Chair:
Prof. Alberto Berizzi

DOCTORAL PROGRAM IN ELECTRICAL ENGINEERING

The main objective of the PhD Program is to allow a direct, prompt and productive involvement of PhDs in any research body such as an R&D department of a production or services 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 circuits and electromagnetic fields as well as methods and applications in the main disciplines of Basic Electrotechnics, 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 presented in the PhD dissertation.

The main research areas are:

A) Circuits 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 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 methods for 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 involves studies in the following subjects: Electrical energy production (e.g., frequency and voltage control, protection systems, renewable energy sources, dispersed generation); Electrical energy transmission (e.g., power system analysis and dispatch, optimization of real and reactive power, security and stability, integration of renewables by probabilistic methods); Liberalized market issues (e.g., market models, ancillary service management, regulatory issues); Power quality and distribution systems (e.g., Smart Grids, line current harmonic distortion, active filters, UPS, interruptions and voltage dips, direct current distribution); Optimization by innovative algorithms (Neural networks, Genetic algorithms, etc.).

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 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.
During the first year, the students carry out 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". The choice of the subject must be approved by the Supervisor. Moreover, they have to deeply investigate the subjects related to the proposed area of research by means of a bibliographical research.
The second year is dedicated to complete the training through the basic PhD Courses, as well as to the acquisition of specialized skills necessary for the final dissertation that will be completed during the third year. Students are required to carry out a specific training for research through specialized seminars, conferences, and research activities closely associated with the topic of dissertation, and are encouraged to perform research activities in an international framework.
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, that will be evaluated by an international Commission.

After graduation, PhD are typically employed at:
- Major research centres, including University and Academic institutions;
- R&D departments in public and private industry;
- Power generation, transmission and distribution departments;
- Engineering consultancy firms;
- Metrology reference institutes and certification laboratories;
- Process and transport automation areas;
- Public bodies such as Regulatory or Government agencies.

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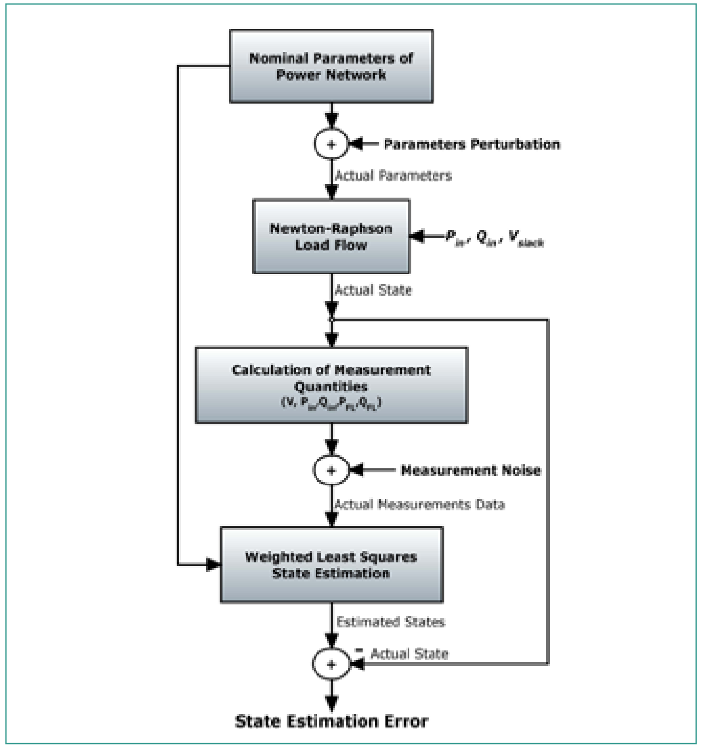
SENSITIVITY ANALYSIS OF POWER SYSTEM STATE ESTIMATION REGARDING TO NETWORK PARAMETER UNCERTAINTIES

Mehdi Davoudi

In this thesis, the effects of both network parameters uncertainty and measurement uncertainty on Weighted Least Squares (WLS) State Estimates has been analyzed. An algorithm for simulation of the uncertainty effects on the state estimator is proposed and shown in Figure 1 and simulated on IEEE power network test cases based on Monte Carlo trials. In Figure 1, it can be seen that the algorithm considers nominal network parameters and noisy measurements as inputs for State Estimator and compares its output with the actual states derived using Newton-Raphson load flow.

