11. Project description

The acceleration of the corrosion of the underground metallic pipelines (water-lines) due to the electromagnetic pollution of the soil (the totality of currents that go through the soil and who's current lines can cause perturbation in the electric double layer of the metallic water-lines/soil system) is the determinative factor in reducing mentenability and reliability of underground metallic structures, from which results that through it's control it can be assured a growing exploitation duration of metallic transport and distribution of natural gas, with all their social, ecological and economical implication.

In actual technical circumstances, in the transport and distribution systems of electrical energy arises a potential difference at the soil level between diverse geographical points and so implicit stray currents corresponding to a large frequency spectrum. In these conditions the electrical signal which arise at the metal-soil interface is very complex and is the resultant of all overlap stray currents which travel and close through soil (origin from both d.c. alimentation system and from the chain of production/transport/distribution/use of electrical energy), the dominant being the 50 Hz component, which practically is modulated with the other perturbing signals. This imposes a complete study of this electromagnetic pollution and the impact on the underground pipes.

Theoretical studies about the influence of an alternative sinusoidal current (undeformed) passing through the metal/soil interface were realized by J Davay (1964) and proved the fact that the kinetic parameters of electrochemical reactions are influenced by overlap sinusoidal linear signals. In practice, in special in the last decade there were registered numerous accelerate degradations of underground metallic gas pipes, because of the stray currents in a.c. These electrical signals that electromagnetically pollute the soil are very complex; their shape can be very different of a sinus (the invention of the high power thyristors in the electrical drive contributed to the substantial growing of nonlinearity of stray currents produced by the electrical networks).

The biggest percentage of the cases of accelerate corrosion produced by stray currents in a.c. represents those caused by the distribution and transport network of electrical energy. The perturbing signals in a.c. of the corrosion reactions which appear at the metal/soil interface that comes from transport and distribution networks of electrical energy, through inductive coupling electrical line – underground pipes (underground metallic pipes which is posed in the nearby of the electrical aerial lines) and also due to the defect currents which travel through the counter poises afferents of the distribution system of the electrical energy (for example the imbalance which goes between the counter poises of the high/medium voltage station and of the medium/low voltage transformer). In the majority of situations, the a.c. signals overlapping the metal/soil system grow the speed of corrosion of the metal, even if there was assured a cathodical protection, imposes to take supplementary measures (if we don't have cathodical protection, because of the stray currents, we assist, in short time at the damage of the pipe).

It is very important to knowing of the next 2 elements: the pick value of the amplitude of the perturbing signal and the effective value of the perturbing signal. These values can be measured when the corrosion state is analyzed for a pipe in exploitation and the acceleration factors of corrosion (oscilloscope with direct memory between the pipe and the measure check rod placed in the nearby).

The potential that appears at the interface metallic pipe/soil which delivers information about the corrosion speed of the metal and the integrity of the isolation layer.

To realize the protection of the metallic pipes against corrosion in a.c. without a cathodical protection system, they are connected to earth electrodes. This solution is relative cheap, efficient and sufficient only in the case of the a.c. signals of low amplitude (alternative voltage pipe/soil lower then 0.2 of the top voltage; it also appears the conductive coupling pipe – earth electrode). For the signals with higher amplitudes, they are still searching for solutions. In the case of the metallic pipes with cathodical protection, the binding of the pipe to a earth electrode is not possible because it would short-circuit the protection current, so in this case the corrosion control is assured by the implementation of DP type appliance which does not disturb in no way the functionality of the existent cathodic protection.

In the conditions of technological development it is wanted the assuring, on long term, of some clean and sure conditions of work and life, in fact the assuring of the reliability and safety in exploitation of the transport line and the distribution networks. The study of electromagnetic interference between the aerial electrical lines and the underground metallic pipes with a common path, and in the particular study of interference between counter poises of the stations and networks of complex adjacent metallic pipes, together with the study of the control degradation of these pipe networks from the soil makes a problematic of special theoretical complexity and very high practical importance.

The solution of the electrochemistry problem requires experimental techniques and theoretical specific to the study of electrode process, in which time the solution of the electro kinetic problem which appears is a physical-mathematical problem of the electromagnetic field in stationary harmonic conditions.

For the case of electrical protection for the underground pipeline grids, the solution of the electro-kinetics problem is of very high importance. The soil along with the burried grids can be regarded as masive conductor of infinite extension, on which the voltage drops longways the pipes are significant.

