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PhD Yearbook | 2010

DOCTORAL PROGRAM IN ELECTRICAL ENGINEERING

Chair:
Prof. Alberto Berizzi

The main objective of the PhD Program in Electrical Engineering is to allow an efficient insertion of the PhD in any research body such as an R&D department of a production or services company. A PhD in Electrical Engineering has a firm basic knowledge of mathematics and physics. This is essential, particularly for handling and understanding advanced tools and methods as well as for proper modeling, analysis and design of electrical engineering applications, with particular regard to power applications.
The main research areas are:

1. Circuit and Electromagnetics:
This field is intended to provide the basic knowledge of methods in electrical engineering for power applications. The students are specifically trained to develop critical ability and innovative approaches. The training method should encourage the development of discussion and debate skills in a team environment. The main subjects are: Nonlinear networks and periodic time variant networks; Analysis methods for three phase and multiphase systems; Switching circuits; Electromagnetic field equations; Electromagnetic field numerical analysis; Electromagnetic compatibility; Design techniques devoted to electromagnetic compatibility.

2. Power Systems:
A PhD in the field of Power Systems involves studies in the following subjects: Electrical energy production (e.g., frequency and voltage control, protection systems, renewable energy sources); Electrical energy transmission (e.g., Power system analysis and dispatch, Optimal Power Flow, Security and stability); Liberalized market issues (e.g., new generation patterns, ancillary service management, existing market models applied to the Italian system, regulatory issues); Power quality in distribution systems (e.g., line current harmonic distortion, active filters, UPS, interruptions and voltage dips); Optimization by innovative algorithms (Neural networks, Genetic algorithms, etc.).

3. Power Electronics:
This research field is strictly related to the rising demand for improved machine and converter performance, in terms of low price, efficiency, robustness, dynamic response and drive control. This need leads to device optimization and better design and testing criteria. Moreover, a system approach is required for accurate integration of technical and economic aspects for final application. The main subjects in this field are: Use of new materials; Novel magnetic structures; Methodologies of model development for design and operating analysis; Optimization procedures; Use of finite elements code, simulation programs and environments for device study; Control system definition both on the device and system side.

4. Measurements:
This research field concentrates on the fundamentals of metrology, particularly with respect to characterization of modern measurement systems based on complex structures of digital signal processing. Some of the main subjects of study are: measurement methodology as it relates to power systems, and both digital and analog signal processing. Methodologies and measurement systems associated with industrial automation and, in particular, microelectronic sensor applications, field bus based hierarchical and distributed structures, and advanced algorithms are studied in detail.

The PhD Course in Electrical Engineering is organized on a time horizon of three years. Each year, the PhD carries our both didactic and research activities and at the end of each year he is evaluated by the PhD Board. At the beginning of the first year, the admitted students propose to the Board both the area in which they would like to develop their research and a supervisor.
During the first year, the students complete their knowledge by taking some Introductory courses chosen among the MSc Courses at Politecnico di Milano, and begin a training activity thanks to courses specifically designed for the PhD (Main Courses). At the same time, the students must select, among the proposed dissertation subjects, the subject of their research, and must prepare a "Research project" where they explain the way they will develop it. The choice of the subject must be approved by the Supervisor. Moreover, they have to deeply study the subjects related to the proposed area of research by means of a bibliographical research. At the end of the first year, a first examination takes place, based on a report prepared by the students for the Board.
The second year is dedicated to the basic scientific and specialized skills necessary for the dissertation, which will be completed during the third year. During the second year, Main PhD Courses must be taken and students are also required to carry out a specific training for research through courses, specialized seminars, conferences, and research activities closely associated with the topic of dissertation. At the end of the second year, the second examination takes place. Here, the students present a second report to the Board.
The third year is entirely dedicated to the PhD dissertation. Four months before the deadline to deliver the dissertation, each student is examined by the Board to verify the work done. If the research performed is evaluated as adequate, the student is allowed to write his dissertation.
After graduation, typically PhD are employed at:
- Major research centres
- R&D departments
- Power transmission and distribution control centres
- Engineering consultant offices, in particular those involved with national and international security and environment regulations
- Metrology reference institutes and certification laboratories
- Process and transport automation areas

