TECHNICAL UNIVERSITY OF CLUJ-NAPOCA ROMANIA

HABILITATION THESIS

Development of advanced analysis methods and numerical modeling dedicated tools applied in electrical engineering

Assoc. Prof. Dan Doru MICU, PhD
Electrical Engineering Faculty
Technical University of Cluj-Napoca

20.05.2014

TABLE OF CONTENTS

A. Context approach for the habilitation thesis

In the present evolving society, any professional sector needs motivated and very competent employees. To be an university professor represents one of the most complex and challenge professions, which is under constant pressure, generated by the dynamic society changes. To be a university professor means an assumed risk; this is because preparing to teach, to research, to write scientifically papers, to teach others how to learn is a continuous and never ending work, which involves more patience, more passion, moments of uncertainty, discouragement and many hours of study, and the results cannot be measured quantitatively nor immediately. Nevertheless, at the end of this road you can expect much happiness and satisfaction, because you managed to arouse the curiosity of the students in your field of competence, to transmit to them the necessary knowledge and to open the new horizons for research.

Forming a competent university professor is a complex and lengthy process, due to the specific skills and abilities that need to be developed, based on the accumulation of a large quantity and variety of information.

For a successful academic career, the teaching activities have to harmoniously combine with research activities, so that there is a continuous flow of knowledge and information to and from the industrial environment, in order to assure a technological transfer and a subsequent update of the educational programs, respectively.

The teaching and research activities are completed and supported by management and mentoring activities. As a project manager, the professor must be able to perform an active monitoring of the project during the development of each phase / activity, and also of the results processing at the end of the project. Coordination of research team members assumes the definition, control and approval of some procedures for execution of project implementation actions and in addition, activities young researchers mentoring. All the projects' activities must be carried on in accordance with a *clearly defined strategy* of the research team within *an accredited research structure* (research laboratory, research Center): *a small number of people with complementary skills, dedicated to a common purpose, performance goals, and some modalities to work together, for which is considered equally responsible*. In this context, the three steps of the research team development must be followed: *members' inclusion* – sense of belonging; *individual assertion* – capacities expression independent of others; *constructive cooperation* - oriented efforts to satisfy common objectives, which can be achieved, some individually, and others only as a team. Certainly, in parallel, a sustained and continuous activity of fundraising from different funding sources is required (research projects funded by the national, European or international contracting authorities).

In terms of attracting and supervising the students' research activities for elaborating bachelor and master degree thesis, and also for supervising some young researches from the Applied Electromagnetics Research Center – (ELMA – from 2005 CNCSIS accredited) within the Electrotechnics and Measurements Department (ETHM), Electrical Engineering Faculty, Technical University of Cluj-Napoca (TUCN), obtaining the ability certificate and quality of PhD supervisor, comes as a natural step in the professional development of the candidate.

The conjugate involvement of the PhD supervisors within ELMA, who have great potential, plus training young researchers from the ETHM Department, is a premise that gives real chances of further development as the candidate's PhD supervisor.

In this context, obtaining the status of PhD supervisor will have a positive impact on his own teaching and research activities, and also on the activities performed within the Numerical Methods Research Laboratory (LCMN 2010 accredited) and ETHM Department, respectively. The candidate will be a viable link for stimulating teaching human resources and research staff of the ETHM Department and for absorption capacity of research funds.

B. Directions and research skills of the applicant

The candidate's career began with graduation of the Electrotechnics Faculty, Power Systems Specialization, from the Technical University of Cluj-Napoca, in 1998, continued with the graduation of the Mathematics and Informatics Faculty, Mathematics Specialization, from Babes-Bolyai University, in 2001.

The first contact with the university teaching activity was held in 1998 when he was hired in the position of teaching assistant and began to work in the Department of Power Systems in TUCN. During 1998-2004 he was responsible for laboratory works and seminars on field of Power Systems, Electrical Energy Automation, Electromagnetic Compatibility, Energy Management.

From 2004 he is within the Department of Electrotechnics from TUCN, so far being responsible for the courses and applications of Numerical Methods, Complements of Mathematics in Electrical Engineering, Fundamentals of Electrotechnics. The teaching activity was followed by the research activity.

Since 1999, when the applicant was employed as PhD student at TUCN, under the supervision of Prof. Mircea Chindriş, the teaching activity was followed by the research activity. During doctoral internship, the researches were focused on the study of electromagnetic interferences between overhead power lines and nearby technological installation as well the impact of the stray current on the metallic gas pipelines.

The first important step in the professional development of the candidate was represented by two research grants (2000, 2001) at VRIJE University Brussels, in frame of an international bilateral TUCN-VRIJE project BILA 2001/37, *Development of Methods and tools for analysis of the electromagnetic AC interference between high voltage transmission systems and metallic pipelines, Project manager: Prof. Vasile ŢOPA.*

In 2006 was employed on a part-time job, as *Scientific Expert* within the *Managerial Agency for Scientific Research, Innovation and Technology Transfer - Bucharest (AMCSIT)*, where will form his managerial skills regarding the monitoring of innovative projects proposed by industrial environment.

A highlight of the academic career represents the title of associate professor obtained in 2007. This confirmed the achievement of the necessary experience for the next step: research group coordinator and PhD advisor. In the next period, until so far the candidate has conducted an intensive research in collaboration with colleagues and PhD students from the Department of Electrotechnics. Since 2010 he is the Director of the Numerical Methods Research Laboratory, along with members contributing to the completion of 9 research contracts.

After receiving the PhD title in Electrical Engineering from the Technical University of Cluj-Napoca (Ministry Order no.117 of 2 June 2004), the candidate performed various research/teaching stages at prestigious universities in Europe (University of Naples Federico II, University degli Studi di Padova, Universita di Cagliari, Brunel University, West Macedonian University, Fredrick University of Cyprus, University of Novi Sad, Dublin Institute of Technology). The research/teaching topics were focused on study and development of numerical methods for modeling the electromagnetic field and electromagnetic interference phenomena’s, respectively the development of techniques for electromagnetic field synthesis and electrical circuit stability. The mentioned research themes were established as the basis for 3 future grants won as a project manager (financial supported by the national contracting authority) **[A.2.3.1], [A.2.3.2], [A.2.3.3]** as well another 10 grants won as member in the research team **[A.2.3.4] - [A.2.3.19]**.

The candidate is distinguished by enabling his experience in the Technical University of Cluj-Napoca, in three priority research directions at European level and of interest to the two accredited laboratories within ETHM Department: *Laboratory of Modeling and Electromagnetic Compatibility* respectively *Laboratory of Research in Numerical Methods* (http://research.utcluj.ro/index.php/electrical-engineering-138.html):

- numerical modeling of electromagnetic interference phenomena
- electromagnetic field synthesis in non-homogeneous media

- electrical circuits stability and synthesis

In this respect, to support the applicant's professional capabilities and performances, should be mentioned after obtaining the PhD title (2004-prezent) the 7 books, more than 150 scientific papers published in journals and /or presented at prestigious international conferences, 4 tutoring theses completed by members of the *Laboratory of Research in Numerical Methods* (accredited since 2010, whose director is the candidate) and participation as a member/project manager of over 15 research contracts on above mentioned directions.

The candidate skills, developed over the performed work after obtaining the PhD title, could be grouped as follows:

Professional expertise:

- Advanced knowledge’s in electrical engineering in general, and electromagnetic field theory, electrical circuits theory and numerical methods, in particular;
- Knowledge’s of advanced research methods and techniques; use of specific software packages designed to modeling and simulation of the electromagnetic field and electrical circuits; implementation of numerical methods in solving specific power system applications;
- Abilities in identify, formulate and solve research problems from industry

Transversal expertise:

- Skills in management of human and material resources;
- Skills in project management - AMCSIT;
- Skills in ICT use.

C. Scientific and technical statement of the research activity and obtained results

The current habilitation thesis makes a synthesis of the research activity done by the candidate and the obtained results, since he got the title of Doctor in the field of Electrical Engineering from the Technical University of Cluj-Napoca, fact confirmed by the Ministry Order no. 117 from 2nd of June 2004.

The main research fields to which the candidate has contributed since 2004 until today can be grouped in:

C1. Development of advanced analysis methods and numerical modeling dedicated tools designed to identify and predict the electromagnetic AC interference problems

C2. Development of techniques for the electric and magnetic field synthesis regarding the reconstruction of the return stroke currents and the specific design application of the solenoid devices. Electromagnetic inverse problems

C3. Development of field synthesis numerical modeling tools applied to electrical circuits stability and synthesis, respectively electromagnetic field synthesis in non-homogeneous media

The scientific research done, since the candidate got his PhD title, let us to draw some general conclusions and to emphasis the main scientific achievements. Therefore, the work done by the author presents a complex theoretical background, an interdisciplinary approach (combining electrical and power engineering with mathematics and informatics) and solves systematically the presented problems. The applied problem approach, observations, findings and proposed solving methods provide a strong original nature to the author's scientific achievements. As a result, the completed research projects and published papers have a high scientific quality, are rigorously justified and were aimed to develop analysis, modeling, design and testing methods for solving fundamental electrical and power engineering problems.

The research activities done after 2004, were conducted under the supervision of experienced academics from the Electrotechnics Department of the Technical University of Cluj-Napoca (prof. Emil Simion, prof. Vasile Țopa, prof. Călin Munteanu, prof. Gheoghe Mândru, prof. Ovidiu Micu); in collaboration with academics and specialists from Romanian partner universities (prof. Claudia Popescu, prof. Horia Gavrilă, prof. Mihai Iordache, prof. Daniel Ioan – UPB; prof. Ștefan Kilieny – UPT; dr. Lingvay Iosif – ICPE) and from abroad (prof. Dimitris Labridis, prof. Georgios Christoforidis, prof. Grigoris Pappagianis - Salonic, prof. Daniele Desideri, prof. Alvise Maschio, prof. Roberto Turri – Padova, prof. Gary Taylor – Londra, prof. Nouri Hassan – Newcastle, prof. Michael Conlon – Dublin, prof. Carlos Antunes – Coimbra). During this period the author has also worked as co-

coordinator of the PhD students who developed their doctoral thesis under the supervision of prof. Emil Simion and prof. Ovidiu Micu respectively. Many of these doctoral thesis topics were proposed by the candidate, who realized the importance of aligning the research activity within the group to the main European research directions, trends and priorities.

This chapter (C) shows the research results obtained by the candidate after his PhD defense, on the mentioned priority research directions. Scientific results published after obtaining his Ph.D. are summarized in this chapter by referring to these publications (the results are not reproduced in the thesis). These achievements are presented in the overall context of significant scientific achievements and are documented by referring to publications (each reference can be checked (see tables A1, A2)). All original contributions are presented in the context of the current state of the art in the field of electrical engineering.

C1. Development of advanced analysis methods and numerical modeling dedicated tools designed to identify and predict the electromagnetic AC interference problems

C1.1. The scientific expertise of the author in the research field C1

Re-assessing some hypothesis, according to the last results in the field, represent the starting point in the author' s effort of improving the methods of solving interference problems between high voltage power lines (HVPL) and metallic underground gas pipelines (MP).

Author's experience in this research field is validated by the PhD Thesis on the topic of electromagnetic interference between HVPL and MP, by the 150 papers in this field and its contribution as a director / member upon completion of research projects obtained by national competition or with industry: **[A1.1.1], [A1.1.2], [A2.1.1], [A2.1.2], [A2.1.5], [A2.1.7- A2.1.9], [A2.1.11], [A2.1.14], [A2.1.15], [A2.1.21], [A2.1.25], [A2.1.26], [A2.1.28], [[A2.1.29], [A2.1.32], [A2.1.33], [A2.2.1], [A2.2.2], [A2.2.6] [A2.2.7-A2.2.9], [A2.2.11] [A2.2.13], [A2.2.15 - A2.2.17], [A2.2.20 - A2.2.22], [A2.2.25], [A.2.3.1], [A.2.3.3], [A.2.3.5], [A.2.3.7], [A.2.3.8], [A.2.3.10], [A.2.3.11 - A.2.3.13], [A.2.3.15 - A.2.3.19].**

C1.2. The importance and the relevance of the scientific content

European ecological regulations meant to protect nature and wild life along with construction cost reduction policies, generated a set of government regulations that limit the access to new transmission and distribution corridors. As a result, gas, water or oil supply pipelines are forced to share the same distribution corridors with Electrical Power Lines, AC Railway Systems or Telecommunication Lines.

The acceleration of the corrosion of the underground metallic pipelines 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. 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. [1-4]

Analytical and numerical modeling of the real situation (inductive coupling – conductive coupling – real time) represents the only viable and efficient method to predict the risk areas, on which dangerous electrical potentials may arise. [5-8]

From these points of view, the development of specific analysis methods, modeling instruments and collecting information about the electromagnetic interference, represents an important issue in the ENERGY field of research. Developing and implementing these methods, instruments and information should ensure the integrity of the underground pipelines grid, with an immediate effect in the safety of the operating personnel and the environment protection.

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 electrokinetic problem which appears is a physical-mathematical problem of the electromagnetic field in cvasistationary regime.