So as to assure a correct protection to the corosion, it is essential that each of the potential points in the grid to be subscribed in those limits which do not endanger the metal and the electrolysable characteristics of the solution; that is to be fulfilled the thermodinamical stability of the equilibrium metal – solution. This means the exact knowing of the electrical potential distribution in respect with the soil conductivity and exterior power sources.

Analytical and numerical modelling of the real situation (inductive coupling – conductive coupling – real time) represents the only viable and efficient method to predict the risc areas, on which dangerous electrical potentials may arise. Afterwards, the proposal of rigouros methods to remove the negative effects are requested. The analytical and numerical models have to offer reference values for specific measurements in the operational points of a pipeline grid, values that can be extremly useful for the normal exploitation of the pipelines.

From these points of view, the developement of specific analysis methods, modelling instruments and collecting information about the electromagnetic interference, represents an important issue so as to solve the corosion problem. Developing and implementing these methods, instruments and information should enssure the integrity of the underground pipelines grid, with an immediate effect in the safety of the operating personel and the environment protection.

It is well known the fact that the metalic structures (gaz and water transportation and distribution pipelines), and telecomunication cables can be in a close vicinity to each other and to electric power substations. Because of this vicinity to the grounding grids of the power substations one have to take account of the electromagnetic interferences. It is a typical electromagnetic compatibility problem.

In the research context, to model and simulate the electromagnetic interference phenomenons constitutes an up to date problem, regarding both the real implications and the annealing to the european and global standards. The process of modelling in the electromagnetic compatibility requires the establishment of a relation between a cause (an electromagnetic interference source – EMI) and its effect (the response of a circuit as a part of a high complexity plant). The large variety of EMC problems results also from the multitude of the EMI sources presently identified.

In a particular case, for a single phase fault in a electrical line close to a power station, some overvoltages and overcurrents arise with a direct effect on the metalic underground structures up to several hundered kilometers along these structures. In certain areas, the electrical potential due to the induced currents may produce, throughout a process called electrolyze, the corosion of the pipes with rapidly growing and destructive effects, because of the high density induced currents. Uncontroled corosion of metalic pipes can generate, as an example, oil or gas leakages, with serious environmental and economical consequences.

Researches of this domain reveal a series of algorithms to solve coupling problems, but they are restrictive and do not take account of the geometry complexity of the pipeline grids. These algorithms are based on a series of aproximations that rise the particularity of the problems. A separate study of the inductive coupling and of the conductive one without considering the influence of the pipelines grid on the metalic structure of the power station (grounding structure) often leads to important errors.

The traditional approach in the electromagnetic field analysis around infinitly long conductors of cilinder shape situated in the vicinity disipative hemispace (the ground) was published for the first time in a simplified way at the begining of the last century. With all these, the first analytical methods that were elaborated and world wide spreaded were independently developed in the 20’ by Carson and Pollaczeck. From that point a series of improvements of the basic formulation appeared, by taking account of some presumptions and restrictions in the problem modelization. Here can be mentioned the works of Sunde, Wait, Kuester, Olsen, Fraiser, Dawalibi and Luca.

Transversal and longitudinal currents, underground potentials and the surounding magnetic field ar all influenced by the frequency, by the current injection points and by the configuration of the underground pipelines grid.

The analytical expressions to the solutions of the electromagnetic field problems, regarding the cilindrical conductors in the soil, that are feeded with current, may develope in a complex problem even in the case of a simple geometry of the grid.

There are certain dificulties in respect with the underground pipelines:

- The conductors may be long or short, but they cannot be infinitly long or short;
- The conductors are generaly isolated (which cancels the presumption of an exponential propagation in the conductors) and they are in a direct contact with the soil, so longitudinal and transversal currents have to be considered;
- There are conductors with a hemi isolated cover.

The most important results regarding the conducting grids are realted to the study of the near generated electromagnetic field. Most of the cases, the problem is posed when in the grid appear low frequency currents. Difficulties may arouse when a transient regime occures, or high frequency currents are induced. The analysis consists in solving Maxwells equations in the tridimensional space; the upper hemi space is the air, and the lower hemi space, modelled as infinitly extended is the soil. The distribution of the longitudinal and transversal currents along the burried conductors can be determined by their segmentation.

In the majority of the practical cases, the conductors of the very high voltages lines are included in the category of long electrical conductors, meanwhile the underground conductors belongs to the category of short conductors. This clasification depends on the type of the problem and of the geometry. In the present study we consider a common range of long and short conductors.

