Chair:
Prof. Alberto Berizzi

DOCTORAL PROGRAM IN ELECTRICAL ENGINEERING

The main objective of the PhD Program is to allow a direct, prompt and efficient involvement of PhDs in any research body such as an R&D department of a production or service company.
A PhD in Electrical Engineering has a solid basic knowledge of mathematics and physics. This is essential, particularly for handling and understanding advanced tools and methods as well as for proper modelling, analysis and design of electrical engineering applications, with particular regard to power applications. A PhD in Electrical Engineering well knows methods and applications in the main disciplines of Basic Electric Circuits and Fields, Power Systems, Electrical and Electronic Measurements, Converters, Machines and Electrical Drives.
The most important part of the PhD program is the development of the research that will be the core of the PhD dissertation.

The main research areas are:

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

B) Power Systems:
A PhD in the field of Power Systems deals with the following subjects: electrical energy production (e.g., frequency and voltage control, protections, renewable energy sources, Dispersed Generation, Microgrids); electrical energy transmission (e.g., power system analysis, real and reactive power optimization, security and stability, integration of renewables); electricity markets (e.g., models, ancillary services, regulations); power quality and Smart Grids (e.g., harmonic distortion, active filters, UPS, interruptions and voltage dips, DC distribution).

C) Electric machines and drives:
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.

D) Measurements:
This research field concentrates on the fundamentals of metrology, particularly with respect to characterization of modern measurement systems based on complex digital signal processing structures. Some of the main subjects of study are: measurement methodology as it relates to power systems, including medium and high voltage systems and components, as well as both digital and analog signal processing. Methodologies and measurement systems associated with industrial automation and, in particular, microelectronic sensor applications, distributed structures and advanced methods and algorithms for maintenance-oriented diagnosis of complex systems are investigated in detail.

After graduation, PhD are typically employed at:
· Major research centres;
· R&D departments;
· Power generation, transmission and distribution firms;
· Engineering consultant offices;
· Metrology reference institutes and certification laboratories;
· Process and transport automation areas.

The Steering Committee is made by:

Surname	Name	Firm	Position
Canizares	Claudio	University of Waterloo, Waterloo Institute for Sustainable Energy, Canada	Associate Director
Carlini	Enrico Maria	Terna	Head of System and Transmission Control & Operation Central South Italy
Ercoli	Sergio	Zeroemissioni Srl	Presidente CDA
Fasciolo	Enrico	A2A Reti Elettriche	Responsabile Impianti e Reti Primarie
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Lo Schiavo	Luca	Autorità per l’energia elettrica e il gas	Manager
Cherbaucich	Claudio	RSE - Ricerca sul Sistema Energetico	Vice Responsabile Sviluppo e Pianificazione
Mansoldo	Andrea	Eir Grid	Senior Power System Analyst
Monti	Antonello	The Institute for Automation of Complex Power Systems of E.ON Energy Research Center	Director
Zannella	Sergio	Edison – Research, Development and Innovation	Scientific Network Manager

Companies currently providing scholarships:
· MCM Energy Lab
· A2A Reti Elettriche