Researches of this domain reveal a series of algorithms to solve coupling problems, but they are restrictive and do not take into account the geometry complexity of the pipeline grids. These algorithms are based on a series of approximations that raise the particularity of the problems. [9-11]

The traditional approach in the electromagnetic field analysis around infinitely long conductors of cylinder shape situated in the vicinity of a dissipative media (the ground) was published for the first time in a simplified way at the beginning of the last century. With all these, the first analytical methods that were elaborated and world wide spread were independently developed in the 20' by Carson and Pollaczeck using his wide known formulae [12], [13], while various approximating formulae were introduced later [14-18]. With the advances in computer technology and the increase in computational power, more advanced and sophisticated analytical models were adopted. As a result, a technical recommendation was developed [19 - 21], based also on experimental results. During the late 90's two research projects of the Electrical Power Research Institute (EPRI) and the

American Gas Association (AGA) targeted the analysis of power line inductive coupling to gas pipelines using practical analytical expressions. [22]

The analysis of the conductive effects is experimental; was introduced a generalized theory, which studied the conductive coupling between the high voltage systems and the underground metallic structures. [23], [24], [25]

A common research that analysis both the inductive and conductive coupling is realized by SES (Safe Engineering Services) and AGA (American Gas Association). The mechanisms of the inductive coupling, line-underground pipeline, are studied also by other authors for many practical cases. [26-29]

In [30], 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.

A separate study of the inductive coupling and of the conductive one without considering the influence of the pipelines grid on the metallic structure of the power station (grounding structure) often leads to important errors. The contributions on these topics are in [25], [26], [31], [32]

In [33], the authors have developed a three-dimensional computation model in D.C. quasi-stationary regime. The model can analyse 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.

More recently, new methods employing the Finite- Element Method (FEM) or Finite Difference Method (FDM) were proposed that aims to provide an alternative calculation method of the induced voltages on the pipelines. [34-38]

In the topic of HVPL-MP interference, recently was proposed some artificial intelligence techniques, but the imposed solution was not unanimity accepted in the field because of the restrictive algorithms involved in the process. [39], [40], [48-50]

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 (ECCAPP–Electric Power Research Institute; CDEGS-Safe Engineering; CATPro–Elsyca). [41], [42], [47]

In the literature, exists studies of metallic structures corrosion caused by a.c. and d.c stray currents. Regarding the corrosion control in d.c. stray currents, the developed and settlement technical solutions [43] could be implemented relative easily and assures an adequate protection (polarized mitigation, forced mitigation, etc.). In terms of corrosion control due to a.c. stray currents, although exist much more theoretical studies [31, 32, 33, 38, 44] the performances and effectiveness of the protection solutions are not sufficient, decoupling through PCR/ ISP devices (SUA), decoupling with polarization cells (EU, SUA, Canada) etc.

In Romania, there are concerns about studying the accelerating corrosion effects of the a.c. signals overlapped to metal/ electrolyte interferences, studies from which resulted efficient technical solutions for corrosion control in a.c. stray currents. [7, 37, 45, 46, 47, 51].

References

[1]. Braunstein R., Schmautzer E., Oelz M., *Impacts of Inductive and Conductive Interference due to High-Voltage Lines on Coating Holidays of Isolated Metallic Pipelines*, 21st International Conference on Electricity Distribution, CIRED, Frankfurt, Germany, June 6-9, 2011.

[2]. Southey R., et all: „On the Mechanisms of Electromagnetic Interference between Electrical Power Systems and Neighbouring Pipelines", *NACE 2000 T10B Symposium on DC &AC Interference*, Orlando, March 26-31, 2000.

[3]. Abu-Siada A., Bahram M.: „Effect of HVAC System on Neighbouring Pipelines and Communication Cables", *Australasian Universities Power Engineering Conference, AUPEC*, Adelaide, Australia, September 27-30, 2009.

[4]. Ma J., Fortin S. & Dawalibi F.P.: „Analysis and Mitigation of Current Unbalance Due to Induction in Heavily Loaded Multiciruit Power lines", *IEEE Trans. on Power Delivery*, Vol. 19, No. 3,pp. 1378-1383, July, 2004.

[5]. Christoforidis G.C., Labridis D.P. & Dokopoulos P.S.: „A Hybrid Method for Calculating the Inductive Interference Caused by Faulted Power Lines to Nearby Buried Pipelines", *IEEE Trans. on Power Delivery*, Vol. 20, No. 2, pp.1465-1473., April, 2005.

[6]. Al-Badi A.H.: „Analysis of Factors Affecting the Level of Electromagnetic Interference on Pipelines close to Power Lines", *International Conference on Power Engineering, ICOPES*, Rio de Janeiro, Brazil, October 12-15, 2004.

[7]. Dan D. Micu, Iosif Lingvay, Emil Simion, *Modelarea si predictia fenomenelor de interferenta in regim electrocinetic*, Editura ELECTRA, Bucuresti, ISBN 978-973-77728-73-9, 2006

[8]. Braunstein R., Schmautzer E., Propst G.: „Comparison and Discussion on Potential Mitigation Measures Regarding Inductive Interference of Metallic Pipelines", *Electrical Systems for Aircraft, Railway and Ship Propulsion, ESARS*, Bologna, Italy, October 19-21, 2010.

[9]. Dan D. Micu, Emil Simion, Dan Micu, Andrei Ceclan, *Numerical Methods for Induced Voltage Evaluation in Electromagnetic Interference Problems*, 9th International

Conference, Electric Power Quality and Utilisation, Barcelona, 9-11 October 2007, IEEExplore, Compendex 10.1109/EPQU.2007.4424091

[10]. Christoforidis G.C., Labridis D.P., Dokopoulos P.S., Kioupis N.: „AC Interference On A Gas Pipeline Caused By Nearby Power Lines In A Complex Right-Of-Way. Comparison between Measurements and Calculations", *CEOCOR Meeting*, Dresden, Germany, June 15-17, 2004.

[11]. Lee H.-G., Ha T.-H., Ha Y.-C., Bae J.-H., Kim D.-K.: „Analysis of Voltages Induced by Distribution Lines on Gas Pipelines", *International Conference on Power System Technology, PowerCon*, pp. 598-601., Singapore, November 21-24, 2004.

[12]. Carson, J. *Wave propagation in overhead wires with ground return.* Bell System Journal, Vol. 5, April 1926, pag. 539-554.

[13]. Pollaczek, F. *On the field produced by an infinitely long wire carrying alternating current*. Electrische Nachrichten Technik, vol III, 1929, pag. 339-359.

[14]. Gary, C. *Nouvelle methode de calcul des inductances propers et mutuelles des lignes in presence du sol*. Symposium CIGRE Brussels, 1985, pag. 11-17.

[15]. Olsen, R. *On the exact, Carson theory for wires at or above the earth's interface*. PAS-102, April 1983, pag. 769-778.

[16]. Rogers, E. *Mutual coupling between horizontal earth return conductors*. PWRD, July 1990, pag. 1834-1845.

[17]. Lucca, G. *Mutual impedance between an overhead and buried line with earth return*. IEEE Conference, 1994, pag. 80-86.

[18]. Ametani A.: „Investigation of Impedance and Line Parameters of a Finite Length Multiconductor System", *Electrical Engineeering in Japan*, ISSN: 1520-6416, Vol. 114, No. 4, pp. 83-92., 1994

[19]. ****CCITT: Directives concerning the protection against harmful effects from electric power lines*. ITU Geneva CH, 1990.

[20]. ****Standard – Electromagnetic Compatibility.* Journal officiel des CE, (EC 89-336) reference number 1000-4-3: 1995.

[21]. ****Technical recomendation No. 7. Arbitration agency for problems of interference between installations of power utilities Part II*. VWEW Germany 1989.

[22]. **** EPRI/AGA Project 742, EL-5472/PR176-520. *Power Line Fault Current Coupling to Nearby Natural Gas Pipelines*. Palo Alto, Canada, 1993, pag. 35-46.

[23]. Ametani A., Hosakawa Y.: „EMTP Simulations and Theoretical Formulation of Induced Votages to Pipelines from Power Lines", *International Conference on Power Systems Transients, IPST*, Lyon, France, June 4-7, 2007.

[24]. Southey R.D., Ruan W., Dawalibi F.P., Fortin S.: „Estimating AC Mitigation Requirements for Pipelines Installed in High Voltage AC Corridors: Fault Conditions", *CORROSION 2003, NACE International Conference*, San Diego, USA, March 17-21, 2003.

[25]. Li Y., Dawalibi F.P.: „Effects of Current Unbalance and Transmission Line Configuration on The Interference Levels Induced on Nearby Pipelines", *CORROSION 2004, NACE International Conference*, New Orleans, USA, March 28 - April 1, 2004.

[26]. G.C. Christoforidis, D.P. Labridis and P. S. Dokopoulos, *Inductive Interference on Pipelines Buried in Multilayer Soil, due to Magnetic Field from Nearby Faulted Power Lines*, IEEE Transactions on EMC, May 2005, Vol. 47, No. 2, pp. 254-262.

[27]. Southey, R., Dawalibi, F. *Computer Modeling of AC Interference Problems for the Most Cost Effective Solutions*. 53rd Annual Conference in Corrosion, NACE 98, California, March 22-27, 1998, pag 68-79.

[28]. Southey, R. et all. *On the Mechanisms of Electromagnetic Interference between Electrical Power Systems and Neighboring Pipelines*. NACE 2000 T10B Symposium on DC &AC Interference, Orlando, March 26-31, 2000.

[29]. Li, Y. et all. *Electromagnetic Interference Caused by a Power System Network and a Neighboring Pipeline*Proceedings of the 62nd Annual Meeting of the American Power Conference, Chicago, April 10-12, 2000, pag. 311-316.

[30]. CIGRE Working Group 36.02. *Guide Concerning Influence of High Voltage AC Power Systems on Metallic Pipelines*. 1995.

[31]. Satsios, K.J. et all. *Currents and Voltages Induced During Earth Faults in a System consisting of a Transmission Line and parallel Pipeline*. ETEP vol. 8, no. 3, May-June, 1998, pag. 193-199.

[32]. Lucca, G., Zucchelli, L. *Electromagnetic interference produced on a complex metallic pipeline network by a fault in a power substation*. CIGRE, Paris 2002, 36.

[33]. Bortels L., Deconinck J., Munteanu C., Topa V., *A General Applicable Model for Predictive and Mitigation Techniques for Pipeline Networks*, IEEE Transactions on Power Delivery, Vol. 21, No. 1, 2006, pp. 210-217.

[34]. Dan D. Micu, Christoforidis G.C. & Czumbil L.: „AC Interference on Pipelines due to Double Circuit Power Lines: A detailed study", *Electric Power System Research*, ISSN: 0378-7796, Vol. 103, pp. 1-8, 2013.

[35]. Dan D. Micu, I. Lingvay, C. Lingvay, L. Darabant, A. Ceclan, *Numerical evaluation of induced voltages in the metallic underground pipelines*, Revue Roumaine des Sciences Techniques serie electrotechnique et energetique, ISI Journal, Tome 54, 2009, Issue: 2, ISSN 0035-4066, pp.175-184.

[36]. Dan D. Micu, A. Ceclan, Laura Darabant, Denisa Stet, *Analytical and Numerical Development of the Electromagnetic Interference Between a High-Voltage Power Line and an Underground structures*, 6th International Symposium on Advanced Electromechanical Motion Systems, Electromotion 2009, July 1-3, 2009, Lille.

[37]. ***PN-II-ID-PCE-2007-1, nr. ID_1024: *Model matematic pentru studiul influentei poluarii electromagnetice in c.a. a conductelor metalice subterane de gaz, cu si fara protectie catodica, aflate in vecinatatea unei statii de transformare*. Director: prof. Emil Simion

[38]. Dan D. Micu, Radu Munteanu jr., Georgios Christoforidis, B. Manea, A. Ceclan, *Original Approaches for Solving Electromagnetic Interference Problems*, Advances in Electrical

and Computer Engineering, ISI Journal, No 2-2009, pp. 82-90, ISSN: 1582-7445; e-ISSN: 1844-7600.

[39]. K.J. Satsios, D.P. Labridis, P.S. Dokopoulos: *An Artificial Intelligence System for a Complex Electromagnetic Fiels Problem: Finite Element Calculations and Fuzzy Logic Dvelopment*, IEEE Trans. on Magnetics, Vol. 35, No. 1, January 1999

[40]. S. Al-Alawi, A. Al-Badi, K. Ellity: *An artificial neural network model for predicting gas pipeline induced voltage caused by power lines under fault conditions.* COMPEL: International Journal for Computation and Mathematics in Electrica land Electronic Engineering,Vol. 24, No. 1, 2005.

[41]. Bortels, L., Munteanu, C., Deconinck, J., Topa, V. *A User-Friendly Simulation Software for AC Predictive and Mitigation Techniques,* 58th Annual Conference and Exposition, Corrosion NACExpo 2003, San Diego, USA, 16-20 March 2003.