In 1995, as part of CIGRE Working Group 36.02, the document named *Guide Concerning Influence of High Voltage AC Power Systems on Metallic Pipelines* was elaborated. This document approaches the influence of the high voltage power devices over the metallic pipelines situated in their neighbourhood. This study represents a reference document in this field and it describes the simple evaluation methods of the electromagnetic interference phenomena and the method for measuring them.

In the world, there are a few software packages, available on the market, for simulating the electromagnetic interference phenomena in quasi-stationary regime, harmonic type, between the high voltage transmission lines and the underground metallic pipelines, based on the method described above. From the most known software packages of this type, are:

- ECCAPP developed by Electric Power Research Institute and American Gas Association (EPRI/AGA);
- CDEGS developed by Safe Engineering Services (SES);
- CAT.Pro developed by Vrije University of Brussels in co-operation with the firm Elsyca.

In fault conditions, the analysis of the conductive and inductive coupling, which is a recent problem, is not completely studied yet, first of all because of the great number of parameters that interferes in physical processes. The most important contributions on this subject derive from Sunde (analytical study), Favez and Pohl (experimental study) papers.

A common research that analysis both the inductive and conductive coupling, is realized by SES (Safe Engineering Services) and AGA (American Gas Association). The analysis of the conductive effects is experimental; Farid Dawalibi has introduced a generalized theory, which studied the conductive coupling between the high voltage installation systems and the underground metallic structures. The mechanisms of the inductive coupling, line-underground pipeline, are studied by Olsen for many practical cases.

A group of researchers from the VUB University of Brussels, in co-operation with the firm Elsyca from Brussels, have developed a three-dimensional computation model in D.C. quasi-stationary regime. The model can analyze structures composed by wide networks of underground pipelines; can evaluate inclusively the stray currents derived from the others systems of cathodic protection or from the railway respectively.

CatPro programme is very flexible and allows the evaluation of a great number of electric parameters (e.g.: the value of the electric potential in the ground at different depths) for random geometrical configurations.

Within the Romanian-Flemish bilateral agreement research between the Electrotechnics Department of the Technical University of Cluj-Napoca and ETEC Department of VRIJE University Brussels, BILA 2001: *Development of methods and tools for analysis of the electromagnetic AC interference between high voltage transmission systems and metallic pipelines*, an accurate solution for the field problem was determined and a new fundamental solution was implemented using the method of boundary conditions. Through this step, the computation time was considerably reduced by eliminating the discretization of the interface between the two half-spaces and the accuracy for the numerical solution increased.

RIGHT-OF-WAY is software created by SES for the analysis of electromagnetic interferences between the high voltage lines and adjacent technological installations, as underground pipelines. This software was specially created to simplify the numerical modelling of the complex configurations of the common paths between the line and the pipeline. The programme can automatically simulate the faults on the transmission line at the regular intervals in the common area, line-pipeline. Using this software one can calculate the induced longitudinal currents in a pipeline, the injected currents in the ground, the potentials between different points, etc.

Right-of-Way software contains TRALIN (Transmission Line Parameters) and SPLITS (Simulation of Power Lines, Interconnections and Terminal Stations) modules. The programme can generate the victim structures (the underground pipelines system) and using ROWPlot module the potential curves, the longitudinal current from the pipeline and the currents injected in the ground are realized. The MALT programme includes six input elements:

- configuration of the earth network;
- ground modelling where the network pipelines and safety earth terminals are placed;
- injected currents in pipelines or in the network connected to the earth;
- characteristics of the underground pipelines;
- frequency of the excitation current;
- location, where one wants to determine the potentials at the ground and to calculate the magnetic field in the air.

MALT programme can calculate the following quantities:

- Longitudinal currents that flow through the pipeline;
- Potential increasing in every pipeline segment;
- Potential values at every point in the ground;
- Induced currents densities in the ground;
- Intensity of the magnetic field in every point from the air.

HIFREQ Programme calculates the current distributions in the underground pipeline networks or above the ground and based in these distributions it calculates the electric, magnetic fields and the potentials in the ground and air for different observation points. It can works at the frequencies that vary from 0 to tens MHz. HIFREQ can perform these calculi for the underground pipelines in infinite medium, in uniform or slaty ground.