CONSERVATIVE FUNCTIONS: AN APPROACH IN NONLINEAR AND SWITCHED NETWORK ANALYSIS

Simone Barcellona - Supervisor: **Gabrio Superti Furga**

Conservative functions or generalized powers in the electric network are those that satisfy the balance Tellegen's theorem, and they are powerful tools in different contests. The attention for these functions is still, at the present time, very animated. The main reason behind that is the wide diffusion and usefulness of the reactive power for practical and theoretical point of view for linear networks under sinusoidal steady state. It is significant to recognize two formal properties of reactive power under sinusoidal steady state conditions: the balance property and its invariance on resistors. The balance property states that the algebraic sum of reactive power on the single one-port elements in a network is equal to the corresponding term on the whole network. The invariance means that the reactive power is always nil on resistors. However, important changes have occurred in the last 50 years. In the electric networks, the presence of power electronics equipment, arc and induction furnaces, in addition to clusters of personal computers, represent major nonlinear and parametric loads proliferating among industrial and commercial customers. The main problems emerge from the flow of nonactive power caused by harmonic currents and voltages. The efforts to extend the concept of reactive power also under distorted conditions provided significant results for the analysis and theoretical comprehension of the distorted steady state. The literature on this subject is very large; in the past many authors have proposed different definitions of nonactive power in distorted steady state. In particular, when power converters are present in networks, as sources of distortion or as active filters to eliminate this distortion, these networks are considered as time-variant networks and called switched networks. They pose several challenges in the construction of efficient time domain simulators. Due to the wide range of applications, operating conditions, and phenomena to be studied, many different tools for computer analysis and simulation of switched networks have been developed. The switch model plays an important role within the analysis and simulation of switched networks. The ideal switch model is the simplest possible one and has several advantages with respect to others. In the presence of switching, classical issues that rise up are related to network solution and inconsistent initial conditions. Network solution is fulfilled by several methods. The main one is the complementary approach, where commutations are basically the external constraints to a time-invariant multi-port. Meanwhile, inconsistent initial conditions, caused by switching, imply discontinuities on state variables and impulsive behavior on some voltages and/or currents. In fact, Dirac's delta impulses of voltage and/or current may occur at the switching transitions. Impulses redistribute charge and flux at the switching instants when capacitor voltages and inductor currents, respectively, are discontinuous. Nevertheless, as a whole it appears to lack general principles as well as applications of generalized powers in the field of switched networks.

In this work, according to the concept of "area" on the *v-i* plane, a new approach called Swept Area Theory, under both nonlinear continuous and discontinuous conditions, is developed. Novel conservative functions, as Area Velocity and Closed Area over Time, involved in this theory, are proposed.

An analysis is carried out, by means of these functions, over nonlinear R, L, C elements and over the ideal switch and ideal diode. In addition, jump discontinuities are discussed in detail. The Closed Area over Time is related to the harmonic reactive powers and under sinusoidal steady state becomes proportional to the classical reactive power. A balance rule concerning harmonic reactive powers over nonlinear resistor under continuous conditions is obtained and discussed as a novel interesting result. This aspect impacts on a possible extended definition of reactive power under distorted conditions. Thanks to the Switching Power, a novel quantitative relation between hard switching commutations and Closed Area over Time is obtained, with both theoretical and applicative relevance.

More explanation is presented through a demonstration that shows how ideal switch and power converters can become sources of reactive power. Issues of principle regarding the ideal switch model with respect to the real one is another important result of this work. Moreover, concepts of Ideal Switch Multi Port and multilevel voltage/current elements are proposed as a unified theory of power converters, whereby most of the power converters existing can be recognized in a general and modular way. Furthermore, the Swept Area Theory is extended to the Ideal Switch Multi Port in order to find relations between Switching Power and commutations of power converters. In this way, the possibility of a power converter to generate or absorb reactive power is proved. Hence, a contribution will be available to develop new control strategies of power converters based on the Swept Area Theory.

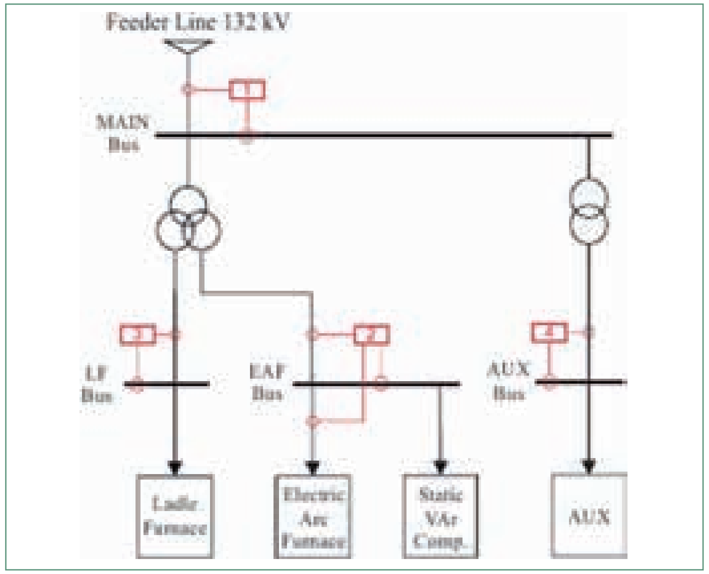
Another conservative function, called Jump Power, is proposed in order to address some properties and issues of principle regarding one-port elements, in particular ideal diodes and ideal switches, in the presence of jump discontinuities. Some theorems based on the Jump Power are stated. In particular, possible conditions in networks are addressed whereby soft switching, passive or active hard switching commutations occur.