[42]. R.D. Southey: CDEGS *Engineering User Manual How To…* – SES.

[43]. ***EN 12954 – 2001 *Cathodic Protection of Buried or Immersed Metallic Structures* – Application for Pipelines.

[44]. Li Y., et all: „Electromagnetic Interference Caused by a Power System Network and a Neighbouring Pipeline”, *62nd Annual Meeting of the American Power Conference*, pp. 311-316, Chicago, USA, April 10-12, 2000.

[45]. I. Lingvay *Metoda si dispozitiv pentru electroprotectia structurilor metalice* - brevet Ro nr. 113778/30.09.1998.

[46]. ***CEEx, nr. X2C37/2006: *Impactul campurilor electromagnetice de natura antropica asupra ecosistemelor* – ICEMECOS, Director proiect: prof.Claudia Popescu (Universitatea Politehnica Bucuresti); Responsabil partener UTCN: Dan D. Micu.

[47]. ***Ro-Flemisch Project-2000: *Development of methods and tools for analysis of the electromagnetic AC interference between high voltage transmission systems and metallic pipelines*. 2000-2003. Director: prof. Vasile Topa.

[48]. Dan D. Micu, Levente Czumbil, Andrei Ceclan, Georgios Christoforidis, Laura Darabant, Denisa Stet, *Electromagnetic Interference between HV Power Lines and Metallic Pipeline Evaluated with Neural Network Technique*, 10th International Conference Electric Power Quality and Utilisation, EPQU'09, 15-17 September 2009, Lodz, Poland.

[49]. Dan D. Micu, Czumbil L., Christoforidis G.C. & Simion E.: „Neural Networks Applied in Electromagnetic Interference Problems”, Revue Roumain des Sciences Techniques, SEE, ISSN: 0035-4066, Vol. 57, No. 2, pp.162-171., 2012.

[50]. Dan D. Micu, Czumbil L., Christoforidis G.C. & Ceclan A.: „Layer Recurrent Neural Network Solution for an Electromagnetic Interference Problem”, IEEE Transaction on Magnetics, ISSN: 0018-9464, Vol. 47, No. 5, pp. 1410-1413., May, 2011. Doi: 10.1109/TMAG.2010.2091494

[51]. ***CNCSIS TE 34/09.08.2010: de grant: *Solutii de modelare, predictie si proiectare, cu maxim de performanta, pentru reducerea impactului curentilor de dispersie asupra conductelor metalice subterane de transport gaz*, Director: Dan D. Micu.

C1.3. The scientific expertise of the applicant. Expertise domain and significant results - both theoretical and practical

Significant scientific results obtained, reflect the intense work and research skills of the applicant. This field research integrates the previous concerns of the ETHM department staff, the results of the applicant's contribution being a collective teamwork:

1. In **[A2.1.14], [A2.3.3]** the applicant developed a differential mathematical model in order to calculate the induced voltage in an underground metallic pipeline which shares the same distribution corridor with an overhead high voltage power line, using a plan-parallel model and rectangular discretisation network. The model starts from the Maxwell equations for magnetic quasistationary state in a homogeneous media; Taylor series and contour integral methods were used to determine the numerical form of the Helmholtz equation for rectangular discretisation network and plan-parallel symmetry and also was determined the numerical form of the Helmholtz equation for non-homogeneous media.
2. In **[A2.3.1]** the applicant developed a generalized hybrid method to model the common power line-pipeline distribution corridor and calculate the induced currents and voltages in pipeline. The hybrid model was introduced in **[A2.1.29]** as a study concept of an equivalent circuit power line - pipeline. The main advantage of this method over previous ones developed by the applicant in [**A2.3.7], [A2.3.10], [A2.3.15], [A2.1.16]** consist in the fact that in the same model it was used either field calculations and electrical circuit methods being possible to take into account existing faults in pipeline insulation. This method gives higher accuracy to results by optimizing the model through a multilayer soil type consideration. The proposed hybrid method uses the differential model developed in **[A2.3.7]** and improved in the **[A2.1.7], [A2.1.8], [A2.2.6]** to determine the induced magnetic vector potential on the overhead power line conductors' surface being under fault condition, and on the pipelines surface placed in the same distribution corridor. Then using a combination between Faradays law and the results obtained for magnetic vector potential it was calculated the self-inductance of power line and pipeline and the mutual inductance between this two structures.
3. In the papers **[A2.1.32], [A2.1.33]** was presented the subdivision of the complex underground pipelines network, into pipe-elements, in order to reduce the computation effort, the numerical model created was inserted into an optimization module. These so called pipe-elements are modeled like a cylindrical structure, but they were extended to more general geometries. The form of the function

representing the solution for a pipe-element was assumed to be axial-symmetric in the literature. This fact implies that the variation of the solution is assumed to be linear along each pipe-element. For electric potential calculation, it implies that the induced current density and the potential between a point on the pipeline 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 pipe-element the potential and current density are constant. All these approximations and these suppositions may sometimes fail for some cases, so in **[A2.1.29]** the applicant performed a clear estimation of the error due to these approximations for real situations of polyetilen pipeline, and of course for pipelines with different diameters. For this purpose, some analytical computation and numerical simulations – as well as measurements – were performed for real practical situations.

4. In **[A2.1.15], [A2.3.7]** it was developed a generalized mathematical model for a precise effects estimation of the inductive and conductive couplings in steady state on any underground pipeline network situated in close proximity of a substation in which could appears a single phase fault on a line which enters in the substation; the complex pipeline network are connected directly to the earth electrode network of the substation. These mathematical equivalent models for inductive and conductive coupling simulation, establish the risk points and introduce the electromagnetic cathodic protection devices. This will ensure the pipeline network integrity, which brings to the safety of the working personal and environment protection.

5. In **[A2.2.21], [A2.1.25], [A2.2.25]** was developed and implemented a software called ***Fuzzy Calculation***, created in Delphi program, based on the previous developed algorithms, for solving the problems of interference between HVPL and MP:

- software implementation was done on a case study of an HVPL-MP right of way
- it was proposed a new approach of the problem using neural networks (NN) and implementing different constructive architectures
- it was created two fuzzy blocks to calculate the phase and module of the magnetic vector potential (MVP) whose input data are: the separation distance between the HVPL and MP, soil resistivity and coordinates of where MVP is determined
- some neural network architectures have been developed for which satisfactory solutions have been obtained in calculating the MVP module and phase, compared to the results provided by finite element method (FEM).
- it has been shown that the deviations of the solutions provided by the implemented neural networks, to those provided by FEM, are very small, insignificant for training data set and somewhat higher but still in the range of negligible error in the case of test data set

- it was thus proved that the method of determining the MVP for different geometries through neural networks is very effective, the solutions provided by the neural networks are obtained instantly by the program when in the case of FEM they are very laborious
- using MVP values obtained with the two implemented neural networks it was determined the self and mutual inductances of the structures that compose the problem and based on that, an equivalent circuit model it was built to provide the induced voltages/currents in the pipeline

6. In **[A2.3.1], [A2.3.15], [A2.3.16], [A2.2.15]** the author have made a series of theoretical and applied research in order to design a stray current mitigation device, in order to reduce the induced currents in the pipeline that share the same distribution corridor with a HVPL. Destructive phenomena produced by stray currents generated by the HVPL on the coating and tubular material of the buried pipeline are well documented in the literature. In previous studies, conducted by the author in the research projects **[A2.3.3 – A.2.3.7]**, was demonstrated that pipelines with superior quality coating, characterized in terms of quality as good and very good insulations, will be strongly influenced in a negative way. The absence of pores in the insulation means there is no contact between the ground and the metal parts of the pipeline. The induction that occurs in this kind of pipelines (HVPL operation due to different loads), without mitigation towards the soil, can produce voltage spikes of 5-6 V, very harmful for the insulation of the pipeline. HVPL induce sinusoidal currents in the gas transmission pipelines which are in their vicinity. If the positive component of this sinusoidal signal is drained to the ground, the negative component overlaps over the injected signal by the cathodic protection station, causing a decrease of the pipeline – soil potential. Thus, cathodic protection is more effective only on the signal induced by the HVPL into the MP, signal whose positive part is drained. In Romania it is known a number of devices that limit the amplitude of AC voltage induced in the pipeline to acceptable values in terms of reaction in time of the pipeline coating. Their disadvantage is that the amplitude of the negative alternation is not limited to an acceptable level, which does not harm the insulation applied to buried pipelines. Potential whose actual values are more negative -1100 mV, measured through the electrode of Cu-$CuSO_4$, damage insulation applied to pipelines, leading to cathodic unboundment. Worldwide, there are many devices that drain stray currents induced in underground pipelines, but there is no information available regarding the instantaneous potential limitation. The disadvantage of these devices is the overall dimension, the absence of potential control of cathodic protection (potential IR_{free} what should be between -850 mV and -1100 mV), and that insulation is not protected for cathodic overprotection. Thus, a potential solution, for controlling the coupling between the HVPL and a pipeline, it was developed in **[A2.3.15], [A2.3.16]** where a mitigation device are designed to protect metallic buried isolated pipelines. The advantage over existing devices is the possibility of mitigation only the positive alternation from the sinusoidal current induced in the soil – pipeline, which is harmful for cathodic protection. The device was designed to eliminate the cathodic overprotection due to currents induced in pipeline by HVPL, avoiding the cathodic unboundment of insulation, and to limit the values of the voltages induced in the pipeline, values which were estimated previously using methods developed by the author. The device have to protect any pipeline located near the HVPL, including the situation of a defect, on one phase (one phase accidentally touching the earth, outside the right-of-way), or on two-phases (according to models developed by the applicant), knowing that at the beginning of the fault an over voltage can be induced in the pipeline. Regarding this fact, it’s important to ensure a good time response of the device. Before checking the operation and efficiency of the mitigation device, this one was subjected to functional testing and simulations in laboratory conditions. An equivalent circuit of the device was implemented in PSpice and the behaviour of the device was simulated, for real conditions **[A2.1.8], [A2.3.1]**.

7. In **[A2.1.1], [A2.1.7], [A2.3.1]** was developed and implemented an equivalent electrical circuit to model the specific situations by considering an optimal number of sections for power line and pipeline. The equivalent circuit contains their resistance, their self and mutual inductance and leakage resistance (to consider insulation defects). Once these parameters are determined through the differential numerical model, the equivalent electrical circuit was calculated. The equivalent electrical circuit was implemented in PSPICE module of the ORCAD program. Due to the large number of circuit elements, the input file for this software was obtained in txt format, as a result of a MATLAB routine. To substantially increase the accuracy of the numerical results of this method it was taken into account the ill conditioned nature of the impedance matrix. This hypothesis is neglected in **[A2.3.7]**, the involvement of the condition number in the study of electromagnetic interference between power lines and nearby pipelines being an original idea introduced in **[A2.3.1].**

8. In **[A2.1.5], [A2.2.22], [A2.2.20]** was presented the induced potential in a underground pipeline calculation, by a specific synthesis method, which entail an inverse formulation of field problem **[A2.2.16]**, 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 was identified 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.

9. In **[A2.1.26], [A2.3.7], [A2.3.13]** the applicant developed a numerical evaluation of the solution’s non-uniformity due to the proximity of earth electrodes from the earthing equipment or other underground pipelines. For the computation of the non-uniformity was used some particular numerical evaluation techniques (generalized Newton Raphson, modified Newton, conjugated gradient) and was developed an original iterative solving algorithm that takes into account the ill conditioning character of the system of equations provided by the mathematical model. This inconvenient wasn’t considered in the existing literature, all authors solving this system using the iterative solver GMRES (Generalized Minimal Residual Algorithm). In fact, the quality of this solver mostly depends on the condition number of the matrix and it was proved that solving problems with this solver fails when the system is ill conditioned (case that appears when a fault current enters the earthing equipment).

10. In **[A2.1.9], [A2.1.28]**, using the data obtained through the generalized hybrid method and previously retained in a data base, the applicant implemented some solutions for solving the electromagnetic interference problems between overhead power lines and metallic gas pipelines, based on artificial intelligence techniques. Artificial intelligence techniques have a growing impact in solving problems from various scientific fields. These methods starts from a basic set of solutions determined by different methods (in our case results obtained with the generalized hybrid method) and scale the solutions for flexible geometry configurations of the studied problem based on the training data set. The advantage of these artificial intelligence techniques (Fuzzy Logic, Neural Networks, Genetic Algorithms) is that once implemented and trained to solve a specific problem, they provide solutions with reduced computational effort for any other geometric configuration of the studied problem, unlike conventional numerical methods which take a long processing time and a considerable computational effort for each configuration separately. There are some attempts in the specialized literature to use artificial intelligence techniques to solve these electromagnetic interference problems, between overhead power lines and metallic pipelines. In **[A2.1.28]** was used Fuzzy Logic to study an electromagnetic interference problem between a 145 kV HVPL with a single-phase grounding fault and an underground gas metallic pipeline. Also in the paper was developed the theoretical background for an interference study between an overhead power line and a metallic pipeline using artificial intelligence techniques.

