THE FINITE ELEMENTS METHOD APPLIED TO ELECTROMAGNETIC COMPATIBILITY STUDY

Guillermo BETOLAZA
PA Consulting Group – Argentina
guillermo.betolaza@paconsulting.com

Juan Santiago GALLINO
IAE, Universidad Austral – Argentina
SGallino@iae.edu.ar

ABSTRACT

The Electric Power development faces a new variable that must be considered: "The Ambient Environment". There is a critical relation between the ambient environment preservation and the sustainable development that must satisfy the current generation needs without jeopardizing the well being of the future ones.
Considering also a great explosion of the international sensitivity of ambient environment groups, the conclusion drawn is that the environmental aspect must be considered in all the areas of the electric activity, particularly in processes of legislation and management, to the extent that the growth in electric power is compatible with the ambient care and the social environment.
Over the past 15 years, given that society concern on electromagnetic contamination has intensified, the EMF is now being studied in depth. This has caused important advances in calculation methods that "work well" for simple configurations, but simulation models available usually do not include diverse environment conditions, making necessary the application of new simulation techniques for the analysis of this physical phenomenon, such as Finite Elements Method (FEM).
This paper shows the methodology, results and conclusions of the EMF study generated by 132kV and 500kV overhead transmission lines applying FEM, in order to determine EMF for different configurations of overhead transmission lines (delta, vertical coplanar, double circuit) with classic and compact design, vegetation environment, for an hypothetical load and voltage stadium, by solving the Maxwell Equations in terms of electric and magnetic field.

EMF AND THE AMBIENT ENVIRONMENT

The Electric Power development faces a new variable that must be considered: "The Ambient Environment". There is a critical relation between the ambient environment preservation and the sustainable development that must satisfy the current generation needs without jeopardizing the well being of the future ones.
The generation and utilization of electrical energy have associated a series of activities that due to its diversity, characteristics and relative importance it causes diverse environmental impacts that have origin in the obtaining, processing, transport, distribution and consumption of it.
Each new project associated with electric power will produce an inevitable modification to the ambient environment. In all the cases, this affectation must be minimized considering certain aspects in the study stage previous to the project development. We cannot forget the public concern caused by the high voltage (HV) and extra high voltage (EHV) systems installations especially those related to overhead transmission lines.

Environment issues to be considered

The main aspects to be considered in the project study stage can be classified in the following the four groups [1]:

- Terrain occupation
- Crown effect
- Low frequency (LF) EMF
- Gas production

The existing regulatory actions make emphasis on a progressive exposure reduction of people to EMF, so it tends to explore new ways so as to reduce the EMF around electric power systems, especially overhead (OH) transmission lines and Substations.
The OH transmission lines generate low frequency EMF that are function of the transport voltage and current, which values are shown in the next table as a reference [1]:

Transmission voltage [kV]	Electric field (under the line, 1m above ground) [kV/m]
115	1 a 1.5
230	2 a 2.5
345	3.5
500	6 a 8
765	8 a 12

Transmission voltage [kV]	Magnetic field (under the line, 1m above ground) [μT]
115	2 a 6.3
230	3.5 a 11.8
345	6.8
500	8 a 50
765	10 a 31

Power systems frequency is sufficiently small so that the electric and magnetic fields can be considered independent . Therefore, both fields can be calculated under the assumption that the static theory is applicable, and their values can be obtained from a potential.
Knowing the conductors geometry, the superficial distribution of the potential and the electrical currents, it is possible to calculate the electric and magnetic fields by the

application of the Maxwell equations.

EMF study methods

There are a variety of methods to calculate electric fields and current induced due to the LF EMF exposure.

The first mathematical models were used to calculate current and electric field induced in the body to simulate work environments and animal exposure in laboratory studies.

With the development of efficient computational algorithms and high speed computers, the application of numerical methods becomes more adequate to solve the Maxwell equation for the human body. The advantage of these methods resides in the simplicity to model complicated shapes, especially the human body, being able to assign different conductivities, in order to estimate currents and electric fields in small boxes [2].

A variety of numerical-computational methods are used in the bio-electromagnetic calculation. The numerical methods used with greater frequency to compute E and J induced by LF EMF are the following [2]:

- Finite Difference Method – Time Domain
- Finite Difference Method – Scalar Potential
- Finite Elements Method (FEM)

The fundament of the numerical methods to solve differentials equations is the discretization of continuous models and equations which have infinite degrees of freedom into discrete counterparts, in order to obtain a discrete problem represented by an algebraic equation system characterized by a finite number of variables that can be solved by a computer.