Other conservative functions, called Inductive Impulsive Power and Capacitive Impulsive Power, are defined in order to analyze the switched networks in the presence of Dirac's delta impulses in the electric quantities. These impulses are due to inconsistent initial conditions caused by switching. Also in this case, some properties and issues of principle regarding one-port elements, in particular ideal switches and ideal diodes, are addressed. Moreover, some theorems based on Inductive Impulsive Power and Capacitive Impulsive Power are stated. These conservative functions, despite having similar properties to the Connection Energy that was presented in the past literature as a function regarding the whole network, are still more powerful and meaningful. In fact, through Inductive Impulsive Power and Capacitive Impulsive Power functions, it is possible to separate the effect of capacitors from inductors. Furthermore, an interesting result is found: the ideal switch can absorb or generate electric energy when an impulse of current or voltage occurs meanwhile the ideal diode can only generate. These facts are important mathematical aspects regarding the ideal model of switches and diodes. In some cases these facts cannot have a physical meaning as it is shown in analytical examples. However, the total energy absorbed by switching has a clear physical significance, as it is related to the variation of energy stored in the set of reactive elements or generated by electric sources. On the other hand, in the presence of more than one element, the partition of this energy among the different switching elements still has no physical correspondence with the loss of energy into the single element.

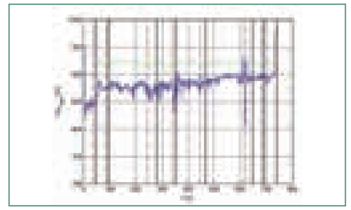
INSPECTION METHODS AND ANALYSIS OF ELECTRIC POWER QUALITY INFLUENCE ON PRODUCTION PROCESSES: AN APPLICATION TO EAF OPERATIONS

Daniele Clerici - Supervisor: **Prof. Loredana Cristaldi**

Arc furnaces have seen a widespread diffusion in melting facilities in the last decades. Key factors for this kind of process are accurate melting process control, less expensive melting charge material (steel scrap), small production batch capabilities, and lower energy requirements.
It is well known that the melting process depends on the presence and propagation of the electric arc between electrodes and scrap charge. The heat produced by the arc current melts the scrap to create the molten steel.
The characteristics of the electric arc depends mainly on two factors: the "quality" of the scrap charge and the "quality" of the electrical supply.
The furnace process control is automatically set to maintain a specific energy delivery from electrodes to scrap charge; effectiveness of this action is reduced if the feeding voltage is unstable and/or the scrap charge density is uneven or too low (presence of holes and spots inside the charge or poorly conductive pieces of scrap). Scrap charge density is indirectly influenced by charge composition, so melting process performance is in a way correlated to the type of employed scrap mixture. How strong is this correlation depends on several other factors involved in the melting process and scrap selection.
Arc furnaces can be considered electrical polluting devices from the electrical point of view; the uneven nature of the electric arc, due to uneven density of the media in which it takes place (air and scrap), as well as its tendency to be displaced by electromagnetic forces, result in a consistent harmonic content both in arc currents and voltages. Distortion of arc electrical quantities influences also the harmonic content at primary side of the furnace transformer and definitely in the whole electric system connected to it. Disturbances are present in the connecting point to the supply grid; they are related to both furnace activities and external sources. These phenomena can alter voltage and current profiles significantly and can result, beyond disturbance injection from the steel plant to the grid, in voltage profile non-uniformity and variability.
The stability and uniformity of voltage levels is essential for the melting process because, in the furnace control system, voltage is not under closed loop control; this means that, if voltage profile at the primary side of the furnace transformer isn't steady during the process, electric arc characteristics can be different from the desired and scheduled ones. As a result, electrode regulation cannot be performed in the correct way and energy transmission from arc to scrap is negatively influenced.
The main objective of this work is to discover specific electric supply conditions that could be correlated with poor melting performances of the EAF. For this task, a case study was selected and a distributed measuring system has been developed in order to monitor voltages and currents in the points of interest within the electrical system. A steel plant has been chosen as a case study: Acciaierie di Calvisano steel plant is located near the city of Brescia, in the main steel manufacturing district of northern Italy in the north-east part of Lombardia region.
A scheme of steel plant electric system and the measuring points is represented in Fig.1.
From voltages and currents measured values, other electrical quantities of interest were derived, in particular active and reactive powers and harmonic indexes.
Particular attention was given to the electric asset at the connecting point between the plant electric system and the supply grid, that is at the Point of Common Coupling (PCC) as usually referred to.
In order to directly compare actual and preset secondary voltage and current, the electrical quantities at the secondary windings of the EAF transformer have also been estimated. In this way the analysis is referred to the same point in which the EAF control system measures voltages and currents for process control.
As a result, the deviation of the actual voltage values from the preset ones can be computed in order to verify how the actual conditions are far from the desired ones (see Fig.2).
Data from production records are employed in conjunction with those obtained from the analysis of the electrical quantities in order to verify the effective correlation between electric supply conditions and process performances for each melting process.
Furnace activities were monitored for several months and a comprehensive set of melting processes was built; then a classification has been made and influence of electrical supply conditions on melting performances was evaluated through a statistical analysis.
This analysis shows that, in the presence of variable and non-uniform voltage profiles, about 50% of the processes melting performances are poor and for the remaining ones better results are obtained only by means of a longer refining process; this action leads toan increase in energy consumption
The analysis of the voltage profiles, both on the primary side of the furnace and at PCC, allowed detection of the main factors which influence voltage levels uniformity and stability: voltage transients due to voltage regulation performed in the grid, and wrong voltage regulation on the busbars of furnace supply section.
One of the main problem in voltage regulation is the voltage drop in the circuit from the busbar to the furnace transformer; this is due to harmonic content of furnace voltages and currents, which are directly related with arc characteristics. Furthermore, the arc is heavily influenced by the melting conditions inside furnace and from scrap characteristics.
Moreover, further developments of this analysis will lead to a classification of scrap charges and process stages, based on the analysis of the harmonic content of the electrical quantities , obtained by means of the implemented monitoring system. Starting from this classification it can be possible to obtain a set of suitable voltage set-points for different operating conditions.
In addition, an improved monitoring system, interfaced with the furnace control system, can be implemented in order to automatically set both furnace and voltage set-point regulation parameters, thus attaining better melting performances in every operating conditions.