11. In **[A1.1.1], [A2.1.11], [A2.3.1]** the applicant achieved the implementation of a neural network which calculates directly the induced voltage in pipeline, but using some simplifying assumptions (elimination of air-earth interface, considering the single-phase fault far away from the common distribution corridor). Re-evaluation of these assumptions, according with the latest studies in this area, constitutes the starting premises in seeking to improve these methods to solve HVPL-MP interference problems. Thus, the author considered relevant to implement a general solution using artificial intelligence techniques to solve different particular HVPL-MP electromagnetic interference cases, like: operation in normal conditions with or without cathodic protection, respectively in single, two or three phase fault conditions for different geometric configurations for HVPL. The innovative idea consists in combining alternative solutions, based on the developed artificial intelligence techniques, in a main Fuzzy Block which was created to identify parameters that define the specific operating conditions (based on a defined set of fuzzy laws) and using the solution or solutions that may solve the specific HVPL-MP electromagnetic interference problem **[A2.2.1], [A2.2.2]**. If there are several possible solutions (solutions with similar accuracy) for a specific problem, this main Fuzzy Block provides a final solution by weighting the provided results (outputs) of these alternative solutions. For each particular case of HVPL-MP electromagnetic interference was created a training data base by solving that specific problem using the hybrid method. To test and validate the obtained solution, determined using artificial intelligence techniques, it was chose a set of real HVPL-MP electromagnetic interference cases which were solved with the proposed method and the obtained results were compared with in-field measurements. Testing cases were provided by the national gas transmission system operator, SNTGN TRANSGAZ S.A. Medias with which the ETHM Department have collaboration **[A2.3.1], [A2.3.15], [A2.3.16].**

12. Following 2 research projects **[A2.3.15], [A2.3.16]** between Technical University of Cluj-Napoca and S.N.T.G.N. TRANSGAZ S.A. Medias, the applicant and his team from ETHM, has developed and implemented in Delphi, a software package named *InterfStud* for solving electromagnetic interference problems between HVPL and gas underground pipelines **[A2.2.7], [A2.2.11].** The software evaluates the induced voltages and currents in pipelines which runs in the same right of way with HVPL, using the equivalent electrical circuit model developed in **[A2.3.1].** The improvement was that the generalised developed model takes into consideration the inductive and also the capacitive couplings to evaluate the induced voltages and currents in onshore pipelines. Through this program can investigate the interference phenomena between HVPL and MP occurring in steady state (under normal operating conditions, symmetrical or non-symmetrical load phase conductors of the HVPL), respectively under fault conditions (single phase to earth fault, short circuit in power stations, etc.) if the fault appears far away from the common distribution corridor **[A2.2.13], [A2.2.17].**

13. In **[A2.1.21], [A2.2.15], [A2.2.13], [A2.3.1]** the author developed technical solutions to minimize corrosion phenomena existent in the electromagnetic environment by reducing induced voltages in gas pipelines by an overhead electrical line that share the same distribution corridor. In some identified scientific papers equivalent circuit is recommended for the study of galvanic corrosion, since it can lead to a simplification of the understanding mechanism behind this phenomenon. But because corrosion is not due to a single mechanism, the applicant has considered several equivalent circuits to describe exactly how physical and chemical aspects are relevant in the corrosion process. For this purpose in **[A2.2.8], [A2.2.9]** was proposed a circuit in which the modeling of the corrosion process of metal pipelines, which runs in the same right of way with an overhead line, was made by choosing the circuit elements designed to model parameters such as soil resistivity, resistance to leakage, corrosion rate. The author have developed methods for locating and quantifying the peak induced voltages in the pipeline and simulations were performed in specialized software (Maxwell, Comsol) to study the effectiveness of these methods for different geometries and at different load conditions of the HVPL.

14. To prevent voltage peaks induced in a buried pipeline, common distribution corridor of HVPL-MP was designed taking into account the effect of electrical or geometrical discontinuities in the area of influence. In order to reduce the inductive coupling, in **[A1.1.2], [A2.3.3]** the applicant proposes HVPL design solutions to generate constant and minimum longitudinal conductive electric field in the adjacent pipeline. In **[A2.1.2]**, without a relevant demonstration, it is shown, that for a particular configuration of power line, is feasible to minimize the electric field in the common corridor through a proper phase conductors sequence. Another possible technique to reduce the longitudinal electric field in the common corridor is to use an auxiliary grounding and shielding conductor, installed between overhead electrical line poles. In the context of this research, based on the developed hybrid model, in **[A2.1.8]** the efficiency and limitations of these techniques in order to reduce the longitudinal electric field for different geometries and different loading conditions of the power line, was gradually analysed. The developed algorithm, in order to calculate the longitudinal electric field, was modified for this analysis, because it must include the effects of the auxiliary conductor. Calculations were made with and without the auxiliary conductor, in order to evaluate the effectiveness of the attenuation techniques. The procedure was repeated for each geometry and power line phase conductor examined.

15. In **[A2.2.6]** it was used an approximation according to which the horizontal grounding conductors are not affected by the conductive electric field generated by an adjacent electric power line which has the same right of way with a metallic pipeline. If this hypothesis is ignored, to compute the attenuation (when the equivalent electric circuit is modeled) it is compulsory to take into account that in the grounding conductors may appear appreciable values of the induced voltages. Since in the literature were identified only restrictive algorithms, the applicant in **[A2.3.1], [A2.2.7], [A2.2.15]**, have developed some algorithms to calculate the attenuation effect for each grounding conductors configuration, for conductors with arbitrary electrical conductivity and permeability, diameters up to 25 mm and for the entire range of possible soil resistivity. In the literature each conductor was considered as individual, thus the attenuation was made in a single point of the pipeline. In general, due to multiple physical or electrical discontinuities from the common corridor, more voltage peaks are induced in a pipeline (more picks). Installing a single attenuation conductor can reduce local induced voltages on the pipeline, but does not affect other picks. So, to develop a complete attenuation method, individual successive attenuation methods of voltage peaks induced in a pipeline was developed and implemented by the applicant, in order to reduce the induced voltages in considerable length pipelines.

C2. Development of techniques for the electric and magnetic field synthesis regarding the reconstruction of the return stroke currents and specific design application of the solenoid devices; Electromagnetic inverse problems.

C2.1. The scientific expertise of the applicant in the research field C2

Author's experience in this field is validated by more than 50 scientific papers and its contribution as a director / member upon completion of research contracts obtained in national competition or with industry in the research direction C2:

[A2.1.2], [A2.1.3], [A2.1.5], [A2.1.18], [A2.1.22], [A2.1.30], [A2.1.31], [A2.1.34], [A2.2.5], [A2.2.16], [A2.2.18], [A2.2.23], [A2.2.24], [A.2.3.2], [A.2.3.4], [A.2.3.6], [A.2.3.8], [A.2.3.11], [A.2.3.12], [A.2.3.17], [A.2.3.18], [A.2.3.19]

In this research field the applicant has achieved solutions for spatial and temporal reconstruction of the lightning return stroke currents, from the values of electric and magnetic field generated. Such research concerns: the debate and the development of mathematical models fully connected between the return stroke current and the electric / magnetic generated field; extend the assumptions of environmental characterization; testing regularization procedures proved viable in similar applications; precise identification of spatial-temporal distribution of the return stroke currents. The results are very useful to improve electromagnetic compatibility procedures.

C2.2. The importance and the relevance of the scientific content

The power electricity Transportation Operator in Romania, TRANSELECTRICA, reports that in 2009, a rate of 27% of the total damage to high voltage power lines, is due to atmospheric over voltages. Over voltages may occur through inductive coupling, or by driven disturbance. There are reported another phenomenon encountered in practice: the current leakage through the installation of arrester - which is positioned vertically on the walls of a building - generates around a field so intense, which may affect the operation of various electronic equipment. Such example has been reported at the Cluj-Napoca International Airport. The same concern for protecting and shielding of electrical and electronic systems are demonstrated to operators of power distribution grids, which also often suffer damages with a high frequency, mobile communication operators, and those developing wind farms.

So, in the author's opinion, there were sufficiently serious reasons for developing research in this field.

Lightning strikes generate harmful effects on the electrical systems. For a proper design of insulation, shielding and optimal coordination of protections it is necessary, first the exact determination of the causes – the return stroke currents. Knowing the distribution of these currents, due to the numerical modeling it becomes possible to determine, as effect, the spatial-temporal distributions of the electric and magnetic field generated in the impact zones of lightning strikes, both remote and nearby. When the accumulated charge in the clouds causes an increasing electric field over a certain limit, ionization occurs and the breakthrough of air initiates a current channel called direct or descendent from the clouds toward the ground leader [1]. As the descendent leader is propagating, to a relatively small distance from the ground, about 10 - 100 m, opposite charge accumulated on the ground, cause a reverse discharge, a phenomenon that leads to the appearance of an electric current, called return stroke current, or ascendant leader (one main, followed by secondary ones) [2]. The amplitude of the ascendant leader is usually situated in the range 2 ÷ 100 kA and is several times greater than the descendent leader. Length of the spreading return current varies between a few nanoseconds, to several tens or even hundreds of microseconds [3].

Based on the completed bibliography, these references are made to the current state of research in identifying the return currents:

- There are 4 well-known variants of modeling the lightning phenomenon [4], [5]. Of these, the so-called engineering model clearly reflect in coherent terms, the link between the return current - cause - and the field generated – effect- through integral equations of Fredholm type.
- According to the engineering model, the lightning strike is similar to a vertical antenna, positioned between the ground and clouds [6]. Most of the times thunder strike is formed on a sectioned of oblique direction, an aspect totally neglected.
- When modeling assumptions allowed the soil to be flat, homogeneous and infinite conductivity, without the existence of towers, the link type expressions, called Green functions, are dependent on spatial coordinates, frequency, speed of the current front, height of the channel [7]. So, the soil is very much idealized.
- When modeling assumptions take into account a non-homogeneous soil, with finite conductivity and possible existence of towers (electrical network poles, telephone antennas, or radar, lightning rods), then it the link appears as expressions depending on Bessel type functions and half infinite integrals, difficult to solve, which restricts the use of integral equations [8].
- Measuring electric or magnetic field is carried out by sensors, on different frequencies and in different locations in the impact area [9].
- It is possible to locate the exact position of the lightning impact, using devices called Lightning Location Systems, LLS, and a correlation with the sensors measuring the field in the site [8].
- Spatial-temporal distribution of the return current is expressed by the product of a function of time, called the base current, and a function of spatial variation of the current, along the channel between the ground and clouds [10]
- In the case of lightning towers or artificial triggering of lightning (triggered lightning), the current can be registered as amplitude and temporal variation. A number of plausible researches challenge the correct registration of the current base, due to the reflections that occur in the collection devices / lightning rods [11].
- Mathematical techniques to identify the spatial distribution function of the return current, on the height of the channel, consists in an attempt to match by *trial and error* methods, the field values measured with the field values calculated, by imposing exponential models, MTLE, or square root one, MTLL. These models introduce generally accepted errors [5] in the range of about 16 to 20% [12]. Thus, the major objective of identifying the return stroke current it is seriously affected by errors.

- Recently, it was noted the appliance of the collocation method to the numerical solution of integral equations for this problem [13]. Accuracy is improving, but the issue that remains unresolved is the stability of the solutions. Values taken from field measurements may be affected by perturbations, so that because of the ill condition of the Fredholm integral model, these perturbations can be excessively amplified in the solution.
- A precise determination with streak cameras indicates that the spatial propagation speed of the ascendant leader decreases, with increasing height and has estimated values within the range of $9.5\cdot10^{7}...1.9\cdot10^{8}\ m/s$, reduced compared to the speed of light due to corona phenomenon that accompanies the return current channel [14].

At international level, there have been recognized several research centres in a broader context, to study the phenomena of thunder and lightning and the impact on the environment, including electrical systems. It could be mentioned: Switzerland pole, Italy pole, Canada pole, Pole Florida. Mainstream of the today`s published science papers is dominated by names like: Nucci, Andreotti, Delfino, Guerrieri, Borghetti, Cooray, Rachid, Bermudez, Rubinstein, Heidler, Hussein, Fuchs, Thottoppillil, Petrache, Favre, Wagner, Rakov, Janischewskzj, and so on. The applicant and his team already initiated cooperation with Switzerland and Italy pole. In the above were covered essential aspects involved in characterizing and determining the return stroke currents.

In [15] the applicant deals exhaustively certain ways of expressing the Fredholm integral equations of the first kind. It is emphasized, with arguments the demonstration that these are incorrectly formulated mathematical models which in a classical way, lead to multiple solutions, unstable and without physical sense. Further, there are described, developed and tested various special numerical methods for solving integral equations, generically called regularization methods. For this round are tied some contributions [16], [17] of the applicant and his team, with the clear intention of generalize them to solve any kind of Fredholm integral equation model. In order to extend the validity of the regularization methods - applied to Fredholm integral equations of the first kind **it was** studied the problem of space reconstruction of the return current initiated by the lightning. Further, the methods of regularization introduced are functionally validated in applications for the synthesis of electric and magnetic field [18], and for the configuration of special coil type inductive sensor [19], or in magnetic treatment industry [20].