The classic method to solve partial differential equations is the finite differences method, where the discrete problem is obtained replacing the derivates by incremental quotients involving the variables values in certain points.

In the last decades the importance of this type of solutions has gradually increased, specially the Finite Element Method (FEM).

The FEM method applied to Electromagnetism

A first approach of electric and magnetic fields values can be made using simple computational programs based on the analytical method of the load images, assuming cylindrical conductors of infinite length and parallels to the ground that assume plane and good conductor as well.

If a deeper study of the fields should be necessary, considering other variables such as multiple conductors, asymmetric configuration, asymmetry in phases, multiple circuits, complex geometry, irregular ground, several types of ground with its respective conductivity, permittivity and permeability, obstacles presence (trees, mills, etc.) we must look for programs based on numerical calculation.

The advantage of the FEM method compared with that of the finite differences is that complex geometries, border conditions and variations or non-linear material properties can be managed with relative facility.

In all the cases mentioned above we could find unnecessarily artificial complications when using finite differences. In addition, the clear structure and the versatility of the FEM method, allows to build multipurpose calculation routines that can be applied to different physics problems solution, for example, the case of this study electromagnetism, by developing smaller adaptations. Finally, we can say that this method has a solid theoretical base that increases its calculation accuracy [3].

For the EMF calculation of this study the FEM model developed in the ISEP group of the FI-UBA was used, within the framework of the doctoral thesis of Fernando Ponta (ref [4]), that constitutes an effective technique for the implementation of the method.

CASE STUDIES

The study of LF EMF generated by OH transmission lines is very wide, being able to analyze the behavior of EMF for different configurations and variables. In this paper, simple well-known configurations, non-conventional configurations (compact structures) and effects of near vegetation were modeled.

Next, there are the hypothesis adopted, and results in terms of E and B fields distribution maps for these configurations:

- Single circuit 132kV delta config.
- Double circuit 132kV vertical config.
- Single circuit 500kV horizontal config.
- Single circuit 500kV horizontal w/ vegetation

Hypothesis Adopted

In all the cases studied, the hypotheses adopted were:

- The ground was assumed as leveled
- The EMF were calculated for a cross section of the transmission line in the middle of the vane (minimum distance to the ground)
- The conductor sag considered correspond to the state of maximum temperature
- The conductors were supposed punctual, regarding the diameter is despicable compare to the distances where the EMF were calculated (1m above the ground)
- The voltage used for 132kV and 500kV in both cases was 1.05 above nominal (138kV and 525kV)
- The current for the 132kV lines correspond to the thermal limit of the conductor Al/Ac 300/50 (I=600A; S=353.8mm2)
- In the case of 500kV I=500A was adopted per conductor of each phase
- The study enclosure was considered sufficiently distant to avoid E and B fields and to obtain accuracy fields curves.
- Ground, air and vegetation σ, μ y ε values were adopted [5]

Final Results

Once field distribution maps are obtained for each configuration modeled, we have made some comparisons between the different configurations, to determine the optimal arrangements, field reduction and variations due to element distortions and near vegetation.

In the next sections there is a selection of some configurations modeled.

Single Circuit 132kV Delta Configuration

This is a typical configuration for single circuit HV 132kV transmission lines in rural areas, where two phases are at one side and one in the other side of the pole, forming a delta.

Figure 1, shows the distribution of the E field in a transversal plane in the mid point of the vane where the distance to ground is minimum and figure 2 is the distribution of the magnitude of the field 1m above ground.

