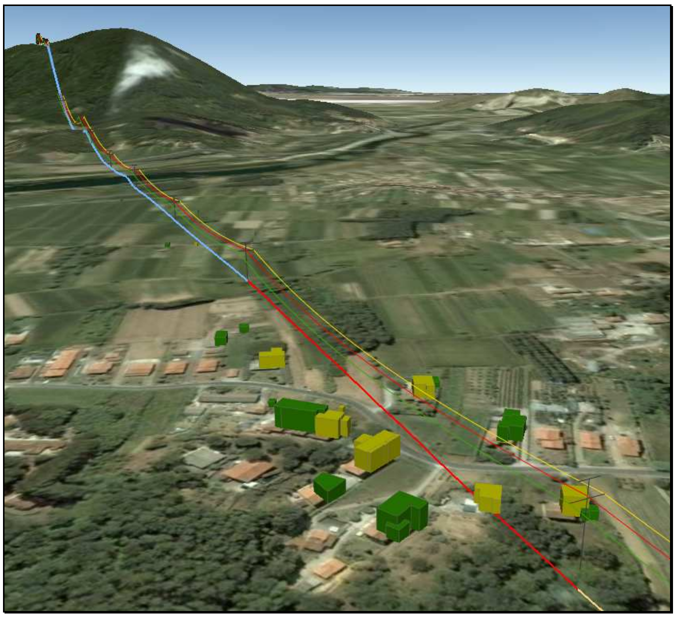


Figure 7 – Indicator visualization in GoogleEarth environment (bright blue and red lines, on the ground) for each span and field evaluation in the buildings (green and yellow solids).

In this way, the indicator is defined for each span (see Figure 6), and it allows to define the most critical tracts. An inspections campaign has started in correspondence to such spans to verify the data consistence with those owned by the Agency.

Isosurface calculation round about the considered power line

A further calculation modality supported by PLEIA allows to define the surface containing the volume round about an electric power line with field levels higher than those defined by the user.

The user is able, in this way, to control through suitable tools (like Google Earth or ESRI ArcScene) the possible intersection of such surface with the 3-dimensional building model, with no approximation as the calculation in the buildings centroids.

The following figures describe the volume calculation methodology just exposed: along the considered power line the evaluation sections (Figure 8, on the left) are automatically defined by the software, depending on the parameters defined by the user.

The vertical sections above illustrate how the points round the wires correspond to the wanted field value previously fixed by the user (Figure 8, on the right).

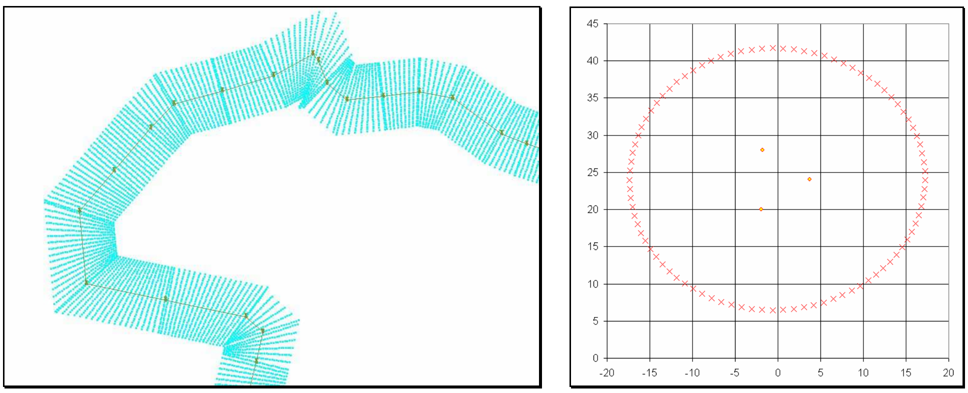


Figure 8 – Determining the field calculation sections for a particular power line (on the left) and the obtained points for a particular section (on the right).

The isofield surface is obtained by the union of subsequent sections points (see Figure 9).

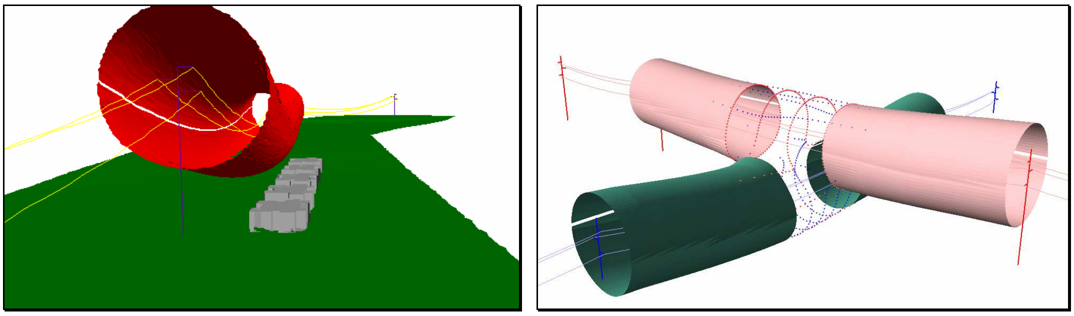


Figure 9 – Determining the isofield surface for a single power line (on the left) and in proximity of two lines crossing (on the right).