At this stage, there have been adopted integrated models in a flat and perfectly conducting ground assumption. There were used in the idea of procedural validation, electrical and magnetic field values obtained by simulation with test functions MTLE respectively MTLL. Also, it was considered a range of possible cases regarding: the location of the sensors measuring the radial or axial field, variable distances for the channel current, frequency sampling, various fields *measured.* The large range of results obtained, proved to be viable, and assures a degree of increased accuracy of the proposed procedures was relatively little disseminated [21-34].

These latter issues, together with the potential solutions foreseen by the applicant and his team, referred to the problems treated as inconsistent, constitute a sufficiently strong motivation to continue the research in this field, using the combined approach: incorrectly formulated electromagnetic inverse problem – regularization.

References

[1]. Degauque P. and Hamelin J. (editors), *Electromagnetic compatibility*, Oxford Science Publications, New York, 1993.

[2]. Gomes C., Cooray V., *Concepts of lightning return stroke models*, IEEE Trans. Electromagnetic Compatibility, No. 42, 2000, pp. 82-96.

[3]. Rachidi F., Nucci C. A., Ianoz M., Mazzetti C., *Influence of a lossy ground on lightning-induced voltages on overhead lines*, IEEE Trans. Electromag. Compatibility, No. 38, 1996, pp. 250-264.

[4]. Uman M. A. and M.cLain D. K., *Lightning Return Stroke Current from Magnetic and Radiation Field Measurements*, Journal of Geophysical Research, Vol. 75, 1970, pp. 5143 – 5147.

[5]. Rakov V. A., Uman M. A., *Review and evaluation of lightning return stroke models including some aspects of their application*. IEEE Trans Electromag. Compatibility, No. 40, 1998, pp. 403-426.

[6]. Andreotti A., Delfino F. and Verolino L., *An identification procedure for lightning return strokes*, Journal of Electrostatics, Vol. 51, No. 52, 2001, pp. 326-332.

[7]. Andreotti A., Delfino F., Girdinio P. And Verolino L., *A field based inverse algorithm for the identification of different height lightning return strokes*, COMPEL, Vol. 20, No. 3, 2001, pp. 724-731.

[8]. Bermudez J. L., Lightning currents and electromagnetic fields associated with return strokes to elevated strike objects, Ph. D. Thesis, No. 2741, EPFL, Lausanne, 2003.

[9]. Dib Djalel, Haddouche Ali and Chemam Faycal, *The Return-Stroke of Lightning Current, Source of electromagnetic Fields*, American Journal of Applied Science, No. 4 (2), 2007, pp. 42 – 48.

[10]. Javor V. and Rancic P., *Computation of lightning electromagnetic field using new return stroke channel-base current function*, OIPE, X-th International Workshop on Optimization and Inverse Problems in Electromagnetism, Ilmenau, 2008, pp. 170-171.

[11]. Pavanello Davide, *Electromagnetic Radiation from Lightning Return Strokes to Tall Structures*, Ph. D. Thesis, No. 3713, EPFL, Lausanne, 2007.

[12]. Andreotti A., Assante D., Falco S., Verolino L., *An Improved Procedure for the Return Stroke Current Identification*, IEEE Transactions on Magnetics, Vol. 41, No. 5, 2005, pp. 1872-1875.

[13]. Delfino F., et all, *Lightning return stroke current identification*, Archiv fur Elektrotechnik, Vol. 84, No. 1, 2002, pp. 41 – 50.

[14]. Rakov A. Vladimir, *Lightning Return Stroke Speed*, Journal of Lightning Research, Vol. 1, 2007, pp. 80 – 89.

[15]. Andrei Ceclan, Vasile Ţopa, Dan D. Micu, Amedeo Andreotti, Lightning Inverse Reconstruction by Remote Sensing and Field Synthesis, IEEE Transactions on Magnetics, ISSN: 0018-9464, Vol. 49, Issue 5, 2013; 10.1109/TMAG.2013.2243425

[16]. Ceclan Andrei, Dan D. Micu, Man Lucian, Simion Emil, *Regularization method for ill-conditioned linear systems of equations*, Intern. Symposium on Electromagnetic Fields in Mechatronics, Electrical and Electronic Engineering, 2007, Prague, ISBN 978-80-01-03784-3, pp. 259 – 262.

[17]. Ceclan Andrei, Dan D. Micu, Micu Dan, Simion Emil, *Tikhonov Regularization for Electric Field Synthesis*, NUMELEC'06, 5th European Conference on Numerical Methods in Electromagnetism, Lille, 2006.

[18]. Simion Emil, Ceclan Andrei, Dan D. Micu, *Inverse Problem Identification of Electric Field Sources,* Proceeding of the International Symposium on Electrical Engineering and Energy Converters, ELS-07, Suceava, 2007, pp. 257 – 263, ISBN: 978-973-666-259-1.

[19]. Dan D. Micu, Micu D., Ceclan Andrei, Simion Emil, *Synthesis Method of an Inductive Sensor using Tikhonov Regularization Procedure*, International Journal of Applied Electromagnetics and Mechanics, IJAEM - Volume 26, Nos 3,4, 2007, IOS Press, ISSN 1383-5416, pp. 243-251.

[20]. Ceclan Andrei, Dan D. Micu, Man Lucian, Simion Emil, Synthesis Design of Electromagnetic Device for Magnetic Treatment of Textile Bands, International Aegean Conference on Electrical Machines and Power Electronics & Electromotion Joint Conference, Bodrum Turkey, Sept. 2007, ISBN 978-975-93410-2-2, pp. 236 -240.

[21]. Mimouni Abdenbi, Rachidi Farhad and Azzouz Zin-eddine, *Electromagnetic Environment in the Immediate Vicinity of a Lightning Return Stroke*, Journal of Lightning Research, Vol. 2, 2007, pp. 64 – 75.

[22]. Nucci C. A., *Lightning-Induced Voltages on Distribution Systems: Influence of Ground Resistivity and System Topology*, Journal Lightning Research, Vol. 1, 2007, pp. 148 – 157.

[23]. Nucci C. A., *Lightning-Induced Voltages on Distribution Systems: Influence of Ground Resistivity and System Topology*, Journal Lightning Research, Vol. 1, 2007, pp. 148 – 157.

[24]. Ceclan Andrei, Constantin Barbulescu, Stefan Kilyeni, Dan D. Micu, Emil Simion, Power Flow Non-linear System of Equations with SVD Regularization Newton Method, 6th International Conference on Electromecanical and Power Systems, SIELMEN'07, Chişinău, 2007, ISSN 1582-7194.

[25]. Ceclan Andrei, Barbulescu Constantin, Dan D. Micu, Czumbil Levente, Magnetic Field Synthesis and Parameter Regularization by Fuzzy Inference, Human System Interaction

Conference (HSI 2008), Poland, 2008, ISBN: 1-4244-1543-8, IEEE Catalog Number: 08EX19995C, Library of Congress: 2007905110, pp. 390 – 393.

[26]. Javor, V., Rancic, P.D., *On the choice of the lightning channel current decay constant in the modified transmission line model with exponential decay*, SoftCOM 2009 - 17th International Conference on Software, Telecommunications and Computer Networks, art. no. 5306869, 2009, pp. 29-32.

[27]. Vanegas, A., Velilla, E., Herrera, J., Valencia, J.A., *An efficient procedure for computing lightning induced overvoltages on overhead lines*, CPE 2009 - 6th International Conference-Workshop - Compatability and Power Electronics , art. no. 5156062, 2009, pp. 368-374.

[28]. Wu, Q., Jiang, B.-H., *Efficient expression of electromagnetic fields of lightning return stroke current*, 12th Biennial IEEE Conference on Electromagnetic Field Computation, CEFC 2006, art. no. 1633056, 2006.

[29]. Rachidi, F., Rubinstein, M., Montanyà, J., Bermúdez, J.-L., Sola, R.R., Solà, G., Korovkin, N., *A review of current issues in lightning protection of new-generation wind-turbine blades*, IEEE Transactions on Industrial Electronics 55 (6), 2008, pp. 2489-2496.

[30]. Baba, Y., *Review of electromagnetic models of the lightning return stroke*, IEEJ Transactions on Power and Energy 129 (9), 2009, pp. 1139-1151.

[31]. Karami, H.R., Moini, R., Sadeghi, S.H.H., *A model-based parameter estimation of current distribution along lightning return stroke channel*, Proceedings of the 18th International Zurich Symposium on Electromagnetic Compatibility, EMC, art. no. 4388259, 2007, pp. 317-320.

[32]. Sarkar, M.Z.I., Sarker, M.A.I., Ali, M.M., *Effect of lightning return stroke current parameter's on the components of lightning generated vertical electric field over finitely conducting earth,* Proceedings of ICECE 2008 - 5th International Conference on Electrical and Computer Engineering 1, art. no. 4769170, 2008, pp. 43-48.

[33]. Hao-Jiang, W., Li-Hua, S., Bin, Z., Yan-Xin, L., Yi-Chao, Z., *Development of the measuring system for lightning current on high tower*, IEEE International Symposium on Electromagnetic Compatibility, art. no. 4413453, 2007, pp. 150-153.

[34]. Zhang, Q.-L., Qie, X.-S., Zhang, T.-L., Zhao, Y., Yang, J., *Observation and numerical simulation of lightning discharge current along the lightning channel*, Tien Tzu Hsueh Pao/Acta Electronica Sinica 36 (9), 2008, pp. 1829-1832.

C2.3. The scientific expertise of the applicant. Expertise domain and significant results - both theoretical and practical

Although the problem of identifying the spatial-temporal distribution of the lightning return current is naturally modeled by integral equations, previous techniques for obtaining solutions are focused on trial and error type experiments.

The applicant, originally proposed in the interpretation of the Fredholm integral equations as an inverse problem, with its natural incorrectly formulated character and further, the application of regularization techniques. The bibliography research did not identified such an approach. The author and his team treated the complete model obtained by demonstration, in which kernel Green start from rational expressions to simplifying assumptions, and go to the Sommerfeld integral expressions with Bessel functions.

Regularization techniques are recently introduced, and their application to similar problems of electromagnetic field synthesis is already validated. The research conducted by the applicant was directed to better characterize the phenomenon of lightning, and to increase accuracy in estimation of the return stroke current - as a cause of potential harmful electromagnetic fields.

1. Development of some Fredholm integral models for the reconstruction of the return stroke currents [A2.2.5], [A2.2.16], [A2.2.18], [A2.2.23], [A2.2.24], [A2.3.2], [A2.1.31]

It was expanded the assumptions regarding the description of integral equations models, using the following means: formulating models with the dipole theory in curvilinear coordinate system; analysis of models to pass from the time domain in a frequency domain; the soil is considered with finite conductivity; appearance of some attraction towers of lightning channel; the air change its properties during weathering. The integral models identified in the bibliography, which were derived by image method, does not reflect the actual properties of the soil, do not take account of changing the complex air permittivity during storms. The dipole modeling theory allows superposition, by demonstration of the three possible field components: static, induction, radiation.

1.1. Deduction of some electrostatic testing models from the general integral field equation

In a simple case of approach, for the current channel replaced with a linear charge distribution, the field model becomes electrostatic. In this reduced model it is estimated that the transition to curvilinear coordinate system may be useful, such that the channel can be considered to be vertically or diagonally. Electrostatic integral equations can serve to a series of subsequent tests, with built-in functions of charge distribution line.

1.2. Case study regarding the influence factors: geometries, material/ environment characteristics, sampling frequencies, extracted field components

In case of dynamic modeling of the lightning phenomenon, the integral equations kernels depend of the geometric coordinates, the frequency of the generated electromagnetic field, the current front propagation speed. It was followed up: the model transcription in curvilinear coordinates on an oblique channel; study regarding the influence introduced by the complex permittivity of air, like an electrolytic medium; the models expression in relation to the fields' projections by the coordinate system axes. There were discussed some possible scenarios for the location of field sensors, for radial or axial components.

There was approached various ways to express the current propagation speed. If it is accepted a constant speed, using the argument that between the current peaks and the measured field, there is a linear relationship, then there is the risk to transmit forward quantitative errors in the current identification process. Otherwise, the speed, which is considered as time variable, complicates the passage of the model from time to frequency.

1.3. Analysis of some field models, with complex variable, in curvilinear coordinates and the assumption that the soil is plane-(non)homogenous, with finite conductivity

If the soil has finite conductivity, the method of images is no longer viable. The applicant indicates to use, for this link demonstration, the dipole theory. With increasing frequency, high frequency components of the field will be attenuated in the soil.

The real soil involves the use of Bessel functions in semi-infinite integrals of Sommerfeld type. Few details were found on this direction, due to the complexity of the models On the other hand, numerical meshing of these kernels can improve stability of the solutions, and therefore it was tried to detail this issue **[A2.2.16]**.

This stage result in a clear and as much as complete package of models, shown individually in relation to soil characteristics.