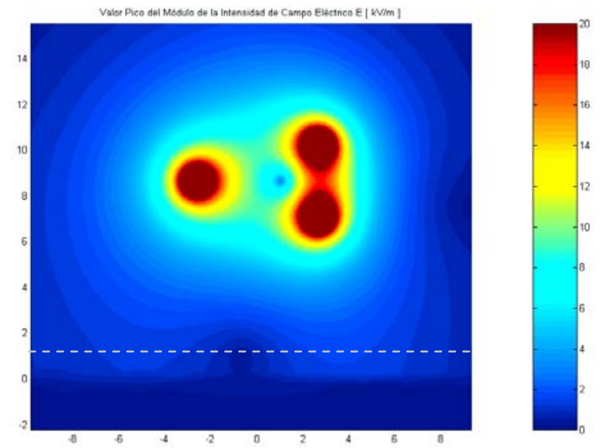

Figure 1. E field - HV 132kV delta classic

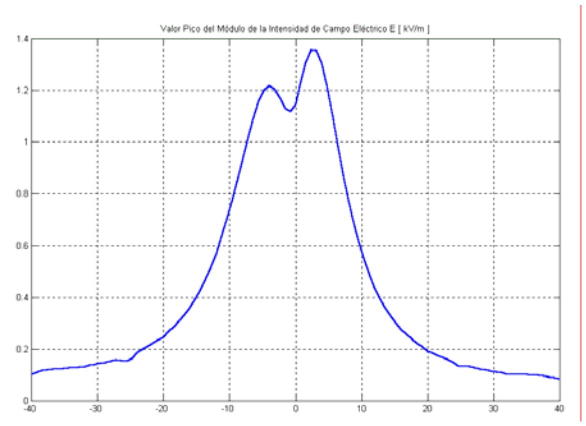

Figure 2. E field distribution 1m above ground - HV 132kV delta

Double Circuit 132kV Vertical Configuration

When more power is needed to transport, we have to think about multiple circuits or higher transmission voltages. For a given voltage level it is possible to arrange multi-circuits lines, so we can have 2 or more circuits in the same (or similar) pole.

In this case we studied a 132kV double circuit vertical configuration line, where the circuits are arranged at both sides of the pole.

This phase arrangement could be independent of each circuit, so we can have a symmetric arrangement (R, S T and R, S, T), or invert one regarding the other (R, S, T and T, S, R). This effect was studied and results are shown in this section.

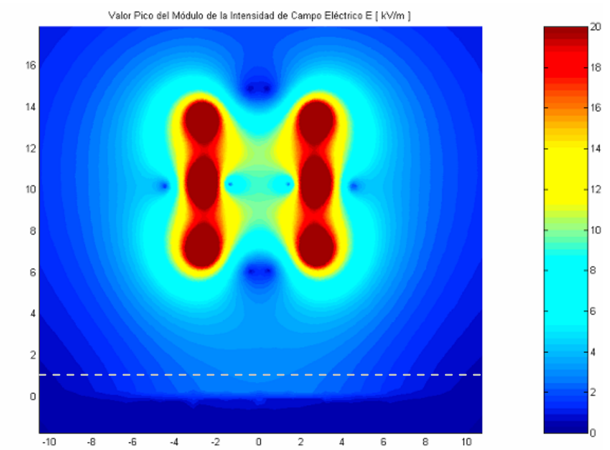

Figure 3. E field – HV 132kV Double circuit

Next figures 4 and 5 correspond to classic configurations; figures 6 and 7 to compact configuration and figures 8 and 9 to inverted phases configuration.

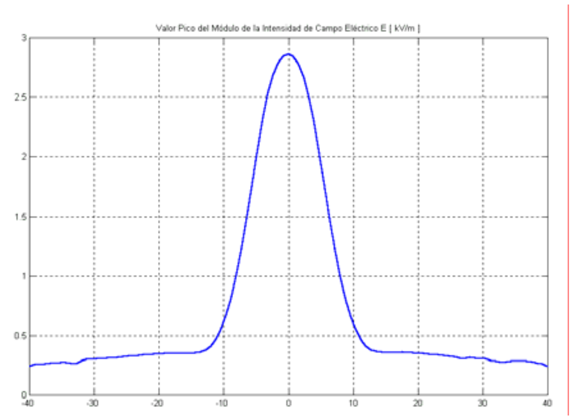

Figure 4. E field - HV 132kV double circuit classic configuration

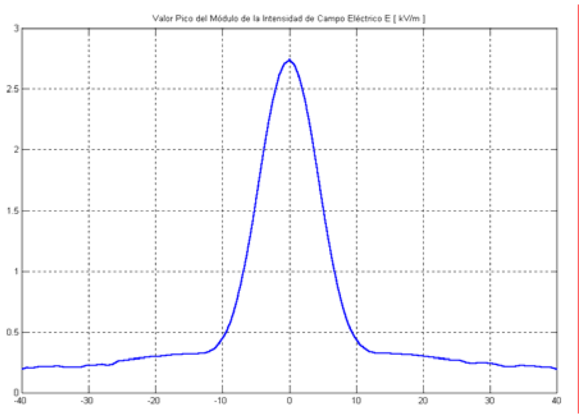

Figure 5. E field – HV 132kV double circuit compact configuration (line post)