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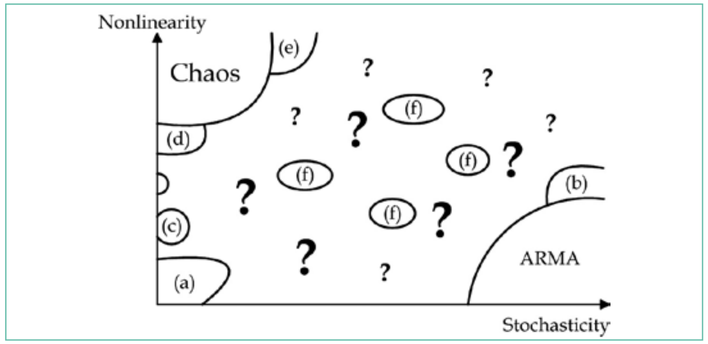
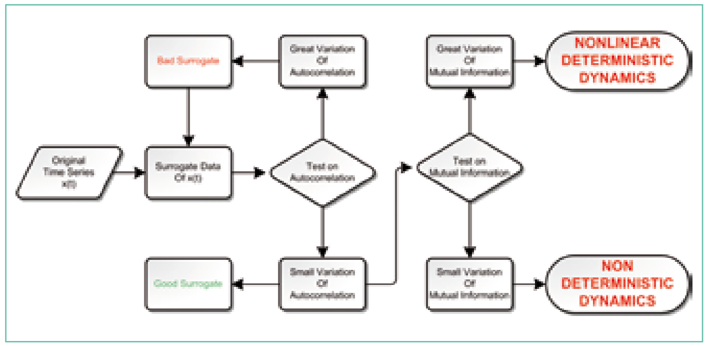
ANALYTICAL AND EXPERIMENTAL STUDY OF DISCHARGE PHENOMENA IN GASEOUS AND SOLID DIELECTRIC MATERIALS

Luca Barbieri

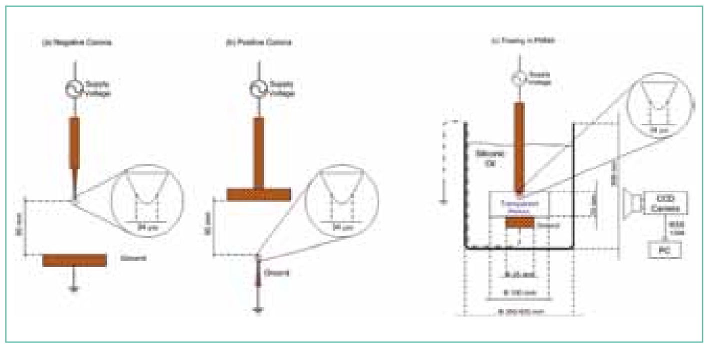
The role of PD in degradation and eventual failure of insulation systems is a well-established fact. The PD phenomenon manifests in a wide range of ways. For example internal discharges within the bulks of the insulation, surface discharges on the surface or at the interfaces of two different dielectric media or as corona effect in air.
The severity of the effect that PD have on the overall insulation depends on the nature and the location of the PD defects. For instance, corona occurring externally to equipment will have no harmful or disastrous effect on the insulation. On the contrary, PD occurring within transformer windings or in slot sections of a motor can have disastrous consequences. Thus PD detection and recognition has become an important tool for the evaluation of insulating degradation in large power apparatus. For this purpose, the phase φ, the apparent charge *q* and the value of occurrence *n,* have been generally accepted as the basic parameters for the pattern recognition of PD by using the standardized algorithm based on the statistical data treatment named PRPDA. However, this method has been insufficient to identify the nature of the PD source in power apparatus. In PRPDA, pulses related to the partial discharges are superimposed within a certain number of phase windows corresponding to the applied voltage. In this way, the correlation between consecutive pulses could not be clarified from one to the other in connection with the applied voltage and the timing of occurrence. Furthermore, inadequate understanding on partial discharge mechanism it makes the pattern identification and insulation diagnose effect of PD monitoring far from reaching practical needs for applications. For this reason, after a brief introduction about the different types of discharges and the main mechanisms of air discharge, in order to achieve greater understanding of the problem, the first chapter introduces two analytical models. The first, developed by Gemant and van Philipoff in 1932 and named *"abc model"* is a circuital model which has been widely used for a qualitative understanding of the phenomenon as well as a starting point for the construction of measuring instruments. This model shows, however, limits and therefore subsequently was shown an analytical model based on field considerations. This way, much more rigorous, has been shown to be a difficult because very often many quantities are unknown and difficult to measure. In reality the only data available appears to be a set of measured numerical sequence. In this case the only feasible procedure, necessarily of type synthetic and deductive, is first in the classification of the system from the observations and only then to identify a model that can predict the evolution of the dynamic system. When we are trying to understand an irregular (which essentially here means non-periodic) sequence of measurements, an immediate question is what kind of process can generate such a series. In the deterministic picture, irregularity can be autonomously generated by the nonlinearity of the intrinsic dynamics. In real world systems, pure determinism is rather unlikely to be realized since all systems somehow interact with their surroundings.
Thus, the deterministic picture should be regarded only as a limiting case of a more general framework involving fluctuations in the environment and in the system itself. However, it is the limiting case that is best studied theoretically and that is expected to show the clearest signatures in observations.
The deterministic approach is not the most common way to explain irregularity in a time series. The two paradigms, nonlinear deterministic and linear stochastic behaviour, are the extreme positions in the area spanned by the properties "nonlinearity" and "stochasticity" (Fig. 1).
The second chapter initially describes the major concepts of nonlinear dynamics. Subsequently, recalled the concept of *"chaos"* and the properties associated with it, are introduced techniques for the analysis of the acquired time series. First was shown how to detect the presence of determinism within time series through a test of null hypothesis (see the scheme represented in Fig. 2).
Subsequently, we introduced the main techniques to process and characterize the time series. These techniques are then used in the third chapter for the analysis of the acquired time series. The figure Fig. 3 shows the pattern of the objects under test, used for the generation of the phenomenon analyzed. The results show that it is possible to say that the phenomena of discharge contain chaotic dynamics. Finally, it is shown how, through the analysis of invariants, it is possible to characterize and distinguish between their various phenomena.
Moreover, in the case of treeing, it is possible to estimate the state of degradation of the insulating material.