1.4. Analysis of some field models, with complex variable, in curvilinear coordinates and the assumption that there exist some lightning towers

When on the soil surface, regardless of how its properties were considered, there are capture towers of the lightning channel, due to electrical current reflection, this current may be contaminated. So, even with a good precision of measurement in these cases is possible to obtain a wrong return base current. The applicant give some arguments for this hypothesis, using the results obtained in **[A2.2.18]**, and also using an approach from **[A2.2.5]**. Therefore, it follows the discussion of the problem of modeling, focusing on the issue of changing the speed front current in the tower (lightning conductor), respectively the possibility of introducing some correction functions in the models.

1.5. On performances characterization of the numerical models: numerical approximation and integration versus boundary elements integration

The electrical return stroke current reflections by lightning conductor, when it exists, the measurement errors introduced by the field sensors, errors that are introduced by LLS devices, all in the process of transition from full integral-analytical model to the numerical one, become potential sources of errors, or structure errors, which may lead to uncontrolled rise of the solutions: spatial-temporal distribution of the return current.

For this reason, special importance was given to methods of transition to the numerical model to linear or nonlinear systems of equations. It was found that the interchangeability property of the variables of Green functions (changing the source point with the observation point), the kernel of the integral equations, can significantly improve the conditioning of the system matrix. Approximation and numerical integration, directly applied to the analytical model are relatively easy and suitable for (non)homogeneous environments. On the other hand, for linear models, the author has recently developed algorithms for the application of the boundary elements method on integral equations **[A2.2.24],** like a field synthesis problem. The applicant intends to extend this procedure to present models, compared with classical numerical meshing.

2. Advances on a regularization module for integral equations that correspond to the lightning phenomenon

[A2.1.3], [A2.1.2], [A2.1.5], [A2.1.18], [A2.1.22], [A2.1.30], [A2.1.31], [A2.1.34], [A.2.3.17], [A.2.3.18]

The concept of the advanced regularization module refers to the grouping and adjustment of some numerical regularization algorithms, to be applied in solving system equations, derived from the Fredholm integrals of the lightning modeling.

The aimed algorithms involve their writing into pseudo code and also the implementation of the library of exec. routines in MATLAB program. The structure of an algorithm aims to:

- Develop effective procedures of regularization, with optional external call to a method for choosing the regularization parameter;
- Fix assessment criteria of effect error and cause error, after the first solution - the spatial-temporal distribution of the return current - will be decomposed as a complex value, into the real part, with physical relevance, respectively into the imaginary part, which is desired to be minimum;
- Evaluate the computational effort;
- Test the solution performance indicators: stability, accuracy, reliability.

2.1. Discussion of some functional algorithms for regularized conjugate gradient method - identification of curve L ribbon from the number of iterations

It was adapted an algorithm that already has proven its performances on the field synthesis applications and optimal design of inductive sensor coils, respectively of magnetic treatment of textile bands. In addition, it was desired to include the choice of the regularization parameter from the parametric representation, as an *L* curve, from the difference between the standard solution, versus the standard effect error (the difference between the measured field and the calculated one). This curved representation was found in the iterative process of the RGCM method.

2.2. Adapting algebraic reconstruction technique in deterministic and randomized versions

The algebraic reconstruction technique has grown as a recently imposed numerical method, used to solve equation systems. The applicant **has originally applied this method** to solve low conditioned equation systems, from field synthesis problems, that were incorrectly formulated.

The method was validated through precision comparative results with the one that use specific regularization procedures. On this base, it was considered that the method is viable to be applied to the identification of the *return stroke current*, both in the iterative deterministic or random system of equations.

2.3. Harmonic reconstruction analysis

The applicant has achieved a statistical study regarding the singular values and vectors variations, corresponding to a relative high number of ill conditioned matrices, specific to incorrectly formulated problems. The graphic representations can be characterized by a harmonic analyse of a signal, and even more, the solution of an ill conditioned system can be expressed by a balanced sum of signals, more exactly, singular vectors **[A2.1.2]**.

The major conclusion of the study was that regularization – to reaching solutions **-** can be considered as a harmonic filter process. It was proposed the same steps for algorithmic adaptation, with the observation that in case of reconstruction of the lightning current, the solutions are complex numbers.

2.4. Partition regularization and variants of local over-regularization, implemented to integral transpose models

It was desired to follow up the obtained performances with some particular techniques of regularization. *Partition regularization* was applied with success by the applicant, in power grid systems for power flow calculus **[A.2.3.18]**; it implies to improve the conditioning for only some of the sub-matrices from the kernel matrix.

The author justify the possibility of implementing this method, by calling the same property of interchangeability of Green functions, so the bad conditioning nature of the kernel matrix, appears to be concentrated in sub-matrices.

The local over-regularization, proposed by the author in an original way, consists in smoothing fluctuations of the solution margins, and may be necessary in evaluating any integrated mesh model.

The work proposes the introduction of some algorithms, as extension of local over-regularizations routines, when it is necessary.

2.5. Implementation of a fuzzy module to choose the regularization parameter

From the previous research, the applicant has observed that the iterative methods of regularization (iterative Tikhonov regularization, regularized conjugate gradient method, algebraic reconstruction) manifest high performances, if the regularization parameter is adjusted on each iteration step **[A.2.3.17].**

So, it was implemented a fuzzy regulator used for the parameter adjustment, coupled in MATLAB, with some mentioned regularization algorithms. There must be done some modification on the fuzzy block, so as to be used for the specific problem.

2.6 Establish performance indicators for a qualitative ranking of solutions, obtained from incorrectly formulated models

The degree of precision, the stability and reliability of solutions of the return stroke current can be measured only by evaluating some indicators, named by the author, of performance. It is desired that these indicators shall be included in the proposed regularizations algorithms.

From previous experiments, it was estimated the development of the following indicators: Picard’s condition, condition number, imaginary complex part of the solution, computation effort, and also the effect errors and the solution error.

For a qualitative appreciation of the regularization methods and their solutions, some of the proposed indicators, it was needed the evaluation before and after regularization.

In the light of the treated aspects, it is summed up what the applicant considers to be unsolved problems and potential solutions, in studies to identify the spatial-temporal distribution of ascendant leader:

- Vertical antennas do not rigorously reflects the lightning channel: it was proposed the modeling in generalized curvilinear system, so the current channel to be shaped by cone generators, or truncated cone.
- Idealized soil properties may be used to test validation techniques of proposed numerical solution
- When one considers the soil with finite conductivity, Bessel functions and Sommerfeld integrals appear, semi-infinite; the author found that the numerical

meshing of integral equations kernels, containing Bessel functions, can drive to the improvement in conditioning a system of equations to be solve, so we have a stability signal of the solutions. In another research contract, the author has successfully treated a numerical evaluation of semi-infinite integrals, applying iterative methods or Monte Carlo type ones

- To avoid contamination of the current base measurements, due to reflections that occur in lightning towers, it is considered the full identification, spatial and temporal, of the return current from the electromagnetic inverse problem, incorrectly formulated.
- Collocation method, as a mean of numerical solving the Fredholm integral equations, do not treat the stability issue of the solutions, so that the results can be affected by uncontrolled amplification.
- MTLE models, respectively MTLL introduced to characterize current space attenuation are affected by substantial errors. The proposed regularization techniques, estimates to improve the accuracy of ascendant leader identification.

It is thought considered that the **rigorous research is directed,** with a **central objective.** The applicant puts less emphasis on the idea of interdisciplinary collaboration, but greater emphasis on collaboration-oriented themes and equally transmission of knowledge gained, toward environments that follow the establishment of concrete measures for protection against lightning strokes.

C3. Development of field synthesis numerical modeling tools applied to electrical circuits stability and synthesis, respectively electromagnetic field synthesis in non-homogeneous media

C3.1. The scientific expertise of the applicant in the research field C3

One area of research that highlights the complementary research directions (Electrical Engineering + Power Engineering + Mathematics) successfully addressed by the applicant, is the synthesis of the electromagnetic field in non-homogeneous media respectively the application of some numerical modeling elements specific for field synthesis at the study of electrical circuits stability and synthesis.

The disemination of the results obtained in this area are: **[A.2.2.4], [A.2.3.2], [A.2.1.31], [A.2.1.30], [A.2.1.4], [A.2.1.2], [A.2.1.18], [A.2.2.12], [A.2.1.10], [A.2.2.14], [A.2.2.19], [A.2.3.6], [A.2.3.8]**

The materialization of all these applications is based on a common core, electromagnetics and mathematics. More specifically, phenomenological modeling uses tools of electromagnetic field synthesis and the mathematical model uses the concept of regularization. The practical guidelines are supported rigorously by applied scientific research in the field of electromagnetic field synthesis and electromagnetic inverse problems. Any qualitative aspect newly introduced in industrial practice comes mainly from experimental laboratory results.

Multidisciplinary complementary electrical engineering aims both theoretical-mathematical enrichment and their certification by obtaining concrete practical - phisical results. This refers to the theoretical approach regarding the electromagnetic field synthesis in non-homogeneous media using Monte Carlo method, in close relationship with the finite difference Poisson equation.

C3.2. The importance and the relevance of the scientific content

Presently, in this domain, there is still no unified point of view on how to elaborate the synthesis problem. Even the adopted name, "*synthesis*" is often replaced by the notion of "*inverse problem*", this last name having a more general sense. But if we assume that the direct problem of the electromagnetic field is the analysis problem, then it is logically to propose the inverse problem of the electromagnetic field to be the synthesis problem. Here are some bibliographic sources referring to the notion of *'synthesis'*: [1], [2], [3]. These authors give a four section classification for the synthesis:

- projecting synthesis, which appears when in the conception process of an electromagnetic device there have to be realized some characteristics in connection with the properties of an electrical or/and magnetic field [11], [16], [20].
- identification synthesis, which pursuits that part of the theory and application of the synthesis where the verifications of the properties of an electromagnetic device after an operating period or after some repaired damages is a necessity [6], [13], [18].
- optimization synthesis, constitutes a problem when, under certain restrictions, an electromagnetic field has to be precisely realized [4], [5].
- secondary sources synthesis, is about assimilation of the boundary conditions with secondary sources (single or multi-layer) [2], [15], [20].

The applicant considers that under the notion of projecting synthesis all the practical applications of the synthesis theory may be grouped. The identification synthesis is in fact a designing procedure, the optimization synthesis can be integrated in the projecting synthesis, being the most spectacular chapter of its, and secondary sources synthesis reflects a specific projecting method.

Nowadays, the process of elaborating the synthesis problem is very closely related to the process of elaborating the electromagnetic field analysis problem. In the analysis problem there are given the following dates:

1) the material conditions (permittivity, permeability, conductivity); 2) the moving conditions (for mobile mediums); 3) the initial conditions (for variable state regime the magnetic and electric field has to be known in each of the domain points in the initial moment); 4) the boundary conditions (the values of some components of the electric and magnetic field at the edge of the domain, inclusively for the infinitely case, if the domain is infinite); 5) the sources conditions (which implies to know on each of the domain points the volume density of the electrical load, the volume density of the electrical flow, the polarization, the flux density, the imprinted electrical field; if there is some inhomogeneous sub-domains, the superficial density of electrical load, respectively the surface electrical current at the limit of these sub-domains have to be known).

Under the hypothesis that all these conditions (unique conditions) are determined, and the domain is specified, the analysis problem requires to find the state dimensions of the electrical field (E,D) and/or the magnetic field (H,B). In these conditions, the analysis problem has a unique solution. If the electrical and magnetic field are in a steady state regime, the conditions are: 1), 4) and 5). The electromagnetic field synthesis problem uses the following conditions as to be known:

- the electric field and/or magnetic field on the entire domain, or only on a sub-domain [4], [9], [18].
- the whole domain or only a part of it (the configuration of the boundary may be requested when certain conditions have to be accomplished). [5], [9], [19].
- the material conditions on the entire domain or only on a part of it (the unknown condition are to be determined along with the other dimensions). [5], [10].
- the boundary conditions on all of the frontiers of the domain, or only on a part of them, the rest of the boundary out coming to be funded. [9], [17], [18].
- the sources conditions totally, partially or not at all. [6], [13], [14].

For all the facts above, by projecting synthesis it may mean we want to find:

- the optimal configuration of the unknown boundary (on this boundary conditions may or may not be priory known). [5], [19].
- the material conditions on certain sub-domains. [5], [10].
- the limit conditions on certain frontiers. [9], [17], [18].
- the sources conditions, totally or partially. [6], [13], [14].

The synthesis is called simple if one of the conditions is requested and composed if two or more conditions are simultaneously wanted. Any kind of synthesis problem of electromagnetic field type assumes to go through some specific stages in the solving process. The weight of each stage and also the difficulty rate of them is different from a problem to another. These stages are shortly exposed below:

1) Establishing the phenomenological model (the physical model)

This stage needs an explanatory note about the unique conditions and about the imposed field, such that to be clearly determined which are the unknown dimensions in the synthesis process.