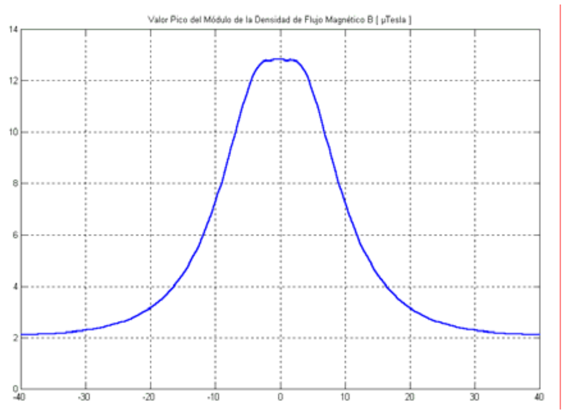

Figure 6. B filed – HV 132kV double circuit classic configuration

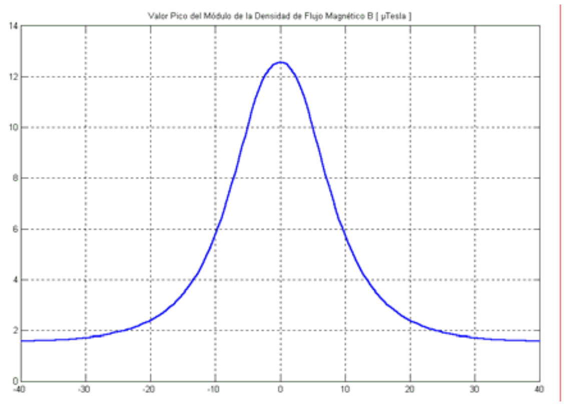

Figure 7. B field - HV 132kV double circuit compact configuration (line post)

Given that fields generated by circuits where three-phase alternating current circulate acquire the temporary phase difference of the current and tension that causes them; we analyze EMF generated by a double circuit transmission line. Inverting phases of one circuit regarding the other, the EMF produced may be annulled reducing their values in some points.

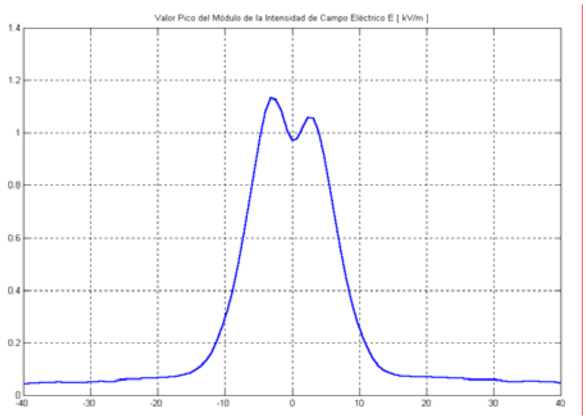

Figure 8. E field – HV 132kV double circuit compact configuration w/ phase inverted

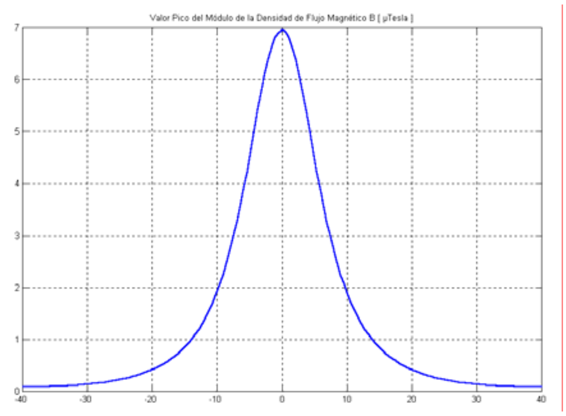

Figure 9. B field – HV 132kV double circuit compact configuration w/ phase inverted

Single Circuit 500kV Horizontal Configuration

There are different types of EHV 500kV transmission line structures, in general there are metallic reticulated, which can support one or more circuits (in some cases up to 4 circuits). Phases are multi-conductor and could be arranged horizontally, delta or vertically in most cases and depending on phase distance they could be classic or compact.
Figures 10, 11 12 and 13 correspond to E and B fields for the classic configurations.