1. Sketch of the variety of systems spanned by the properties "nonlinearity" and "stochasticity". Areas where theoretical knowledge and technology for the analysis of time series are available are outlined. Besides the (possibly noisy) periodic oscillations (a), these are mainly the deterministic chaotic and the linear stochastic areas. Also the common routes to chaos (c) and (d), and extensions for small nonlinearity (b) or small noise (e) are marked. There are a few "islands" (f), like hidden Markov models and a few others, where a connection can be made between a nonlinear stochastic model approach and particular real world phenomenon.
This sketch has been inspired by a similar representation by O. Kaplan.



2. Scheme of the procedure for testing the presence of nonlinear dynamics into a time series

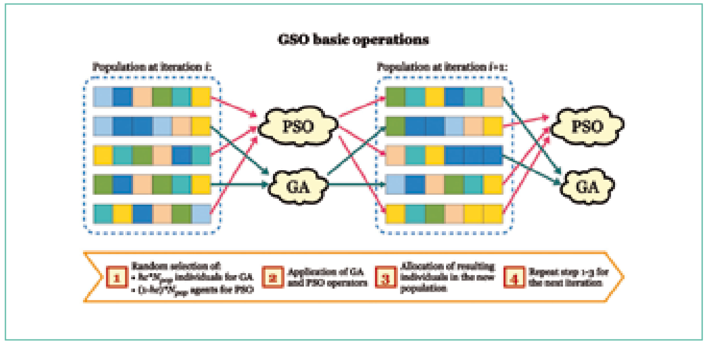


1. Scheme for the object under test:
(a) Negative corona (b) Positive corona (c) Treeing

ANALYSIS OF INNOVATIVE METHODS FOR WSN MANAGEMENT OPTIMIZATION

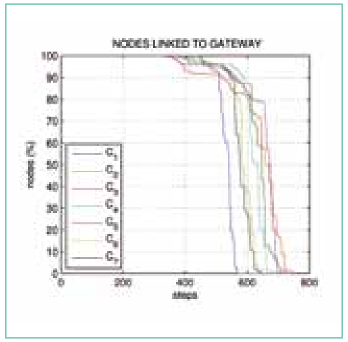
Davide Caputo

Recent advances in highly integrated digital electronics and wireless communication technology have led to the development of low cost, large-scale and low power sensor networks. Such networks are composed by a large number of micro-sensor nodes, which are equipped with sensing and minimal computation capabilities and the ability to communicate with each other without wires. A network composed by these small sensor nodes can monitor a region or phenomenon of interest and provide useful information about it by collecting, processing and combining measurements taken by individual nodes and then communicated over the wireless medium to interested users. Sensor networks are typically composed of a base station, connected to the grid and many sensor nodes powered by a battery and thus, tightly constrained in terms of transmission power, processing capacity and storage; all of the nodes communicate with each other via wireless links. Radio communication represents one of the main advantages of wireless systems because it allows an easy deployment and configuration of the network but at the same time it introduces a series of drawbacks. In fact, in wireless sensor networks,