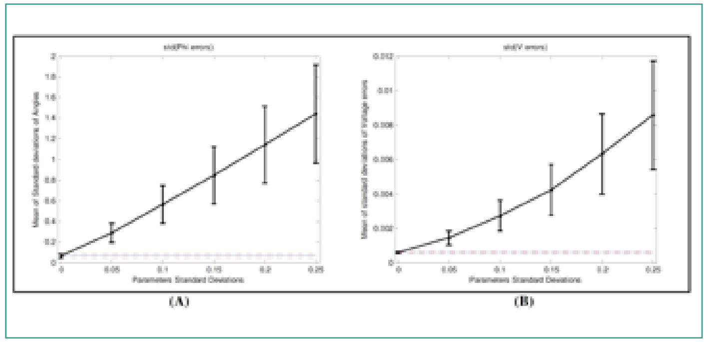
The implementation of this algorithm on the test cases enables us to analyze how much the state estimator's output is affected according to the network parameters uncertainty. The results of simulations show that the state estimator's accuracy is affected considerably according to the network parameters uncertainty. The amount of variations in estimator's accuracy is illustrated by means of state errors distribution (in terms of error bars representing the distribution mean and 1σ standard deviation) versus the network parameters uncertainty for the test cases. Furthermore, WLS State Estimation provides a mathematical expression for calculating the variance covariance matrix of state estimates and it is



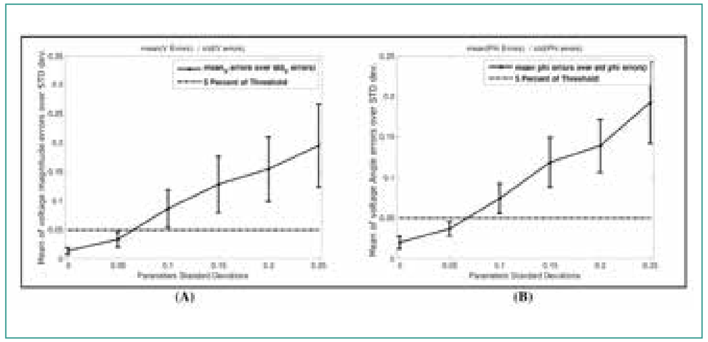
1. The flowchart of implementation. It is used in order to analyze the sensitivity of power system state estimation regarding to both the network parameters uncertainty and measurements uncertainty.

also confirmed numerically that when there is network parameter uncertainty the standard deviation of State Estimator's output is underestimated significantly. As an example, the error bars plots for mean and standard deviation of voltage magnitude and voltage phase angles versus the network parameters uncertainty samples are shown in Figure 2.

Generally, a serious defect in an estimator is the lack of unbiasedness. In literature the analysis of network parameters effects on WLS state estimator's bias performance is missing, hence it motivated us to perform a new prominent analysis to find how network parameters uncertainty can affect the state estimator bias (for a given measurement uncertainly). It is done using distribution of the ratio of the absolute value of the state errors mean by the related standard deviations versus the network parameters uncertainty and comparing it with a predefined threshold. As a case in point, Figure 3 shows the bias test for IEEE 14-bus test case.



2. Mean and Standard Deviation of Voltage Magnitude Errors (A) and Voltage Phase Angle Errors (B) for IEEE 14-Bus test case. The figures clearly show that by growth of the network parameters uncertainty, the mean and standard deviation of errors considerably grows.



3. Ratio of the Mean of voltage magnitude errors (A) and voltage phase angles errors (B) by related Standard Deviations for IEEE 14-Bus test case. A horizontal dashed line is depicted to give an idea about the 5 percent of threshold, meaning that the state estimator is not biased for the network parameters uncertainty range below this line. According to the figures, it is apparent that the State Estimator is not biased for the parameters uncertainties up to nearly 7 percent.