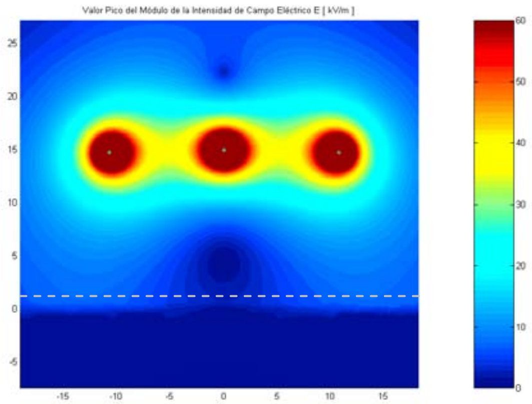

Figure 10. E field – EHV 500kV horizontal configuration

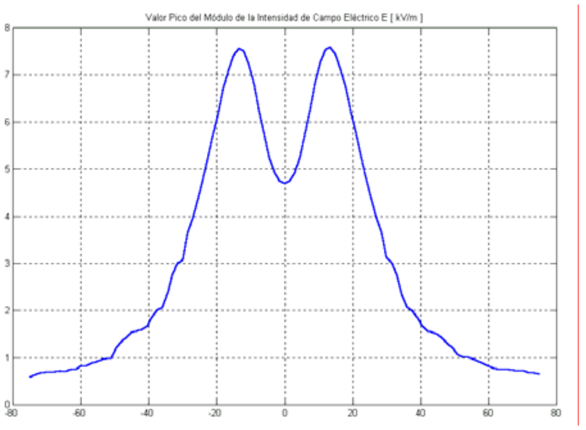

Figure 11. E field – EHV 500kV horizontal configuration

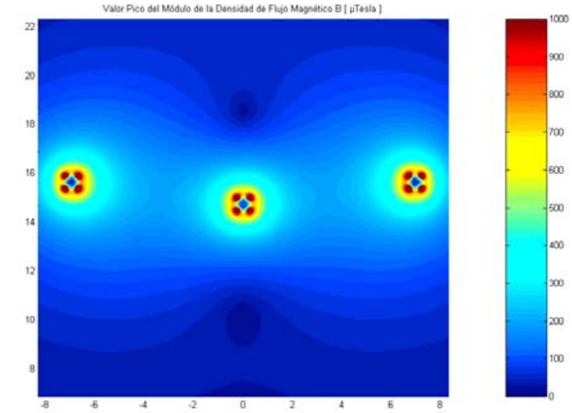

Figure 12. B field – EHV 500kV horizontal configuration

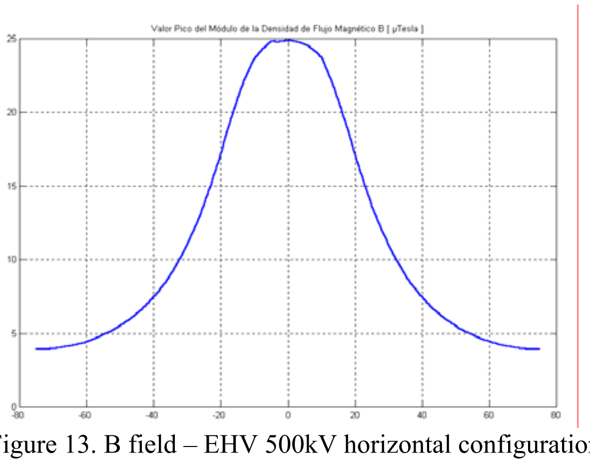

Figure 13. B field – EHV 500kV horizontal configuration

Single Circuit 500kV Horizontal Configuration with Near Vegetation

Last, we simulate tree interaction with EMF to identify distortions or filed deflections, so at one side of the line we put some trees considering allowed distances as shown figure 14.

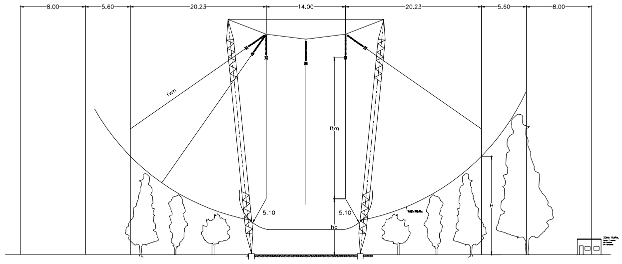

Figure 14. Allowed distance for EHV 500kV transmission lines

Next figures show E field for the mentioned configuration. B field is not presented because the dielectric parameters adopted for vegetation did not produce any distortion effect to EMF.