1. Electrical scheme of Calvisano steel plant; measuring points are represented in red



2. Actual voltage profile (in blue) and preset voltage profile (green dotted line) at the secondary side of the furnace transformer

COMPUTATIONAL INTELLIGENCE PORELECTROMAGNETIC COMPONENTS

Linh Ho Manh - Supervisor and Tutor: **Prof. Riccardo E. Zich**

This thesis discusses a novel approach to solve complex electromagnetic problems by computational intelligence techniques. Chapter 1 provides background materiai on computational intelligence techniques: from originai Particle Swarm Optimization (PSO); Genetic Algorithm (GA) to their variations namely Genetic Swarm Optimization (GSO) and Meta-PSO. The theory of Artificial Neural Network (ANN) and its training algorithms are also presented in Chapter 1. Chapter 2 discusses a traditional approach by applying heuristic optimizations to EM components. Various new designs of EM structures from multilayer microstrip antenna and metamaterial inspired antenna, to frequency selective sur face are optimized. The core challenge is the identification of an appropriate cost function and it was done by properly modeled electromagnetic objects by commerciai full-wave analysis. However, this traditional approach is always expensive in terms of computing time and the dynamic memory required for each assessment is relatively big. Therefore, with the aim of reducing computational efforts and memory consumption, an equivalent surrogate model for antenna design by Artificial Neural Network (ANN) is intepreted in this thesis. In this thesis, after being sufficiently trained, an ANN is used as a surrogate model to substitute completely full-wave characterization. Two different optimization schemes, also the different approaches in sampling target data, are clearly explained in detail in chapter 3, which also marks the end of the first half for this thesis.