2) Developing the mathematical model

The mathematical model may be chosen in a various way. Thus, if the electromagnetic field laws are used under their differential form, then the mathematical model is considered differential; if to the laws are associated equivalent energetic functional, the model is variational; and if the laws are applied under their integral form it is said that the mathematical model is integral. To a phenomenological model any kind of mathematical model can be attached, but generally there are objective criterions (regarding the type of the problem) or subjective ones (depends on the affinity to a certain model) that make the difference.

3) Developing a method to perform the mathematical model

This method may be analytical or numerical. The analytical method is applied when - by effective solving of the equations of the mathematical model (generally, differential) - there is a stated symmetry. The most adequate method is to variable separation. The numerical method used for analysis is closely related to the chosen mathematical model.

The differential mathematical model involves the application of the finite difference method or Monte Carlo method. [14], [15].

The variational mathematical model imposes the use of the finite element method, in this way being an additional intermediary method to pass from the analysis method to the synthesis one [5], [13].

The integral mathematical model has the corresponding method for processing the boundary elements method [17], [20].

By analogy reasoning with the terminology from the analysis theory one can claim that the mathematical model alongside with the processing of the numerical method constitutes the numerical model of synthesis. Performing the numerical model of synthesis it is obtained a linear system of equations which in most of the cases is degenerated (this degenerated being due to the overconditioning, a specific situation of the inverse problems) or ill-posed. From this point, the synthesis problem begins.

4) Developing the synthesis method

The synthesis method selected takes account of the type of the resulted system of equations from the last stages.Thus, the numerical method which goes with Monte Carlo return a system of m equations with n unknowns, mxn. A good conditioning of the system is achieved with the statistical method of randomizing, and the pseudosolutions are unique (the r rank satisfies the condition r=n) and generally accepted. By the other synthesis methods we receive systems of equations which pseudosolutions are unique, but unacceptable in most of the cases (they cannot be realized physically) or they get systems of equations with infinity of pseudosolutions and the normal solution being inadequate. Therefore, it is necessary to use the regularization. The regularization method [8], [13], [17] makes a compromise between the norm of the error (precision) and the norm of the solution (accomplishment, stability).

A conclusive image of the actual state in the research of synthesis follows these directions: new visionary approaches and new mathematical structures and theories of inverse problems, degenerate systems, conditioning number, regularization; an evaluation of the extent of the computational algorithms used to treat the mathematical and numerical models, with an important impact to a more flexible approach of the theoretical hypothesis; grouping the soft operate methods (fuzzy; neuro-fuzzy; genetic algorithms; adaptive methods); extract and eventually conceptualize the procedure particularities from the rich field of existent applications; an analogy with the theoretical and practical improvements from other domains, in the way of finding and developing adapted solutions. The actual tendency in the scientific community [6] – [15] is to consider, indirectly, the estimating parameters problems, as inverse nonlinear problems. For a specific study case, with the mathematical model attached and the observable date being known, it is to be found the parameters that explain the physical phenomena that happen. The identification of these parameters lead to optimization problems, which generally are grounded on nonlinear least square methods. The attempt is to use on a large scale the regularization methods of Gauss-Newton Tikhonov and Gauss- Newton of minimizing the norm. They are both converging to a solution with a minimum norm.

References

[1]. Brooks N. R., et all, Application of Nested Optimization/Regularization for the Magnetostatic Field Synthesis Algorithm, Variable Field Generation, IEEE, Trans. Magn.,Vol. 42, No. 4, pp. 1147 – 1150, April 2006.

[2]. Beltrame P., and Burais N., Application of regularization method of quasi-singular integrals to compute eddy-current distribution near cracks, COMPEL, Vol. 21, No. 4, pp. 519 – 533, 2002.

[3]. C9. Chadebec O., et all, How to Well Pose a Magnetization Identification Problem, IEEE, Trans. Magn., Vol. 39, No. 3, , pp. 1634 – 1637, May 2003.

[4]. Jiu-Kyu Byun, Il-han Park, Song-yop Hahn, *Topology optimization of electrostatic actuator using design sensitivity*, IEEE Transactions on Magnetics, vol. 38, no. 2, March, 2002.

[5]. J. Byun, J.Lee, I. Park, H.-B. Lee, K.Choi, S. Hahn, *Inverse problem application of topology optimization methodwith mutual energy concept and design sensitivity*. IEEE Transactions on Magnetics, vol. 36, no. 4, July, 2001.

[6]. Daniela Calvetti, Numerical Aspects in Inverse Problems, Kuopio and Tahkovuori, Finland, 23-27 February, 2004.

[7]. Albert Tarantola, Inverse Problem Theory and Model Parameter Estimation, Barnes & Noble, SIAM, 2004.

[8]. Ronny Ramlau and Gerd Teschke; Tikhonov replacement functionals for iteratively solving nonlinear operator equations; INSTITUTE OF PHYSICS PUBLISHING, Inverse Problems 21, 1571–1592, 2005.

[9]. Lars Elden and Fredrik Berntsson; A stability estimate for a Cauchy problem for an elliptic partial differential equation; INSTITUTE OF PHYSICS PUBLISHING; Inverse Problems 21, 1643–1653, 2005.

[10]. Abdellatif El Badia; Inverse source problem in an anisotropic medium by boundary measurements; INSTITUTE OF PHYSICS PUBLISHING; Inverse Problems 21, 1487–1506, 2005.

[11]. Gang Bao and Peijun Li; Inverse medium scattering for the Helmholtz equation at fixed frequency; INSTITUTE OF PHYSICS PUBLISHING; Inverse Problems 21, 1621–1641, 2005.

[12]. Thorsten Hohage, Numerical Aspects in Inverse Problems Kuopio and Tahkovuori, Finland, 23-27 February, 2004.

[13]. Olivier Chadebec, Jean-Louis Coulomb, Mauricio Caldora Costa, Jean-Paul Bongiraud, Gilles Cauffet, Philippe Le Thiec; A new regularisation method of magnetostatic inverse problems applied to thin-shells; LEG/ENSIEG, BP 46, 38402 Saint Martin d'Hères, INPG/UJF CNRS UMR 5529-France, 2004.

[14]. Min Xu, Min Xu, City University of New York, IUSL Electric field Monte Carlo simulation of polarized light propagation in turbid media; 27 December 2004 / Vol. 12, No. 26 / OPTICS EXPRESS 6539, 2004.

[15]. Magda El-Shenawee, Carey Rappaport, Michael Silevitch; Monte Carlo simulations of electromagnetic wave scattering from a random rough surface with three-dimensional penetrable buried object: mine detection application using the steepest-descent fast multipole method; OSA A, Volume 18, Issue 12, 3077-3084 December 2001.

[16]. R. Zaridze, D. Karkashadze, K. Tavzarashvili, A. Bijanov, E. Moreno, "PBG device simulations," Progress in Electromagnetics Research Symposium PIERS 2002, July 1-5, Cambridge MA, USA, pp. 443, 2002.

[17]. Jerry Eriksson and Per-Åke Wedin Regularization Methods for Nonlinear Least Squares Problems, Part I: Exactly Rank-deficient Problems, Technical Report UMINF-96.03. Submitted to SIAM Journal on Scientific Computing, 2005.

[18]. Michael Jacobsen; Two Grid Iterative Methods for Ill Posed Problems, Kgs. Lyngby, Denmark, 2001.
[19]. Jeonghoon Yoo; Modified Method of Topology Optimisation in Magnetic Fields; I.E.E.E Transactions on Magnetics; Volume 40, Part I, pp 1796 – 1802, July 2004.
[20]. Fatehi, S.H.H. Sadeghi, M. Fatehi, R. Moini, Computing Electromagnetic Field Distribution Due to an Arbitrary Shape Exciter Near Multilayer Slab Conductors; I.E.E.E. Trans. Magn.; Volume 41; pp. 1132 – 1136; March 2005.

C3.3. The scientific expertise of the applicant. Expertise domain and significant results - both theoretical and practical

The contributions in this field can be divided in **two directions**. The first direction refers on research regarding the **electromagnetic field synthesis**. It is strongly fundament the mathematical basis of the synthesis and also there are mentioned personal contributions on numerical methods used in electromagnetic field analysis. The second direction, concentrates on applying some mathematical synthesis elements to the **electrical circuits stability** and **synthesis**. The regarding matters about electrical circuits are original and the Monte Carlo method is a highly research personal orientation, quoted in the references.

The scientific results obtained are not only original but also driving toward concrete and useful for industrial practice which is the final purpose of the research:

[A.2.2.4], [A.2.3.2], [A.2.1.31], [A.2.1.30], [A.2.1.4], [A.2.1.2], [A.2.1.18], [A.2.2.12], [A.2.1.10], [A.2.2.14], [A.2.2.19], [A.2.3.6], [A.2.3.8]

Obtained research results:

- Developing and implementing a new synthesis method based on geometric inversion for parametric circuits
- Stability testing of parametric circuits using the conditioning number
- Implementation of theoretical solutions on various parametric circuits that have previously been tested in terms of stability using the condition number
- Developing a synthesis method for a device in electric and magnetic stationary state
- Developing an original approach on the synthesis and stability of the electrical circuits, using the condition number and Wielandt - Kantorovitch theorem
- Elaborating the theory of analytical field synthesis for electromagnetic devices in homogeneous and inhomogeneous media in a steady state and variable regime
- Developing a numerical model for an electromagnetic device and its field synthesis
- Formulating the mathematical basis of the synthesis method to be used
- Solving the numerical model through specific field synthesis methods

- Developing efficient algorithms for computing implementable methods in synthesis design of electromagnetic devices
- Solving the numerical model for electromagnetic device synthesis using field synthesis methods and Tikhonov regularization method
- Choosing a relevant regularization parameter using fuzzy techniques

1. Electromagnetic field synthesis in non-homogeneous media

The problem of numerical analysis of the electromagnetic field in non-homogeneous medium is well known. One can find numerous papers in the dedicated references. An original approach in the analysis of the electrostatic field with Monte Carlo method in non-homogeneous media was done by the applicant for a series of particular cases. The Monte Carlo problem in inhomogeneous media rises a series of difficulties related to the movement of the fictious particle; many diverse solving methods are proposed, but they only partially conduct in the proper results. As regarded the synthesis problem of the electric field in non-homogeneous media, a great effort was developed by the applicant and his team.

It can be stated that establishing the theoretical basis of Monte Carlo method needs to precisely indicate the way how the system of equations, specifically to the synthesis process, appears. The system is generally ill – conditioned and its pseudosolutions make up the response to the non-homogeneous synthesis problem. The main approximation, which in fact individuates the proposed synthesis method, consists in the following aspect: the discretisation network must be sufficiently refined, so as to admit that the boundary of the non-homogeneous domains is constructed only from shapes parallel to the coordinate axis. It is necessary to determine the numerical expression of the Poisson and Laplace equations for a rectangular grid, with unequal steps, in homogeneous and non-homogeneous media, in stationary electrical and magnetic field, all due to the fact that the non-homogeneous media have the boundaries parallel to the axis.

It was deduced, throughout an original method the numerical expression of the Poisson equation for a rectangular grid and an inhomogeneous medium, based on the approximation of the potential function and the Taylor series, when the explicit form of the Poisson equation is used. This method is somehow different from those presented in the literature, that directly use the electric flux law in the discretised domain, the electrostatic potential theorem, being here implicitly applied throughout the evaluation of the field by the potential. The method developed by the applicant will rely on the assumption that the non-homogeneities have boundaries parallel to the coordinate axis. This hypothesis does not restrict at all the general character of the problem, giving thus the opportunity to freely choose the discretisation step. It is then possible to simplify the Monte Carlo method. This method is called the contour integral method and its theoretical advantage is: it makes obvious the electromagnetic phenomenon on which the numerical form relies. Moreover, it is clearly delimitated the non-homogeneous area, that corresponds to this relation, and the area seized by the current, that has to be considered. It follows the determination of a mathematical relation, for a different statistical estimator (which could be called the second statistical estimator). This fact is not encounter in the literature. The second statistical estimator is very useful in achieving the potential in the problem of electromagnetic field analysis, if it is applied for each of the evaluated points.

2. The development of a design synthesis by the first kind Fredholm integral regularization, and moreover by designing an inductive position sensor with an imposed characteristic.