After the currents in the conducting network were calculated, using special modules of this programme one can calculate:

- Electric and magnetic field (Ex, Ey, Ez); (Hx, Hy, Hz);
- Scalar electric potential (V) and the vector magnetic potential (Ax, Ay, Az);
- Drop voltage along a path defined by the user.

MALT programme is used for analysis of the safety earth terminals network of the HVAC stations. The programme allows the analysis of the underground networks in the presence of some electrodes or in the case of a fault near or in the area of the station; twisting the potential profile at the ground.

In this project we want to develop a numerical precise algorithm for calculation the induced voltages and currents in a metallic underground pipeline complex network, which are in close proximity of a high voltage substation. The analysis of this problem are made at 50 Hz frequency in monoplane fault condition on the line which enters the substation, taking into account the existence of inductive coupling (produced by the current which passes the electric line) and direct coupling (produced by the fault current injected in soil which passes through the earth electrodes).

The algorithm is divided in the following steps:

-inductor field calculation;

-longitudinal electromotive force and transverse current calculation which represents the electromagnetic influence produced by the source (electrical line) on the victim (metallic pipeline network);
-development of metallic pipeline network and earth electrode models using equivalent electric circuits;
-calculation of induced voltages and currents in the metallic pipeline network;
In the project we will made the assumption: harmonic cvasistationary state, which is generally valid at industrial frequency (50 Hz), this allows us to separately calculate in a first step of the inductor electric field represented by:
- electric field inductive component produced by the fault currents which passes through the faulted phase (this component is responsible of the inductive coupling between electrical line and metallic pipelines network);
- soil potential produced by the *fault current at earth* injected in soil through the counterpoise (this potential is responsible of the direct coupling with metallic pipelines network).
Is important to remark, that the term *fault current at earth*, represents only that part of the fault current which returns through the soil, depending on the earth electrodes system.
In the electric field inductive component calculation, appears some mathematical difficult problems about the Carson integral calculations (Sommerfeld semi-infinite integrals). Certain analytical form for the integrals is deduced in the thesis of Dan Doru MICU (member in this research team), but not completely so in this project we continue with:

- Proposing some analytic and numeric evaluation more precise and more simple of the Carson integral (used for the calculation of proper and mutual impedances of conductors with earth return) using series developments and analyzing this integral by parameter function
- The necessity of additional terms (soil presence) which not appear in literature formulas

The complete solver of interference problem between line and pipeline, carry on by determining an analytical solution for the induced current density and power looses in soil, using Carson configuration and will be elaborated a differential numerical model for calculation the induced voltage in an underground pipeline which runs in close proximity of a substation and is in direct coupling with the counterpoise.
We want to develop a mathematical complete model for calculation, in normal and fault condition, the electromotive forces, the voltages between pipeline and remote earth and the currents which passing through the pipeline because of the induced electromotive longitudinal force and the distribution of induced currents for an existing case (the fault current passes the counterpoise and becomes an inductor element for the pipeline which are in close proximity).
We want to develop a real model of the inductive coupling line-pipeline and earth electrode – nearby pipeline in which will be considered the underground pipeline like an losses electrical line, with a distributed voltage source which appears because of electromagnetic coupling. It will be treated several special cases of the general analysis for induced currents and voltage calculation, pointing out the special characteristics of the inductive and direct couplings. In the above mentioned thesis was taking into account only the inductive coupling, considering the counterpoise far from the metallic pipeline.
It will be managed a verification of the metallic underground pipeline isolation quality (the pipeline has the same right of way with the electric overhead line), using a mobile station of cathode protection (from Transgaz S.A. Medias) and will be compared the measured data (for a real case: underground pipeline in close proximity of a high voltage substation and direct connected to the

earth electrodes of the substation) with the calculated data based on the real mathematical created model.

In comparison with the classical methods we estimate some improvement by:

- Developing a generalized model for estimating with a good precision the effects of the inductive and direct couplings in real time, in harmonic steady state on any pipeline underground network situated in close proximity of a substation in which appears a monophase fault on a line which enters in the substation; the complex pipeline network are direct connected to the earth electrode network of the substation. These mathematical equivalent models for inductive and direct coupling simulation, could be establish the risk points and enter the electromagnetic cathode protection devices. It will be ensure the pipeline network integrity, and this brings to the safety of the working personal and the environment protection.
- The tackle the induced potential in a underground pipeline problem, by a specific synthesis method, which entail an inverse formulation of field problem, in sense of considering a domain, first of all plain and after spatial, with boundary conditions partially known (from current sources from the overhead line and field or potential measurements) It will be made the identification of the magnetic vector potential induced in the inaccessible underground pipeline. The applied numerical method takes an original context: the potential synthesis by Monte Carlo method, this aspect is not well studied in the literature in which only the analysis problems are treated with this method.
- In the oldest procedures, after burying the ditch in which are installed the pipelines, the verification of the electrical resistance isolation was made by empirical testing, along the pipeline being installed electrodes for pipeline-soil potential determination at specific distances (Standard 7335/8-85) at the cathode current injection source. With the help of Pipeline Diagnosis Laboratory from Transgaz S.A. Medias, it will be managed a verification of the metallic underground gas pipeline isolation quality (the pipeline has the same right of way with the electric overhead line) measuring the induced potentials pipeline-earth and after that based on the determined mathematical model it will be compared the measured data (underground pipeline in close proximity of a high voltage substation and direct connected to the earth electrodes of the substation) with the calculated data based on the real mathematical created model.

- Determination with precision, based on real models of equivalent circuits, the induced potential in pipeline, local potentials between pipeline and earth, step voltages; potential distribution in any point in soil and on the soil surface; conduction currents along the pipelines; current densities at the separation surface metallic pipeline – soil.
- The theoretical results obtained based on the created mathematical model will be compared with experimental results using a scale reduced at real models. We want to create a software (cheap, precise, user friendly) based on the algorithms and mathematical models which will be determined, to allow the pipeline network analysis in presence of earth electrodes or in the case of a fault close or in the substation perimeter, changing the soil potential profile.
- To achieve the protection against a.c. corrosion of the metallic pipelines, which not have a cathode protection system, the pipelines are connected to the earth electrodes (equipotentials pipeline-soil). This is a relatively cheap solution, efficient and sufficient

only in case of a.c. signals with low amplitude (alternative voltages pipeline-soil < 0.2 multiplied by peak voltage; appears the direct coupling pipeline-earth electrode) so, for signals with biggest amplitude it will propose solutions.

In literature exists a lot of algorithms for solving coupling problems, but they are restrictive considering only simple pipeline networks. In this project it will be studied complex geometry of pipeline networks and will be studied the general character of the coupling problems, without the assumptions used in the literature, increasing the generality of the problems.

Precise problems that need to be solved during this project:

1. It's very important that starting from the level of designing a new equipment (that creates perturbations or is the victim of existing perturbations) we can estimate the voltages and currents that may be induced in the victim structure, so that a correct sizing of protection can be achieved. This would also allow a more convenient geometrical positioning of the designed structures. Therefore, we aim toward finding and implementing some **numerical computation and estimation algorithms** of these quantities, simulated as some structures of **equivalent circuits.**

2. Using the subdivision of the complex pipes-structure existing in the soil into pipe elements, in order to reduce the computation effort, the numerical model created will be inserted into an **optimization modulus.**

3. These so called pipe-elements are modeled into a cylindrical structure, but they could be extended tom ore general geometries. The form of the function representing the solution for a pipe element is assumed to be axial-symmetric in the existing literature. This implies that the variation of the solution is assumed to be linear along each pipe element. For electric potential problems, it implies that the induced current density and the potential between a point on the pipe and the soil only varies on axial direction and not radial. More precisely, a **linear axial variation** is used, therefore in a plane perpendicular on the axis of a pine element the potential and current density are constant. All these approximations and these supposition, used also by dr. Micu in his PhD thesis, may sometimes fail for some cases. In this project, we will perform a **clear estimation of the error** due to these approximations for real situations of pipes with polyetilen or bitumen cover, and of course for pipes with different diameters. In this purpose, some analytical computation and numerical simulations – as well as measurements – will be performed for real practical situations.

4. An other problem to be studied is the influence of the soil surface (the influence of the depth of the pipe – to be more precise) has on the distribution of the current density induced – also depending on the resistivity of the pipe coating.

5. An other objective is the **numerical computation of the solution's non-uniformity** due to the proximity of earth electrodes from the earthing equipment or other pipes in the soil, used to carry fluids. For the computation of the non-uniformity we use some particular numerical evaluation techniques (generalized Newton Raphson, modified Newton, conjugated gradient) and an **original iterative solving algorithm** that will take into account the **bad conditioning** character of the equations system created by the mathematical model. This inconvenient wasn't considered in the existing literature, all authors using this system using the iterative solver **GMRES** (Generalized Minimal Residual Algorithm). In fact, the quality of this solver mostly depends on the **conditioning number of the system** and it's been proven that solving problems with this solver fails when the system is badly conditioned (case that appears when a failure current enters the earthing equipment becoming that way the inductive structure for fluid carrying pipes placed nearby).