In order to decrease the sensitivity of state estimates to the network parameters uncertainty, a clue can be the inclusion of Phasor Measurement Unit (PMU) in the measurements. According to the simulations, it is proven that when PMU measurement data are included in addition to the traditional Supervisory Control And Data Acquisition (SCADA) measurements, the outputs of state estimator are comparatively much less biased (in some test cases, the State estimator's phases are totally unbiased for huge range of network parameters).

Another analysis regarding to the effect of parameters correlation on WLS state estimator is done considering the network parameters uncertainty. For this aim, the nominal nonzero values of line resistances are correlated and then the bias test is carried out. By comparing these results with the results without parameters correlation, it can be concluded that when the network parameters are correlated, the state estimator is more biased (for smaller parameters uncertainties).

Lastly, an analysis is performed to illustrate how much the State Estimator's results are mutually connected to each other when the network parameters have uncertainty. Interestingly it is seen that when the network parameters uncertainty increases, the estimation errors will be less correlated (the state estimator's voltage magnitude errors will be significantly less correlated and the state estimator's phase angle errors will be a little bit less correlated).

SUPERCACITOR STORAGE SYSTEMS: MODELING, CONTROL STRATEGIES, APPLICATIONS AND SIZING CRITERIA

Vincenzo Musolino

The interdependence between the environmental, social, and economic aspects of today's society is becoming increasingly clearer and more cohesive. The key point is related to the limited availability of the earth's resources. At present, human activities require a large amount of energy and, despite the actual global recession that began in 2008 and continues to show evident effects, the total worldwide energy consumption over the last decades has continued to grow. Although energy is needed for human activities, its use impacts the availability of energy resources in the global ecosystem.

According to this, no energy resource presently exists that meets all of the economic, social, and environmental requirements. One possible solution seems to be increasing the use of renewable energy resources, which has attracted major attention for energy saving. Saving energy, in fact, is the first energy resource because it is environmentally friendly, available in all countries, unrelated to the fossil fuel energy resources, and a source of income, not only from an economic point of view, but also from a technical and industrial point of view. Investing in energy saving is investing in innovation, technical skills, and environmental sustainable activities. More generally, it is investing in the next generation because it actually takes into account the limited availability of resources.

In this general context, among the different forms of energy, electrical energy assumes an important role in our society. In the last decades, the gross domestic products (GDPs) of more developed countries have been characterized by trends involving electric energy consumption. It is possible to transport electrical energy over long distances with high efficiency. It is easy to diffuse, produces no emissions in the place of its utilization, and is easy to convert into other forms of energy in a reversible way. Because of the above-mentioned properties, electric energy is increasingly being diffused, not only for all of the typical grid-connected applications, but also in many others industrial and transportation applications that have not traditionally used electrical energy because they have been characterized by the direct conversion of a primary energy source, typically a fossil fuel source, into mechanical energy. Actually, electrical storage systems play an important role in different solutions. Although the difficulty of storing electrical energy has been an historical limitation of this kind of energy, nowadays the emergence of new needs and new applications is introducing new exigencies for the electrical storage system devices.

Although there are many storage technologies today, none is able to fulfill all of the different system requirements, especially when all of the performances in terms of specific energy, specific power, lifetime, operative temperature range, safety, availability, and cost are taken into account. In the last few years, consistent technological improvements and cost reductions have characterized the evolution of many storage systems, so that more and more attention has been given to implementing, using, and exploiting their benefits in real applications. Among the different technologies, this work focuses on supercapacitor storage devices. This choice is related to different considerations. First, despite the fact that supercapacitors are relatively new for industrial applications, they are characterized by a stabilized production process, with no significant changes in the technology over a period of time. From a technical and economic point of view, this is very important because it indicates the possibility of realizing new designs based on a stable and available technology over a period of years. Second, supercapacitors, as storage devices, show excellent properties in terms of specific power, expected lifetime (up to one million charge/discharge cycles), and a wide operative temperature range, making them very interesting in numerous applications. Third, unlike other storage technologies, supercapacitors are made of abundant and recyclable materials available on the earth.