The shape of the induced voltage related to the position of the coil, being unappropriated to the analogue- digital conversion for a regular coil, the problem raised was to apply a synthesis a special coil, of certain parameters, choose so as the induced voltage to linearly modify with the position of the inductor wire. The applied methods for solving this problem, led not only to a linear characteristic, but also to any continuously or experimental imposed characteristic. Conceptual design of the sensor coil was made with a variable rectangular section on levels. A singular coiling was considered in this case, situated in a level at the s height, with a 2R dimension settled. The other one 2z(s) will be determined in the synthesis so the total amount of induced voltage in the coil varies linearly compared to distance x where the conductive wire is disposed. After that it was considered the Fredholm integral equation, being initially calculated the induced voltage in the whole magnetic coil, in the hypothesis that the coil is constructed from p levels with N/p coiling on each level. An approximate relation of the induced voltage (adequate to the Tikhonov regularization applied method) because if the coiling is continuously executed on the high of the coil, the levels not being clearly delimitated (situation more appropriate to the reality) then this approximate relation express better the induced voltage. Afterwards, it was passed from instantaneous values, to effective values, and the integral equation having the kernel K(x,s) was finally obtained. A software program has been developed for the problem to be solved. The numerical solution of the linear system obtained, depends on the regularization parameter. For a fixed parameter was calculated the values of the induced voltages. The program was conceived so that the solution to reach a minimum error when the parameter is generated. Of highly interest is the interpretation of the results when the regularization parameter has the value $2.96 \cdot 10^{-16}$, which results in a minimum error. This is the point where a specific aspect of the field synthesis problem needs to be discussed. This requires to establish a compromise between the desire of a certain precision of the solution, and practical possibility of achieving the proper construction of the device sensor (this last condition is called the stability requirement). For the mentioned regularization parameter the solution with the resulted dimension is practically unachievable. The error vector norm is $1.75 \cdot 10^{-3}$ and the maximum relative error, in the induced voltage calculation tends to 1.83%. Acceptable values in the sensor dimension are next expressed in mm in the below section with the levels configured from up to down, at a ½ scale, of course for a different regularization parameter. In this situation the difficulty relates to the variation of the level dimension through the winding gauge, for the cases when N_k has values greater than an imposed limit. In the practical conceiving, the errors that appear due to this difficulty tend to be considerable. A simple calculus show that a number of 50 windings enlarges the dimension of the section with 1 mm, corresponding level high h=2mm. But if we modify the scale of the dimensions, this impediment diminishes, that is if the coil has 20 cm high and 40x40 cm2 section, than a rise in the dimension with 1 mm can be achieved with only 500 windings. It can be concluded that this alternative is useful for judicious choose dimensions. Obviously, each of the obtained numerical solutions has a correspondent in the variant with a different number of windings on levels.

D. Complementarity and interdisciplinarity of the research

Double specialization of the author (Engineering 1998- Faculty of Electrical Engineering - UTCN and Mathematics 2001 - Faculty of Mathematics and Informatics, UBB) gives an interdisciplinary approach (Electrical Engineering + Power Engineering + Math + Computer Science) to the research conducted by the author, bringing a contribution of complementarity in the research results.

E. Conclusions

The research carried out by the candidate on the entire professional career is evidenced by:

- 9 Scientific books (first author - 7);
- 203 Scientific papers published:
  - 19 papers published in ISI Journals
  - 17 papers published in ISI Proceedings

  - 29 articles published in international data bases
  - 138 articles published in B+ journals and/or presented at prestigious international conferences
- 46 citations in ISI/IDB indexed papers
- 3 national research contracts won through competition as director
- 1 international project as team member
- 17 national research contracts won through competition as team member
- 18 research projects for industry

F. Career development strategies that need the habilitation certificate

It is considered that the research conducted by the applicant is rigorously directed, with a main central goal. Therefore, the candidate will give a special importance to future topic-oriented collaboration and to transfer the obtained knowhow towards the concerned industries. There is belief that future expected research results will meet the concern and expectations of the research groups with whom the applicant have closely worked in the last years. The possible solutions envisaged, for the problems identified as being inconsistently treated so far, present a strong motivation for the author to naturally continue his research in the C1+C2+C3 fields.

F1. Future development strategies of the research field C1

Metallic pipelines degradation state prediction creates premises for rational and efficient investments. Applied at the design stage, the proposed methods and technologies meant to avoid pipeline corrosion it will provide the proper conditions for a sustainable development, even in highly polluted environments. The author will pursue to offer accurate and realistic design, modeling and prediction solutions with maximum performance, at the lowest costs, for the estimation and evaluation of the complex phenomena which appear in the physical modeling and numerical simulation of the electromagnetic fields interaction with metallic pipelines. The economic (material) quantification of these results is easily carried out by the gas Transportation and Distribution Operators, by the National Power Grid Operators who form the design stage are forced to use the same distribution corridors. If both power grid designers and underground pipeline network designer will take into consideration these research findings then certainly it will lead to the avoidance of electromagnetic incidents between the two sides, and will reduce maintenance costs of metallic pipeline networks.

Reformulation of the design, modeling, construction and maintenance activities regarding the main energetic resource (liquid fuels, gas, etc.) transport systems, is aimed considering a larger context in which are also integrated the industries concerns and requirements according to stray currents and the continuous monitoring of metallic pipelines degradation state. It is intended to develop some evaluation methods and techniques that would allow analysing some specific practical cases regarding A.C. stray currents effect on metallic pipelines; that would allow to establish risk situations; and to perform behaviour studies on the implemented simulation model if corrosion protection measures and solutions are introduced in the investigated system. The viability of those mentioned above will let to extend the adopted technical solutions to other fields, especially to industrial applications.

The proposed future objectives can be achieved by expanding and improving the performances of the *InterfStud* software developed by the applicant and his group, through the ETHM department’s research project with S.N.T.G.N TRANSGAZ S.A. (project no. 27/2010), for the numerical analysis of the electromagnetic interference phenomena that appear between of high voltage overhead power lines and nearby metallic pipelines and respectively in the evaluation of their influence on the electrochemical corrosion process. Therefore, it is intended to increase the implemented software performance by providing higher accuracy results, by reducing the required evaluation effort and computational time through the use of advanced artificial neural networks, by extending the list of EMI applications that can be analysed with the software (parallel exposures between overhead power lines and underground medium/high voltage cables; between power lines, electrical railway traction systems and nearby metallic structures; faulty operating conditions produced by lightning and atmospheric discharges). The performance increase of the *InterfStud* software, through the EMI problems that can be investigated, will supply a solid ground for the continuation of the ETHM department and LCMN research laboratory collaboration with the industry (TRANSGAZ, ROMGAZ, ENERGOBIT, SNCFR etc.).

F.2. Directions for future development of the research field C2

It is believed that the future obtained research results will integrate the concerns of electromagnetic compatibility research groups listed, the next stage in characterization of lightning phenomena, being represented by calculation of coupling field generated with overhead power lines, telecommunication lines, electronic equipment and even underground power cables.

- **Spatial and temporal identification of return stroke current from the integral model with homogeneous and perfectly conducting ground**
    - Testing electrostatic models with regularization module by using imposed distribution functions
    - Spatial identification the return current from complex variable models relative to MTLE distribution, respectively MTLL distribution – functional validation stage
    - Spatial reconstruction of return current from the complex variable models with radial/axial/polar field components statistically or measurements taken
    - Spatial-temporal reconstruction of the return current, without imposing the base current, with regularization by harmonic analysis
- **Spatial and temporal reconstruction of the return current of the integral model with homogeneous soil and finite conductivity**
    - Identifying spatial return stroke current from complex models with flat ground, taking into account the towers - validation distributions MTLE, respectively MTLL
    - Reconstruction of spatial distribution of return current from the field components measured or/ statistical - flat ground, existence of towers
    - Reconstruction of spatial and temporal return current, without imposing the base current, the harmonic regularization - flat ground, existing towers
    - Comparative analysis of the results obtained, proposals for numerical evaluation of return currents, that characterize distributions of electric / magnetic fields related

F.3. Potential for further career development within UTCN

- As the potential for further career development is to integrate research results and collaboration of LCMN as functional structure within the Centre for Applied Electromagnetism - ELMA within UTCN (CNCSIS accredited since 2005) with other UTCN research structures, on the concept of numerical computation software and artificial intelligence algorithms, with applications in electromagnetic interference and numerical modeling of electromagnetic field (Laboratories: Numerical Modeling, Electromagnetic Compatibility, Advanced computational applications, Computational modeling and advanced simulation). Development in collaboration with the laboratories of algorithms for modeling and simulation (easy to use and implement in any professional software, with all related documentation, portability between different computing platforms and operating systems)
- Providing opportunities for education and training: a lot of research results, in the form

of methodologies, amendments and regulations, will be the basis of completion of courses (master, postgraduate) of the Technical University of Cluj-Napoca and also of some training courses for industry professionals

- Proposal of PhD topics in the ETHM department: numerical modeling of electromagnetic interference phenomena; synthesis of the electromagnetic field; synthesis of electrical circuits
- In the existing LCMN and LCEM laboratories of the ETHM Department it is sought out to improve performances of a training center for students and PhD students in C1, C2, C3 research fields
- Through the addressed research fields, through the publication / communication of results in literature, I think that will be a positive impact on the visibility of UTCN Research-Development activity, increasing the chances that Research Centers and Laboratories form TUCN being accepted in consortia of international future projects HORIZON 2020
  - As before research results will be embodied in scientific papers and submitted to international conferences with wider theme, but the main targets will be those domain-specific conferences and specialized publications with visibility, in which paper appreciations are strictly expressed and in which papers preparation requires prior experience (ISI papers: EPSR, COMPEL, IEEE Trans. Mag., IEEE Trans. on EMC, IEEE Trans. on Ind. Applic., IJAEM, ACMM; BDI papers – from international conferences: UPEC, EHE, EPQU, EMC, CEFC, COMPUMAG, ICLP). It intends adopting the new trend assessment research through participation at conferences organized only under the IEEE, and the publication of ISI with high impact factor.

F.4. Potential development in the international and national academic and industrial cooperation

- Some applications discussed by the applicant so far, have been studied in the context of ongoing research and collaborations with partners from academia and industry and are directly related to research. The obtained research results it was proved to be useful in industry:
  - Technology Transfer – towards SC Electrovâlcea SRL, Râmnicu Vâlcea (2008): Comprehensive and predictive procedures and methodologies applicable to equipment and electrical insulating materials built with customization for underground cables
  - Technology Transfer – towards TENARIS (2008) Solutions to eliminate stray currents in electric motor bearings continuously operating

- Technology Transfer – towards SC Utilitas SRL and Siculus Miercurea Ciuc (2008-2009): *Complex method for investigating the degradation by corrosion of reinforced concrete structures for major historical structures*
- Technology Transfer – towards SNTGN Transgaz SA (2011, 2012): Software package for the study of corrosion of gas pipelines, under the influence of overhead power lines with voltages higher than 110 kV
- Technology Transfer – towards ENERGOBIT SA (2013): Protection solutions for cable screens
- Technology Transfer – towards ROMATSA (2014) Equipment protection solutions of DSNA objectives Cluj and Bucharest DR Section PNA / CNS Cluj and Pulsed Electromagnetic surge due to lightning and power supply lines for voice and data circuits

➢ Continue collaborations with companies whose interest fields intersect with the applicant research directions:

- S.N. TRANSGAZ Medias (liquid fuel distribution; technological pipelines, storage and service tanks maintenance) - with which it was signed in 2009 a collaboration contract for dissemination of the research results in this company; Dr. Eng. Vlad Pavlovschi - director of Development-Research Department TRANSGAZ, who together with the project manager published 3 articles in 2008); S.C. DISTRIGAZ NORD S.A. Târgu-Mureş (design, execution and maintenance of gas networks, gas distribution); S.C. METAL BETON S.A. Cluj-Napoca (design and execution of technological pipeline networks, storage tanks and distribution stations); S.N. C.F.R. General Directorate IFTE (design, execution and maintenance of fixed electric traction installations); ROMCATTEL (storage, bottling and marketing of liquefied petroleum gas), LINET Nowcast; S.C. ELECTROMONTAJ S.A. Cluj-Napoca (design and execution of high-power, low and medium voltage lines); S.C. ELECTRICA S.A. Distribution Branch Cluj (distribution of electricity and energy services);
- Strengthening a very useful practical guide for designers, builders and managers involved in the construction and installation of metallic structures through which they can improve their work and find clear solutions of the problems encountered in their research. This guide should include complete methods for the evaluation and assessment of complex phenomena occurring in physical modeling and mathematical simulation of the interaction between anthropic fields and ecosystems
- Lightning monitoring network approach comes with its interest in expanding in Romania by LINET Nowcast. The effect of such an extension would manifest

greatly enhanced recording with precision the lightning phenomena in the country, with implications particularly valuable in predicting possible failures and faults on transmission lines. Discussions in this regard, went on a favourable trend extending such action.

- Boosting the promotion of the obtained research results in academic field, trough reports and papers, and in potentially interested industry fields by oriented presentations, which could later generate funding (HORIZON 2020). It will be tried to strengthen connections with well-known foreign researchers in the area and to promote some collaboration directions. This should raise the international prestige of the TUCN.
- Continuing the existing cooperation the field at national and international level: University of Western Macedonia, Greece (G.C. Christoforidis – 20 papers in collaboration with the author of this thesis); Universita di Padova, Italy (D. Desideri - 10 papers in collaboration with the author of this thesis); UPB (Prof. C. Popescu – colaboration in research projects CEEx X2C37/2006; prof. D. Gavrilă - CEEx 6856/2006); ICPE C.A (dr. I. Lingvay – 10 papers in collaboration with the author of this thesis, 4 research projects).

G. References

* All the author references (Scientific books **[A1.1-A1.1.9]**; ISI papers **[A2.1.1-A2.1.36]**, Data base indexed papers **[A2.2.1-A2.2.29]**; Research projects **[A2.3.1-A2.3.19]**) are in the file *04_Lista de lucrari.*