Such output can be exported as ESRI Shapefile and the viewed in ESRI ArcScene (see Figure 10).

Figure 10 – Visualization in ESRI ArcScene of isofield surface and comparison with the 3-dimensional building model.

A further step allows the conversion in *.kml format, importable in GoogleEarth, as already shown in Figure 7.

Data control from direct experience: validation of CERT archive information

Significant differences have been noticed when comparing the magnetic induction monitoring data with the 3-dimensional evaluations.

Magnetic induction levels inside those buildings closest to power lines depend above all on the distance of the probe from the wires, and on the pylon geometry. In each case, discrepancies between measured and calculated field levels have been studied, and the principal sources of mistakes in modelling have been individuated: distances between wires, (straddles dimensions), position of the line pylons and their altitude above sea-level, lower height suspension point of wires from ground level, catenary constant and minimum wires height from ground level.

To verify the reliability of power lines technical data and of regional digital cartography, several controls "in situ" have been planned and realized. The technicians have been able to determine with a better accuracy the coordinates of each pylon and the relative altitude above the sea level using a single-frequency GPS-palmtop equipped, on which the digital cartography of the interested zone was previously loaded.

A laser telemeter allowed to measure the distances between the pylons and the closest buildings, the heights of the suspension points of the wires (starting and final point of the catenary). To determine in an unequivocal way the correct position of the catenary in the space, the height from ground level of lowest wire has furthermore been determined, both nearby each house, and correspondingly to the point of minimum distance from ground. These values of height depending on temperature, during the inspections technicians had to record this quantity too.

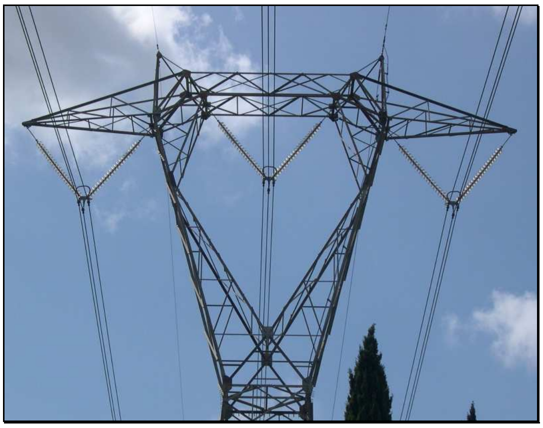


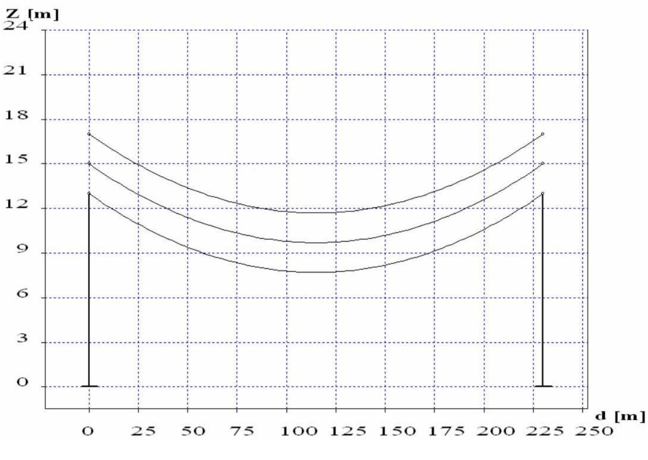
Figure 11 – Standard pylon head for a 380 kV power line (on the left) and for a 132 kV one (on the right)

Wires distances due to the pylon geometries are univocally determined for pylons heads build after 1978, and it is easy to find such data from power lines managers. All previous structures are not standard, and after many years the technical project is not always available.

All the 380 kV power lines follow this standard, while this is true for only the 15% of remaining lines.

Carried out controls have evidenced that distances between wires are accurate and reliable for standard structures.

The problem for homologous distances in non standard head pylons is still open, and ARPAT is dealing with more accurate systems to measure in field also the straddles length.