In this work, after a general overview of storage technology options, a focused description of the supercapacitor technology is provided. In particular, in order to correctly manage and integrate supercapacitor devices, a new supercapacitor equivalent electrical model is introduced. Modeling is very important, especially when the device is used in a wide range of applications that influence the typical device performances. Supercapacitors are not an exception, in fact their behaviors in terms of dynamic response during cycling, efficiency, and self discharge change significantly according to the dynamic of use. The peculiarity of this model is its ability to correctly represent the complete dynamic of the device when operated with a cycle frequency ranging from DC up to 1 kHz. In addition, it is also very important to use model parameters that have clear physical meanings and can be simply determined in order to ensure the model usability. For this, a new and very simplified parameter identification procedure is presented: the peculiarity is that the model order can be a priori chosen according to the accuracy and dynamic that you want to represent.

In order to verify the introduced model, an extensive experimental analysis of supercapacitor storage devices at the cell and module levels is presented. In particular, the analysis aims not only to verify the model validity, but also to point out real supercapacitor performances according to the dynamic of use, especially evaluating the specific energy as a function of the specific power and device efficiency.

The equivalent model that is realized represents a valid and indispensable tool to address supercapacitor system integration. Due to the limited specific energy, supercapacitors, when integrated at the system level, need to be correctly managed according to the application requirements in order to ensure the correct energy flows and optimize the system operations. Thus, in the thesis work, two control strategies for supercapacitor storage devices are presented: the first aims to reduce the voltage fluctuations on a distribution bus where multiple loads and storage systems are connected, while the second aims to reduce the overall system losses. In particular, these control strategies are supported by extensive experimental activity on a real industrial application, and the benefits arising from the system integration of the innovative supercapacitor devices coupled with a traditional storage technology (a lead acid battery) are presented and discussed.

Finally, due to the importance of a correct design for the integrated system, not only from a technical point of view but also under the economic profile, the sizing of the supercapacitor storage is addressed, considering the economic impact of the solution. Considering the current component costs, the return of the investment arising from economic energy saving is evaluated. In particular, two sizing criteria are analyzed. The first one is a deterministic criterion that is useful when the application consists of a well known power profile absorbed by the equivalent load, while the second one addresses the sizing of a centralized storage system using a probabilistic approach when multiple loads are connected to the same distribution bus. In this case, in fact, the equivalent load power profile and, consequently, the energy storage size needed to fulfill the required load functions, cannot be evaluated by means of a deterministic method. The mathematical approach and some experimental results based on Monte Carlo simulations are presented, and their results are compared with the deterministic method.

NETWORK EFFICIENCY AND DISPERSED GENERATION INTEGRATION:

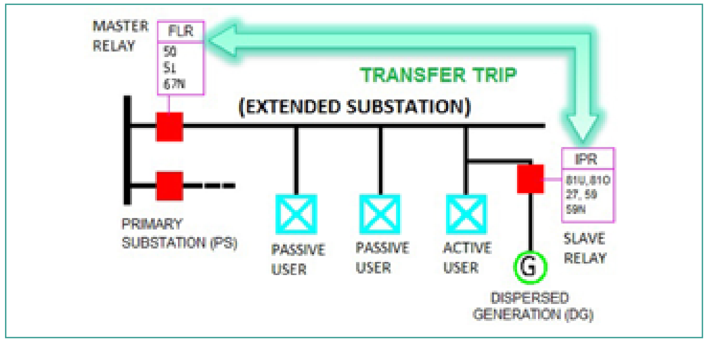
some regulatory studies on a detailed model of Italian distribution networks