A variety of structures in Electromagnetism, representing an indispensable part of physics, sometimes cannot be fully described by simulators. This issue is more obvious in scattering problem when interpreting complex objects and materials, the use of mathematic tools is strongly needed. The research carried out in this context is a boundary-value problem where the aim is to determine radiation field of primary sources illuminating spheroidal structures. Primary sources are Hertzian electric and magnetic dipoles; spheroidal structures are two confocal prolate/oblate dielectric layers (either made of isorefractive or anti-isorefractive material) coating a metallic prolate/oblate spheroid. The problem of one layer coating was already solved by Dr. Askarpour and Prof. Uslenghi in [98, 99], it is relevant to investigate the behavior of primary sources in the case of doublycoated spheroids. The modal expansion coefficients are determined by imposing boundary conditions at various interfaces ç of spheroidal coordinate. With the aim bringing a brief introduction of spheroidal coordinates and problem description, radidal spheroidal and angular spheroidal wave functions are interpreted theoretically in chapter 4. Chapter 5 and chapter 6 provide all the exact solutions of two cases prolate and oblate respectively. All the analytical formulations are retrieved by separations of variables, whereby the field components are expressed as infinite series of products of radial and angular spheroidal wave functions. Numerica! results in these sections also exhibit the profound influences of thickness and material properties of coating layers on both far-field and near-field regions. Conclusions and discussions on the outcomes of each problem can be found at the end of each chapter. At the end of chapter 5, the issues on scattering of a magnetic dipole on Prolate Spheroids is totally covered, it is sufficient to create a representative cost function to optimize radiated far fields of multiple dipoles on the structure.

SIGNAL PROCESSING FOR DISRUPTION DETECTION IN TOKAMAKS

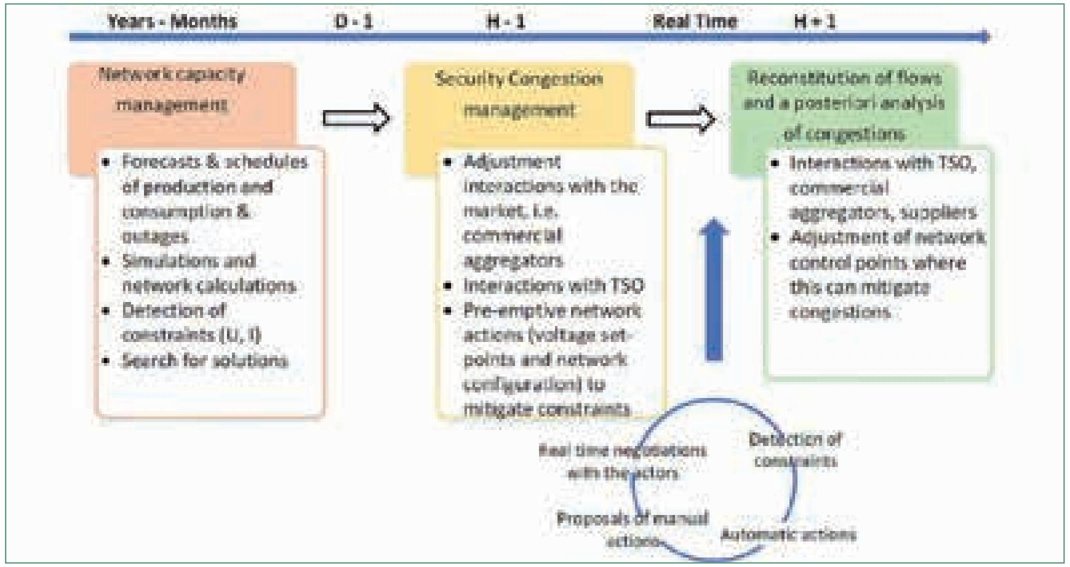
Maia Mosconi - Supervisors: **Gabriele D'Antona, Carlo Sozzi**