1. Basic steps in hybridizing GA and PSO and setting up population for GSO algorithm

communication cost is much higher than the computational cost (e.g. required for sensing and pre-elaborate data) and this makes all of the aspects of communication really crucial in terms of network lifetime. This work has been done to develop effective strategies to reduce power consumption due to data communication, mainly focusing on optimizing the data routing mechanism.
Routing is the act of moving information from a source to a destination. Along the way, at least one intermediate node typically is encountered. Routing involves two basic activities: determining optimal routing paths and transporting information groups, typically called packets, through the network.
Since the path loss of radio transmission scales with distance in a more than linear fashion, communication energy can be reduced by dividing a long transmission distance into several shorter ones (multi-hop routing). Intermediate nodes between a data source and destination can serve as relays that receive and resend data.
In order to maximize the network lifespan, in this work it is implemented the Genetical Swarm Optimization (GSO), a class of hybrid evolutionary techniques which exploit in the most effective way the uniqueness and peculiarities of two classical optimization approaches, Particle Swarm Optimization (PSO) and Genetic Algorithms (GA).
This procedure (see Figure 1) is essentially a inspired heuristic search technique, which can be used to solve combinatorial optimization problems, modeled on the concepts of natural selection and evolution (GA), but also based on cultural and social behaviors derived from the analysis of the swarm intelligence and interaction among particles (PSO).
The proposed technique is here applied to optimize the communication energy consumption by selecting



2. Some results. Percentage of nodes connected to the base station during iterations for different criteria

optimal multi-hop routing schemes.
In applying evolutionary techniques to WSN design, critical issues must be considered to trade-off between different objectives:

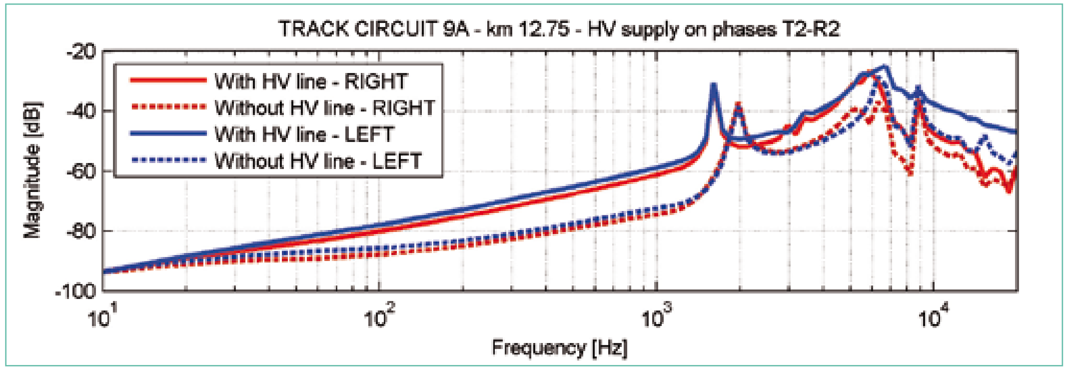
- to reduce the amount of power wasted by wireless devices
- to increase the network lifetime
- to achieve fault tolerance
- in case of individual node failure
- to allow network scalability and deployment
- to reduce bandwidth requirements, enhancing collaboration among nodes
- (e.g. data fusion) since
- the limited wireless channel bandwidth must be shared among all the sensors in
- the network.

Two different case studies has been considered, a partially connected network, where not all of the nodes are connected to each other and fully connected network.
The simulations' environment has been created with a code developed using MATLAB and reproduces the typical tasks of a static wireless network.
The network area is defined as a flat two-dimensional square where n nodes are randomly placed. After the deployment one of the nodes is arbitrarily chosen to be the base station.
The whole network is within the communication range of the base station allowing it to broadcast packets to all the nodes, that is possible since the base station is connected to the grid.
The base station controls the entire network being aware of the battery level of the nodes and their spatial coordinates.
Each node is equipped with a transceiver and a battery.
The radio transceiver of a node can operate in any of four different modes (idle, transmit, receive and sleep mode) and a different power waste is associated to each of them.
In particular, for a fixed data packet size, the transmission cost is assumed to be proportional to the squared distance while the reception cost is constant; sleep mode has very low power consumption. After each simulation round the battery level of the nodes is updated and the dead nodes are removed from the network.
The first scenario simulates the transmission of data from a randomly chosen node to the base station, so basically the GSO is used to choose among the different possible routes which connect the sender to the base station. These routes involve a different number of intermediate nodes and produce a different nodes' usage and power waste.
The key ideas of the proposed approach are to address all the computational costs to the base station (while sensor nodes are involved only in communication and sensing tasks) and to switch the sensor node to sleep mode whenever possible. The other main idea is to use the GSO to perform the choice of the optimal path between base station and nodes on the basis of some routing metrics which take into account different parameters (the energy associated to each link, the residual battery of the nodes involved in the communication task, the distance between the nodes, etc).
In the second scenario, for a given simulation round, all of the nodes have to communicate with the base station and the GSO is used to select the best network configuration to minimize the energy expenses.
In this case, data aggregation is also taken into account.
In both of the numerical simulations several combinations of the different routing criteria are also considered in order to test the hybridization capability of the GSO of enhancing the sensor network lifetime.
The obtained results (see Figure 2) demonstrate the importance of hybridization in defining the best metric to find the optimal path or the optimal network configuration since the best results are obtained using a hybrid criterion.