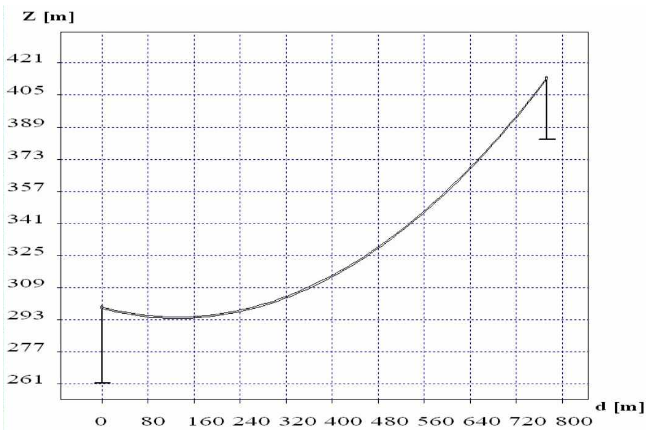


**Figure 12 – Example of span in plain for a 132 kV line (on the left)
and span in slope for a 380 kV line (on the right)**

The power line wires describe a catenary in the space (an arc of a hyperbolic cosine), which profile depends on the mechanical tension and on their linear weight. The catenary constant[2], given by the line owner and function of temperature, correctly describes this profile, but our control has pointed out that such parameter error reaches the 30% for non-standard lines, and is about 15% for more recent ones.

While a 10% error on the minimum wire height can be not meaningful far away from the wires, when the probe is very close to the power line it has repercussions on the magnetic induction levels, invalidating the final result. More complex cases, in which such value estimation is essential, provide a complex orography and spans with a consistent slope.

Conclusions

An integrated system for population exposure evaluation of ELF magnetic fields has been illustrated: it consists of a power lines and stations archive in Tuscany Region, and of a calculation software interfaced to it.

A validation procedure for data in the archive has been developed, using controls made in sample areas, close to high impact power lines. In fact, while the used model reliability is well known, the accuracy of data input is still not available. This refers both to the variety of pylons and the time range in which the lines were built, and the lack of a reliable and validated data base from the lines owners.

If on one side the controls show that the standard lines data are reliable, on the other side they are pointing out troubles due to data incompleteness and inconsistency.

Information obtained in control activities have then allowed a check of the archive data quality for various power lines typologies, and a more reliable estimation of population exposition, through the correction and refining the already present information.

The described system has demonstrated great potential being linked with innovative tools which make easier visualization of lines impact on territory, through suitable indicators that allows — through 3-dimensional visualization tool — to evidence possible critical areas, which can be appropriately dimensioned following the chosen reference value to evaluate the population exposure.

Summary

- Introduction: the archive development
- Population exposure
- Defining an impact indicator: a detailed evaluation for 314 line
- Isosurface calculation round about the considered power line
- Data control from direct experience: validation of CERT archive information
- Conclusions

Acknowledgments

Present work has been worked out with the economic support of Tuscany Region.
Thanks to Dr. Andreuccetti and Eng. Zoppetti from IFAC CNR for the continuous cooperation in the project development.
The measurement campaigns have been possible thanks to the support of Eng. Francesco Salomone and of Eng. Leonardo Martini.

References

[1]. Decreto del Presidente del Consiglio dei Ministri 8 luglio 2003, Fissazione dei limiti di esposizione, dei valori di attenzione e degli obiettivi di qualità per la protezione della popolazione dalle esposizioni ai campi elettrici e magnetici alla frequenza di rete (50 Hz) generati dagli elettrodotti. (GU n. 200 del 29-8-2003).

[2]. D. Andreuccetti e N. Zoppetti: "Campo magnetico disperso da elettrodotti ad alta tensione: una metodologia avanzata di valutazione basata su modelli 3D di linee elettriche e territorio", Atti del convegno "Dal monitoraggio degli agenti fisici sul territorio alla valutazione dell'esposizione ambientale", Torino, 29-31 ottobre 2003, pp. 17-20.

[3]. Comitato Elettrotecnico Italiano, "Guida ai metodi di calcolo dei campi elettrici e magnetici generati da linee elettriche", Norma CEI 211-4, ottobre 1996.

[4]. D. Andreuccetti, N. Colonna, R. Fossi, N. Zoppetti "Campo magnetico disperso da elettrodotti ad alta tensione: validazione di una metodologia avanzata di valutazione basata su modelli 3D di linee elettriche e territorio" Atti del Terzo Convegno Nazionale "Controllo ambientale degli agenti fisici: dal monitoraggio alle azioni di risanamento e bonifica" 7-9 Giugno 2006 Città Studi, Biella.

[2] Considered as the ratio between the mechanical tension and the linear weight of wire.