Valeria Olivieri

Promoting and implementing an Energy Efficiency plan and integrating Dispersed Generation (DG) in the grid are the most important challenges of the near future for power systems in most of EU countries. Over the last several years, there has been an increasing focus on sustainability issues, including measures to address climate change. The existing legislative framework underpinning these areas sets out various targets to reduce Greenhouse Gas emissions as well as to increase the level of renewable energy and energy efficiency.
In many member states, and also in Italy, energy losses on electricity networks are regulated with a specific mechanism: standard losses are procured by suppliers according to factors defined by the Energy Regulator, while the difference between actual and standard losses, either positive or negative, is entirely borne by the Distribution System Operator (DSOs). As a consequence, the present incentive regime encourages DSOs to take operational and investment decisions to reduce losses by rewarding out-performance and penalizing underperformance based on a target level of losses derived from the average real performance (standard losses).
In general there are several methods to reduce technical losses on distribution networks: improve the PF can be seen as the quickest and cheapest of all methods to reduce network losses. In fact, reactive power flows cause higher losses and reduce the effective capacity of the networks (the effective capacity can be seen as a share of the installed capacity).
A consumer can take actions to reduce reactive power by installing suitable correcting equipment, but he has no incentive to do so unless he is charged for the low power factor, either by a specific charge on reactive energy or by a charge for actual rather than effective capacity used.
As for DG integration, DG units are currently increasing in number, as a consequence of incentive schemes in place in Italy (as in many other EU Member States), and of some other benefits such as a simplified access to the grid and priority in dispatching. This high degree of DG penetration has a considerable impact on operation, control, protection and reliability of the existing power systems and requires a conceptual revolution (generally identified as Smart Grid), implying the use of Information and Communication Technology as enabling technology to modernize the power grid and to cope with many challenges that DG poses.
In order to face these new challenges related to distribution grids, the thesis work studies in detail Italian distribution networks, investigating some issues related to energy losses (considering both loss factors and reactive charges) and to DG penetration, in order to envisage possible solutions for a better use of the networks.
All studies were performed considering two different directions of investigation.
The first one consist of the identification of possible technical solutions that can be implemented on the Italian networks. The second one is related to regulatory issues: starting from the current regulatory framework, we tried to define new possible regulating schemes. Many of the results obtained in the thesis work have been used as base for Consultation Documents and Resolutions of the Italian Energy Regulator.
The analysis carried out are mainly focused on MV distribution networks. The evolution towards smart grids has been focused exclusively on this voltage level.
For regulatory purposes, the network efficiency studies were extended to the whole electric system, from transmission networks, to MV and LV distribution networks. To this aim, three different levels of width and depth were adopted: the whole national transmission electrical network; a large sample of MV distribution networks (representing about 10% of MV networks existing in Italy); and a reduced sample of LV distribution networks (representing about 1‰ of MV networks existing in Italy). In fact, while there are many similarities in the distribution networks operated by each DSO, there are some important differences, including: geographical size of the area where the network is located; number of customers connected to the network; quantity of electricity distributed; degree of dispersion of customers along the network; proportion of different types of customers connected to the network, and amount of underground cables compared to overhead lines. Using a large data sample provides more reliable results that can be extended to the entire Italian networks.
The thesis work can be divided in four different parts.
The first one concerns the calculation of energy losses for the transmission and distribution Italian networks, along with and the relevant loss factors (Table 1).
The final results were useful for the Energy Regulator to estimate standard losses closer to the real ones, in order to induce the DSOs to promote energy efficiency measures on the electricity network.
The second part of the thesis work (detailed on MV distribution networks) was focused on the customers' power factor: higher PF limits allow the reduction of losses incurred in transporting electricity through transmission and distribution networks, the reduction in the total capacity needed within networks, the reduction in peak provision by upstream network, with an higher efficiency in energy delivering.
The third part deals with the DG integration into the network.
In order to obtain a realistic evaluation of DG impact on distribution networks, we propose a Probabilistic Load Flow approach that gives a realistic representation of the variability of the actual loading conditions, and has the capability of providing probabilistic margins of DG with respect to constraint violations.
After discussing the impact of DG on the current structure of distribution networks, we performed some studies about smart grids for an improved management of distribution networks, with attention to interoperability, security, and resilience problems in the presence of a huge quantity of DG: this is the fourth part of the thesis work. The studies of this latter part were used as a base for submitting a project in the selection process for smart grid demonstration initiatives currently going on Italy. The aim was to implement and test a novel Interface Protection Relay (IPR, Figure 1), including a suitable communication channel (based on IEC 61850 protocol), that provides an absolutely selective protection for DG units.