This PhD is part of research on controlled thermonuclear fusion, in particular regarding the identification of a precursor signal of disruption and the development of a real-time algorithm for predicting disruptions in tokamaks. Tokamak is an axisymmetric configuration that, through an appropriate combination between a toroidal magnetic field produced by external coils and a poloidal magnetic field generated by a current flowing in the toroidal plasma, achieves the Magneto Hydro Dynamic (MHD) equilibrium condition. In order to obtain controlled fusion, the equilibrium condition must be maintained stable for a period greater than an appropriate time, with respect to any perturbation. A major limitation to fusion goals is made by the onset of magnetohydrodynamic instabilities in plasmas. A class of instability, bounded to dissipative magnetic perturbations, are the tearing modes that occur as an helical perturbations of the current and temperature of the plasma localized around the rational surfaces (surfaces on which the magnetic lines of force of the field B have a rational step) with its rotation speed. Tearing modes instability may take place around the magnetic surfaces with low rational values of the ratio m/n, being m and n respectively the number of toroidal and poloidal revolutions of the force lines of the magnetic field, limiting the performance of a tokamak. The plasma, despite being a good conductor, has a small but finite resistivity, the rational surfaces with constant magnetic flux and pressure tear, allowing to the lines of force of the magnetic field to reconnect in magnetic islands. A tokamak can also operate in the presence of magnetic islands, but their evolution, if not controlled, can lead to disruption, i.e. the sudden fall of plasma current followed by the loss of confinement. Disruption is very dangerous for the integrity of the reactor because the energy stored in the plasma is abruptly released to the wall machine. The study and prediction of disruption is therefore a fundamental research topic in this context.
While many techniques are available today for disruption avoidance and mitigation with some degree of successes, actually there is not any strategy that consent to fully predict and avoid all disruptions. The definition of a precursor signal of disruption is currently an interesting argument of research and in this PhD thesis an original method to determine a precursor signal is proposed.
In this work, the precursor signal is determined through the analysis of the results obtained by applying an algorithm of Singular Value Decomposition (SVD) to magnetic signals. The signals used in this analysis are fluctuations of the magnetic field caught by an array of small multiturn coils, the so called Mirnov coils. The signals have been opportunely filtered and resampled at the frequency of interest for MHD activity.
The work was done in collaboration with the Institute of Plasma Physics of Milan (IFP) and the analysis was applied to the magnetic Mirnov signals of the ENEA Tokamak FTU (Frascati Tokamak Upgrade) Frascati, Italy and after that the same analysis has been adapted and applied to the magnetic Mirnov signal of the tokamak JET (Joint European Torus) Culham, UK. A set of Mirnov coils are circular coils oriented to measure the fluctuations of the poloidal component of the magnetic field.
Through the Singular Value analysis is possible to extract useful markers of the instabilities presence, such as the Entropy H and the marker P1. The entropy H is proportional to the square of the normalized singular values and describes the phase coherence in Mirnov coils signals. The entropy can assume values in the range between 0 and 1 and lower values of the entropy H are indicative of the presence of instability in the plasma. The P1 marker is the relative square magnitude of first couple of principal axes, it is bounded between 0 and 1. P1 is related to the presence of the first mode, i.e. the dominant couple (m,n). The more P1 is close to 1, the more unstable the first mode is. The presence of a mode indicates the growth of MHD activity, if the mode becomes unstable a disruption can occur.
2046 plasma discharges collected between 2008 and 2012 have been selected from the FTU database. No threshold parametrization related to the plasma engineering parameters such as toroidal magnetic field, plasma current and density has been used. The signals considered have been normalized, having the advantage to be independent from sensor calibration and signal amplitude. We distinguished 1665 regular terminations and 381 disruptions without taking any classification on the causes that lead to a disruptive current quench. From the application of SVD analysis to a set of FTU Mirnov coils in previous works the entropy has been resulted to be a good marker for the presence of MHD instabilities. The investigation of the disruption precursor starts with the study of entropy time evolution during the plasma discharge. The two ensembles disruptive shots and regular terminations have been selected and considered separately, evaluating the mean value of entropy around its minimum. This is a good candidate in order to discriminate disruptive shots from regular terminations. The result of this analysis is the identification of a first precursor of disruption, based on entropy mean value around its minimum, able to recognize up to 69% of the disruptions with 20 ms of warning time before the plasma current quench. A further and deeper investigation of the plane H-P1 has brought to the individuation of a precursor based on the square root of the moving variance of the time derivative of the ratio H/P1. This last disruption precursor is able to recognize up to 82% of the disruptions, 79% at least 20 ms of warning time before the plasma current quench.
The same analysis have been adapted and repeated for Mirnov coils signals coming from JET machine, in order to test the robustness of the algorithm in different devices. We have analyzed 2044 plasma discharges collected between 2012 and 2013: 457 disruptive shots and 1587 regular terminations. Also in this case we do not distinguish disruption causes and no threshold parametrization has been established. The developed algorithms based on the SVD analysis of the MHD activity signals from a set of JET Mirnov coils provide a disruption precursor based on the square root of the moving variance of the time derivative of H/P1 able to recognize up to 63% of the disruptions, 50 ms before the plasma current quench. For JET machine, an estimator based on the entropy mean value around minimum seems to be more efficient, being able to recognize up to 79% of the disruptions, at least with 50 ms of warning time before the plasma current quench.
The results presented in this PhD thesis, based on the application of SVD algorithm in the research of a precursor signal of disruption are encouraging, but more detailed investigations are however needed. An interesting prosecution will be therefore try to parametrize the analysis contextualizing to physical meaning introducing for example thresholds related to plasma parameters such as magnetic field, plasma current and density. The markers identified in this analysis can be used in order to classifying disruption causes. For this purpose it is mandatory: analyzing in detail the plasma discharge studying the evolution of different plasma and machine parameters, distinguishing not intentional from intentional disruptions and taking in account experimental conditions. Moreover, it should be important to focusing on the precursor phases preceding the instability and on the plasma development before the thermal quench. The investigation on a possible correlation between time dependence of the markers and the disruption evolution should be done for improve our analysis.