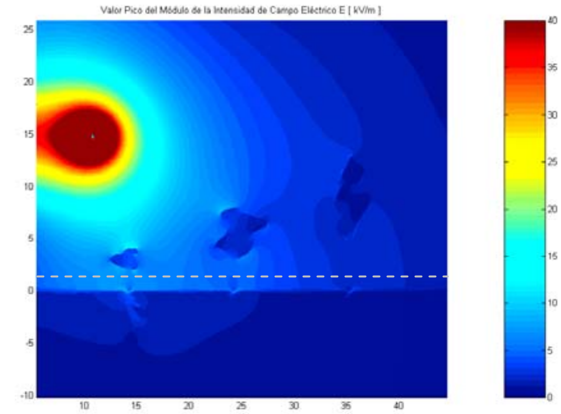

Figure 15. E field - EHV 500kV horizontal configuration w/vegetation

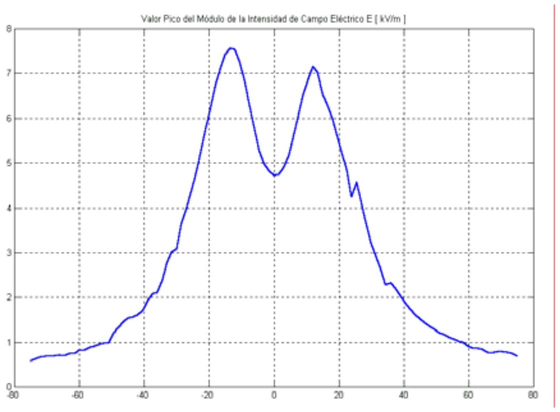

Figure 16. E field - EHV 500kV horizontal configuration w/vegetation

CONCLUSIONS

As a general conclusion from the study, it was possible to identify alternative solutions to obtain an EMF reduction generated by the overhead transmission lines, by modifying classic to compact configurations, by phase inversion in multi-circuits lines or by the action of distortion elements.

Other detailed conclusions are shown below:

- In all the cases studied, maximum field values are within metered values for those voltage and load levels.
- Although in this study an unfavorable situation was modeled regarding voltage and current (Umax and thermal limit), the EMF generated by transmission lines did not exceed regulatory values, for maximum and security border values.
- Regarding EMF reduction due to compact lines design, we concluded that for single circuit 132kV, E and B could be reduced by 10-20% with regard to classic configuration; in case of double circuit 132kV transmission lines the reduction is not much significant for the maximum values 2-4%, whereas in the security border we can have a 15% reduction. Last, in the case of single circuit 500kV analyzed reduction is very significant obtaining a 25% reduction for maximum and security border values.
- In the case of multiple circuits analyzed, results were very interesting when different circuit phases were inverted, achieving strong EMF reductions. Besides, if compact configurations were considered reduction was even better, obtaining a 60% reduction for E field and 45 % for B field, strongly attenuating at both sides, obtaining a 25% reduction in the security border, regarding classic configuration.
- Vegetation near transmission lines had different behaviors depending on the voltage and configuration. In the case of 132kV, Emax had no modification, whereas at the security border fields were attenuated by 37%. In the case of 500kV transmission lines Emax had a reduction of 5.3%, whereas at the security border it had no modification. In both cases B field had no modifications.

REFERENCES

[1] Riubrugent J., Arnera P., Vernieri J.; 1996, "Compatibilidad de Instalaciones Eléctricas con el Ambiente", *Seminario Protección del Ambiente en Electroductos; IITREE, Universidad Nacional de La Plata (UNLP).*

[2] Bailey W.; 1998, "Field Computation Models, Computation in Biological Systems", *S Bailey Research Associates, Inc.; New York, NY.*

[3] Ponta F. L., Ferreira F., Seminara J; 2001, "Variación de los perfiles de campo magnético en líneas de transmisión en diversas condiciones del entorno calculadas mediante el método de elementos finitos", *Proyecto e Investigación I-042 Facultad de Ingeniería, Universidad de Buenos Aires.*

[4] Ponta F. L.; 1999, "Análisis Fluido dinámico de una Hidroturbina de Eje Vertical", *Tesis Doctoral, Facultad de Ingeniería, Universidad de Buenos Aires.*

[5] Tora Galván J. L; 1997, "Transporte de la Energía Eléctrica", *Universidad Pontificia de Comillas de Madrid (ICAI-ICADE).*