6. The interferences computations mainly consist of computing **the inductive and conductive**

interferences performed separately and then combined to yield the final result. These two types of interferences are linear, meaning that if the two longitudinal currents due to both types of interferences are known, they can be added by superposition. Considering the coupling between inductive and conductive interferences, the final values are not precise; therefore **the superposition of independently computed values represents an approximation.** On the other hand, since the values of the induced currents in the pipes due to conductive coupling (if the pipe is galvanically connected to the earthing equipment) are at least ten times lower than those due to inductive interference, one can assume that the errors due to superposition are small for practical applications. But a **clear mathematical proof** of this subject, including the **estimation of all errors** due to this approximation is required!

7. We will try to eliminate these approximations by implementing an **iterative algorithm** that alternates every moment inductive and conductive computations. The currents are determined based on the results of the previous iteration.

8. The inductive interferences computations are performed based on a **hybrid model: field theory-circuit theory**; the circuit theory can be used to obtain the **electrical potentials** at each end of segments, as well as the **longitudinal and transverse currents** on each conductor segment.

The **ECCAPP** software produced by **AGA** performs an analysis of conductive and inductive coupling using a hybrid theory field+ circuit. This consists of analyzing one or more earthing systems (**earthing electrodes**), their effects on buried pipes and **the electrical potential resulting inside the soil and on its surface.**

The first step in the computation algorithm used by ECCAPP consists on using the field theory (the theory of the short conductor) in order to find the normalized values of **the self and mutual impedances** of all the conductors belonging to the earthing system, including **the specific cathodic protection** for the pipes. Then, the circuits' theory is used to find the **voltage drop** on every conductor, due to **longitudinal currents** circulating inside it. In this research project every buried conductor is divided in short (compared to the wave length of the signal transmitted and the total length of the earthing system) segments. This way we can create a model of an equivalent circuit, comprising the internal and external impedances of the segments. Therefore, **the earthing system and the neighboring buried pipes are analyzed as a network of short conductors.**

9. We will continued with the analytical development of the low frequency electromagnetic fields generated by a conductor which is crossed by a current and it is buried in a boundless environment, respectively in a uniform soil.

It will assume that all the points situated on the surface of the earthing conductor have the same potential, so the conductor is perfect. This approximation is valid only for low frequency and short length conductors.

In case of no cover conductors in a conducting environment, however exist a crosswise current along the conductor surface, therefore longitudinal current can't be assume as constant and it has a complex expression because it depends by the conductor positions.

This function satisfies an integral equation which in the most cases has a precisely solution. Using the iterative approximation method it will be desirable to determine a numerical solution for the current distribution along the conductor.

10. If the conductor is divided in short length segments, to determine the current distribution real function it is possible to try using an easier computational method, based on the finite element method. This approach has not result in the specialty literature.

11. The typical buried conductor system consists in no cover cylindrical conductors, connected between them, usually in more points.

The horizontal conductors and the superior ends of the vertical and oblique conductors are buried at least one meter under soil. One or more buried conductors are connected with special conductors. Trough these conductors the fault currents penetrate in the earthing network and may be temporarily or permanently used for some test currents circulation trough the earthing network. In proximity of this network could exist buried conductors too, as example the technological pipelines.

12. It wishes to determine the behavior of the earthing conductors network and the behavior of the conductors that are buried in his neighborhood when the network is energized by the known injected currents. The aim of this analyze is to determine:

- the potential of every node;
- the longitudinal and transversal currents in every conductor segment;
- the scalar potential of every observation point in soil;
- the electromagnetic field of every points in soil.

13. If the distributions function of the longitudinal current it is assumed to be constant the m that will be obtained represents a linear equation set which could be easily solved and supply as resu currents unknown values. If the longitudinal current is not represented by a constant function b function then the mathematical model will generate a system with 2*n* unknowns represented by the coefficient. In this case, it is necessarily a 2n equation to define the singularity of this problem. The will depend by the *n* number of conductors network segments and by the polynomial function rank the longitudinal current distribution inside the conducting segment. This method involves the complex analytical expressions and in the same time introduces computational difficulty.