ADVANCED STATE ESTIMATION IN DISTRIBUTION SYSTEMS

Milos Subasic - Supervisor: **Prof. Cristian Bovo**

This research is composed of two major topics; first, the development of the State Estimation function for distribution systems and second, on of Measurement Equipment Placement for the sake of improvement of observability of distribution network.
The traditional vertically integrated structure of the electric utility has been deregulated in recent years particularly by adopting the competitive market paradigm in many countries around the world. The market-governed electrical business and the Renewable Energy Sources (RES) have changed significantly the power flows in distribution networks.
On the other side, the evolution of the distribution systems seen through the remarkable expansion of dispersed generation plants connected to the medium and low voltage network is one of the main challenges. The growth of the dispersed generation is causing a profound change of the distribution systems in the technical, legal and regulatory aspects; most likely the Distribution System Operators (DSOs) will more and more take, on local dimensions, tasks and responsibilities of the role assigned on a national scale to the operator of the electricity transmission network. In other words, the DSO will become a sort of a "local dispatcher" and will involve its real/passive customers in activities related to the network management and optimization. This, obviously, requires a deep review of the regulatory framework.
In this sense, definition of "Smart Grid", now usually in use, appears reduced as it focuses only on the appearance of the network, while it is more appropriate to speak about "Smart Distribution System" (SDS), extending the involvement also to network users. Among the various initiatives that the distributor must undertake in order to adapt the methods of planning, management and analysis of operation of the network, acquisition of dedicated tools and the related infrastructure plays a crucial role. Some of the roles that need to be taken into account are shown below in Fig. 1.
Most distributed energy resources (DER) can be disposed in the distribution network and to be accessible to provide network support, DER must co-ordinate with the rest of the power system without affecting other costumers. The capability of DER to provision ancillary services will depend on factors such as DER location and number of resources integrated to the grid. Most of the benefits relying on ancillary services will be directly dependent upon the location whereas as the penetration of DER increases, it will impact not only the distribution system capacity restraints but the voltage and frequency stability of the interconnected DER units.
From the infrastructural point of view, there is a clear need of enhancing the observability of the network, now generally limited to the HV/MV substation and the preparation of appropriate channels of communication with the users. Software tools evolution includes the enhancements of the SCADA side for managing the new devices and information coming from the network on one side. In addition, a new family of software applications is being developed to support in both real-time operation and the planning phase.
At this point, the specific software tools for both real-time management and planning of the distribution network need to be developed. To implement these, the developer has to have in mind all the above stated limitations and challenges of modern systems. This thesis provides tools for improvement of the observability of the distribution systems and optimal planning of network for the same cause.
The first motivation to develop the Distribution System State



1. DSO interactions with markets & TSO at different time frames

of the distribution grids.
The second motivation is due to the fact that the increased penetration of dispersed generation is one of the main contributors to the new management mechanisms that are being developed. To improve the hosting capacity of the DN and to reduce the impact of DG on the regulation requirements of the bulk power system, the DG has to provide ancillary services (to solve local and global issues – frequency, reserve, voltage regulation, congestion management). Therefore the distribution system will assume the role of DSO. Premise of this is the knowledge of the network. For this reason, SE applied to DN is a main tool to improve the effects of DG penetration.
On the other side, having elaborated on the fact that the knowledge of the network state is crucial for its operation, it is not hard to understand on genetic algorithms that have proven to possess good properties with large-scale problems like this one. Many different implementation approaches have been developed, tested and compared on large number of realistic test DNs for this dissertation and the best approach is recorded.
Apart from the fact that the OMEP algorithm provides (sub) optimal solutions for all the tested systems, it is also robust, highly modular and easily implementable in DMS solutions.