STUDY OF INTERACTION BETWEEN ELECTRIC POWER LINE AND SIGNALING SYSTEM IN HIGH SPEED/HIGH CAPACITY RAIL TRANSPORT SYSTEMS

Alberto Dolara

The construction of the new Italian high speed/high capacity railway lines opened some new issues about the compatibility between different electric system, which consists of traction circuit, signaling circuit and power transmission lines. These railway lines are supplied in AC, according to the 2x25 kV, 50 Hz scheme, and adopt as signaling system the new European standard called ERTMS level II. High speed lines are flanked on the three-phase line that supply the railway substations (ESS).
The interaction between these systems can cause abnormal operating conditions, malfunctions or failures on signaling systems. This work can be included into the area of electromagnetic compatibility and it is a study regarding how the interaction between the three-phase overhead lines and signaling system takes place and how it would be harmful to the signaling system.
The first part of this work describes the features of the railway system, regarding both traction and signaling system. After a general introduction on the structure of a traction systems, a detailed analysis of the 2x25 kV system, adopted in the new Italian high speed railway lines, is given. Furthermore, the principle of train detection based on track circuit is introduced and different kinds of these circuits are analyzed, with particular emphasis to the audiofrequency track circuits that are the solution adopted in the new Italian high speed railway lines.
The second part of this work introduces the modeling methodologies of the electric connection structure, that is composed by several parallel overhead and buried. The electric lines play a key role in the study of the interaction between power circuits and signaling systems. In order to represent their behavior in a wide frequency range, they require a multiconductor transmission line (MTL) model based on the transmission lines theory (TLT). Rails are conductors of the MTL and they are the means by which the different power electric system can interact with signaling system, as they are the common conductor of traction and signaling circuits and track circuits define a loop which can support induced voltages and currents. Rail is a non-linear ferromagnetic conductor that has a complex shape and that is placed near the ground, so the calculation of the rail parameters is a complex and extremely critical task.
A finite element method (FEM) based on complex magnetic permeability has been developed to calculate the rail internal impedance.
Also the entire system parameters calculation has been based on FEM modeling, in order to integrate the rail model and to take into account other aspects, such as proximity effects due to the presence of several layers just below the rails. Finally, two methodologies for the reduction of the number of conductors in the MTL are proposed. They exploit the characteristics of the system which presents groups of conductors short circuited each other and/or connected to the ground.
The third part of this work concerns the modeling of the entire system and the simulations. Two different kinds of models are implemented. The first one is a reduced model developed in order to assess the impact of the infrastructure, considering a voltage and/or current in one conductor of the MTL a time. It takes into account a MTL 1500 m long and consider two parallel track circuits. In the actual case, MTL voltages and currents depend on the loads, the sources and all equipment connected to the MTL (eg, power transformers in the ESS, impedance bonds, track circuits electrical joints, etc.). So, a complete model of a module of the 2x25 kV system 24 km long coupled with the overhead line that feed the ESS has



1. Basic steps in hybridizing GA and PSO and setting up population for GSO algorithm

been developed. Both models have been implemented in the frequency domain, in order to evaluate the track circuit noise voltage when power circuits are in their typical steady state conditions. Moreover, the linearity of the system allow to evaluate the transfer functions between disturbance source and track circuit noise voltage. So, the obtained results do not depend on the source amplitude but only on the system. The results obtained on the reduced model show that the disturbance transfer functions related to the currents in any conductors of the three-phase line is some orders of magnitude greater than the transfer functions due voltage applied to the same conductor. Moreover, lumped parameters line models instead of the distributed parameters model has been investigated and it has been shown that Γ and reverse Γ models do notrepresent the MTL with enough precision, while T and Π models lead to better results. The solution of the complete model has assessed the noise voltage on the transponder of all track circuits in a typical configuration. In these simulations the interference produced by a source connected to the system is considered, and it is identified in trains on the railway line. Only one train has been considered, and the noise voltage on the transceivers of track circuits has assessed considering several train positions and several ESS connections to the three-phase. The interaction between three-phase line and signaling circuits has been determined comparing the results obtained considering only the rail system and the results from the model that include the three-phase line. Moreover, the equivalent impedance at pantograph terminal is determined and also in this case the impact of three-phase line has been assessed for comparison.
It has been demonstrated that, generally, the contribution on track circuit noise voltage associated with the three-phase line is limited with respect to the contribution related to the electrical conductors within the railway electric system.
The main noise contribution in the low frequency range is due to inductive coupling. Due to the high distance between track circuits and three phase line conductors, voltages induced on the rails has a high common mode component. Track circuits transceiver are immune against common mode rail voltages, only differential mode may create disturbance. Moreover, the ESS transformer converts the single-phase load on its lower voltage side into a two-phase load on its high voltage side: the two opposite currents in the three-phase line conductors induce opposite voltages on each rail, minimizing their sum.
In the audiofrequency range, it is interesting to note that most of the relative maximum and minimum of the track circuit noise voltage amplitude are at the same frequencies at which the equivalent impedance at the pantograph terminal has its relative maximum or minimum points. This indicates that resonances within the system produce a voltage and/or current distribution into MTL that amplify the effect of one or a small group of conductors. While the contribution of three-phase line does not have strong effect on the maximum amplitude of the track circuit noise, his presence changes their spectral distribution.

IMPROVEMENT OF SMALL-DISTURBANCE STABILITY BY FACTS DEVICES

Valentin Ilea

1. Introduction

Low damped electromechanical oscillations, in particular the inter-area modes, have become a common phenomenon in modern power systems especially due to the expansion of the interconnections and to the liberalization of the electricity market. In the traditional approach, these modes are damped using Power System Stabilizers (PSS) installed on the generators. But the effect of a PSS on the inter-area mode is usually weak and, therefore, it is necessary for many PSSs to coordinate their effort to damp these modes; this produces high gains giving birth to destabilizing effects. We overcome the problem by using FACTS together with Power Oscillation Dampers (POD). The FACTS advantage is that not only they improve the small-disturbance stability, but also the steady state and transient system performances. In the thesis we have limited our research to the SVC and the TCSC.

2. Optimal location of damping controllers

It is known that the effect of a damping controller (PSS or POD) on the oscillation modes is proportional with the controllers transfer function (TF) value; the proportionality factor is the residue of the systems open-loop TF. This propriety is traditionally used to design the PSS/POD parameters but, since the residue magnitude gives the strength of the controller, we can use it to find the optimal locations for the PSS/PODs when multiple scenarios are analyzed. Since there can be cases when the residues give very different angular and amplitude eigenvalue shifts, we have proposed the following location methodology: *(i)* we first select the locations with high residue magnitudes in all scenarios and compute the residue deviations with respect to a base case and *(ii)* we chose the location with the minimum deviations as the best one.

3. Global signals

It is well known that an inter-area mode depends on global states. Based on this, we found out that the damping of these modes can improve significantly if *global signals* are defined as inputs to the damping controllers.

The definition was derived noticing first that the variables with the highest participation and observability in the inter-area modes are the rotor speeds or acceleration torques and, secondly, the residue vectors obtained by considering these variables as inputs to PODs are disposed analogous with the mode shape diagram – see, as example, Figure 1.

The local signals are generally very weak for the inter-area modes damping but, by summing them according to the mode shape diagram the effect can be maximized. For our particular example we will have

$$\omega_S = \sum_{i=1}^{N} \pm\omega_i = \omega_{G3} + \omega_{G4} - \omega_{G5} - \omega_{G6}$$

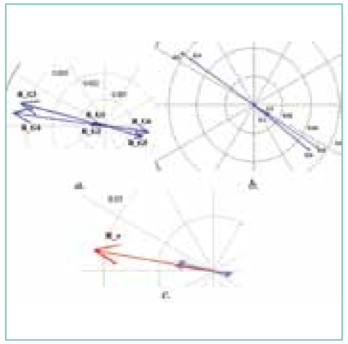
These signals are named *global* or *synthesized* signals and they can be defined using either the rotor speeds or the acceleration torque. The residue corresponding to the new signal – Figure 1, c – is significantly increased and it is usually of the size of a local mode residue for a PSS, which means that an inter-area mode can now be easily damped by a single FACTS device.

4. Optimal location of FACTS to damp the inter-area modes

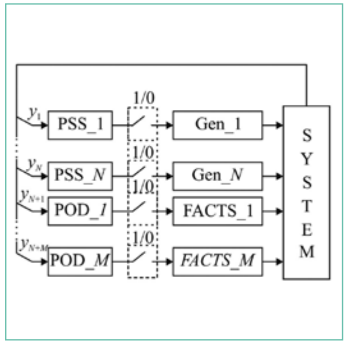
An estimation of how much a physical parameter of the system p can influence an oscillation mode is given by the eigenvalue sensitivity:

$$\frac{\partial\lambda_i}{\partial p} = \psi_i \frac{\partial A_{sys}}{\partial p}\phi_i$$

where A_{sys} is the complete system matrix. Since a FACTS device basically controls a parameter in the network, we use this indicator to estimate the effect of FACTS on a critical oscillation mode.



1. Inter-area mode characteristics for the 3-areas 6-machines test system: *a.* residues derived from local rotor speeds for a SVC; *b.* inter-area mode shape *c.* synthesized signal residues.



2. PSS/POD status representation for GA

Thus, for the SVC parameter *p* will be the shunt reactance of a bus (B_{sk}) while for the TCSC parameter *p* will be the series reactance of a transmission line (X_{km}). Therefore, the optimal installation site of a FACTS device will be the one that gives the highest sensitivity.

5. Genetic algorithms

A major problem nowadays is the necessity for a robust design of PSS/PODs: they should be able to assure adequate damping over the greatest practical range of operating conditions. As possible solution to the problem we proposed two simultaneous design methods that use genetic algorithms.

The first method is more an expansion of the de-centralized residue method since the GA finds the optimal values of the PSS/POD parameters by using the information provided by the system open-loop TF residues. The method implies the pre- localization of the damping controllers as described in section 2. The optimal damping of the oscillation modes is achieved by maximizing the worst damped mode in all the considered scenarios and the PSS/POD parameters are encoded as real type variables.

In the second approach the GA simultaneously fulfils two objectives: it minimizes the number of PSS/PODs and finds the best location (first objective) while maximizing the damping in the system (second objective). To fulfil the first objective the damping devices operating status is represented through binary variables as shown in Figure 2.

The number of the PSS/PODs is minimized by maximizing the number of inactive devices, while the simultaneous achievement of both goals is made by combining the two separate objectives into a new fitness function.

6. Conclusions

All the proposed methodologies were tested on small and medium size networks.

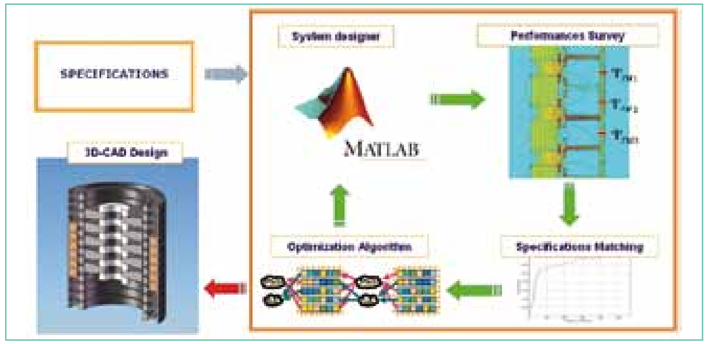
The following major conclusions were drawn: *(i)* the sensitivity method combined with the residue method was capable of finding the best locations for FACTS devices such to maximize the effect on the inter-area modes; *(ii)* the use of FACTS equipped with PODs fed by global signals dramatically improved the damping of the inter-area modes and due to their presence the adverse effects of the PSSs were avoided; *(iii)* the second GA strategy proved to be better since the location problem is modeled as an automatic procedure inside the algorithm.

WSN SUBSYSTEMS MODELING FOR MARINE ENVIRONMENT

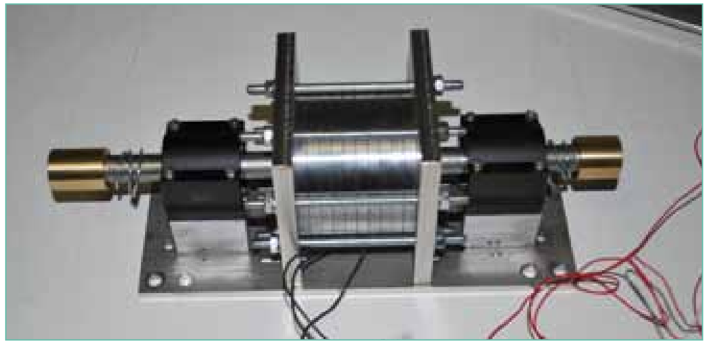
Andrea Pirisi

The impact of anthropogenic factors on climate change has given new impulse to research on environmental monitoring systems, particularly those called *wireless*. The need to control the crucial parameters related to the dynamics of sensible natural areas such as glaciers, tropical forest or coral reef is increasing. Wireless Sensor Network (WSN) environmental monitoring offer the real possibility of managing a large amount of data such as temperature, pressure and acidity in remotely areas accessing from anywhere simply through an Internet connection. Although there are not much models of the "sensor" system across all its components, to support an industrial realization at low cost, the analysis of literary production has revealed how the attention of the scientific community is increasingly focused towards energy issues and long-haul transmission.
The aim of this work is to provide a set of effective approaches in systems and subsystems modeling for the design of Wireless Sensor Networks for environmental application, with particular focus on marine applications.
In particular, this work is focused on the inverse characterization of WSN subsystems and their direct synthesis by using the procedure represented in Figure 1.
This procedure starts from the specifications required to the system performances and use them as constrains of an iterative cycle that involves an equivalent surrogate of the system (predictive model), a *fitness function* that compares the performances of the surrogate with the specifications assigning them a score as input for an optimization algorithm. The optimizator function elaborates this score and generates a new geometric configuration of the physical system, that is represented by the surrogate. The cycle stops when the predicted performances are sufficiently close to the given specification. The procedure provides the final design of the system as output.
By another point of view, the inverse characterization requires numerical simulations and approximative models in order to realize a predictive model of system physical behavior as a function of its constructive parameters. The direct synthesis is based on predictive models and optimization techniques arranged together to realize an automated design of WSN subsystems. This task is make possible thanks to efficient *fitness function* that assign a score to predicted model performances with respect to the specifications required, acting as interface between the system model and optimization algorithms.
The resource limitations of a WSN, especially in terms of energy, require an integrated approach for the different layers of energy scavenging, since the amount of energy from harvesting is typically small and highly variable. In particular, the next generation of advanced sensors for environmental applications requires being equipped with energy harvesting techniques based on water wheels or windmills, and plausibly approaches involving thermodynamics or vibrations, that can be used to extend the time life of batteries.
In order to realize energy harvesting and sensor integrated on the same node of the net, it is necessary to model such subsystem that implies a complete characterization. Since the dynamic response of a system is defined in a *n-dimensional* space, where *n* is the number of independent variables related to the behavior of the system itself, it is possible to bump into computational-onerous circles of simulations. Moreover, complex systems are often characterized by having a dynamic response with random nature that can not provide the continuity required to enforce a graphical interpolation. Fortunatly, some interpolating techniques are conditioned with an ad-hoc set of hypothesis.

The hypothesis that every detected data could be the expression of unpredictable variables and the deepen analysis of the error are useful instruments that form the guidelines of Kriging interpolation technique applied in Chapter 2.



1. Automated design procedure of TPM-LiG by means of FEM analysis and GSO



2. Generator prototype

In order to provide an effective and time-saving modeling of complex systems, an Artificial Neural Network (ANN) can be used as convenient interface between antenna design and global optimization algorithms. An ANN is designed and tested to model the complex relationship between the antenna geometry and the model parameters derived from full wave simulations is presented in conjunction with an optimization algorithm, e.g. the GSO, in order to find out the best design and to improve the performances of a reflectarray antenna.
In recent years linear generators have been proposed in several marine applications as a well-suited technology for energy harvesting such as power buoys. Those kinds of buoys could be used as large-scale devices in power plants and as small-size devices in electronic supply as well.
Starting from the design of a complex EM structures with a lot of degrees of freedom, the aim of this work is also to achieve a novel approach to analyze the dynamics of subsystems for WSN in marine environment. In particular, the aim is to introduce a tubular permanent magnet linear generator (TPM-LiG) as a part of the scavenging device integrated in the sensory buoy, since it can be easily activated by a crossing wave to extend the life-time of batteries.
This novel approach relies on an automated design technique that starts from the specifications required to the system performances and uses them as constrains of an iterative cycle that involves an equivalent surrogate of the system (predictive model) and an optimization algorithm. The procedure provides the final CAD model of the system as output in few machine-hours.
The parametric analysis presented in Chapter 3 has highlighted the influence of geometric parameters on the performances of tubular generator. In this paper the inverse characterization required numerical simulations and approximative models in order to realize a predictive model of system physical behavior as a function of its constructive parameters. The direct synthesis is based on predictive models and optimization techniques arranged together to realize an automated design of WSN subsystems.
As shown in fig. 2, a prototype of tubular generator was set up and measures provided, to a large extent, a first validation of the predictive model used in the proposed automated modeling approach.
A possible development of this work can be the inclusion of tubular generator in an energy harvesting device designed to feed the battery of WSN nodes in marine environment.