VOLTAGE LEVEL AND MEASURING POINT POSITION	
380 kV – Measuring point next to a withdrawal point	0.7
220 kV – Measuring point next to a 380/220 transformer	0.8
220 kV – Measuring point next to a 220/MV transformer or a withdrawal point	1.1
220 kV – Other	0.9
≤ 150 kV – Measuring point next to a EHV/HV transformer	1.1
≤ 150 kV – Measuring point next to a HV/MV transformer or a withdrawal point	1.8
≤ 150 kV – Other	1.5
MV – Measuring point next to a HV/MV transformer	2.4
MV – Measuring point next to a MV/LV transformer or a withdrawal point	3.4
MV – Other	2.9
LV - Measuring point next to a MV/LV transformer	5.1
LV - Measuring point next to a withdrawal point	8.1 – 9.1
LV – Other	6.6 – 7.1

Table 1. Estimated loss factors relating to transmission and distribution networks.



1. Interface protection relay with communication network.

PROBLEMS AND SOLUTIONS IN ROTATING MACHINES CONNECTED TO HIGH POWER DRIVES FOR RENEWABLE ENERGY

Daniel Felipe Ortega Belaundez

The research on this PhD dissertation is related to problems when rotating machines are connected to power converters and their solutions. The first topic developed is Reduction of overvoltage on terminals and windings of Induction Motor fed by Adjustable Speed Drives. Secondly an Online Partial Discharges test on windings of Induction Motor fed by Adjustable Speed Drives, with reduction of Partial Discharge Inception Voltage is developed. Third a Protection against noise in Torque and Currents of Permanent Magnet Synchronous Generator for Wind Energy Conversion System, connected to a Back to Back converter, with a DC-Link capacitance reduction was accomplished.

The overvoltage phenomenon in induction motors connected to inverters has two principal reasons. One of them is when an incident pulse wave from the inverter travels along a cable. When there is a mismatch between the cable characteristic surge impedance and the surge impedance of the induction motor, the reflection occurs. This reflection effect of the pulse could be twice the DC bus voltage on the machine terminals. In order to investigate the phenomena during simulation activities, a universal induction motor model has been developed. It is an extension of the classic T model of induction machine from IEEE 112. The machines and the analyser used for the measurements were provided from an Italian company which was in collaboration with the research for the respective publication of the first paper for this thesis. After run the simulation and the setup on laboratory under the same conditions the accuracy of the motor model was verified. In the case study 1 the overvoltage was strongly reduced by introducing a RC first order filter at the machine terminals.

On the Second case study it is mentioned that partial discharge inception voltage by definition is the lowest voltage that is present on insulation machine when the partial discharge occurs. Thus this thesis states that there is a relationship between the overvoltage and the partial discharge activity.

In this case study the partial discharge inception voltage was mitigated using and LRC filter on the terminals of the inverter. Also an on line partial discharge test technique on rotating machines fed by inverters was analyzed.

During the study of issues on Permanent Magnet Synchronous Generator when are connected to the grid through a back to back converter, harmonics on currents and torque were observed. There were some ripple present on electro-mechanic torque and currents on grid side converter due to the commutation of the switches. The no constant electro-mechanic torque leads to pulsating torque, and the problem is becoming in a mechanical stress on the machine. The use of big capacitance in DC link on back to back converters has the disadvantages of being bulky, expensive, unstable, and unreliable. Those big capacitors also contribute in increasing the response time, cost and losses.An innovative control was proposed to lead the solution. Due to the success of this new control, a reduction of capacitance on DC link was developed.

VOLTAGE CONTROL IN MV NETWORKS WITH HIGH DG PRESENCE USING A REAL-TIME DIGITAL SIMULATOR

Gianluca Sapienza

The widespread of the Distributed Generation, installed in Medium Voltage Distribution Grids, impacts the future development of modern Power Systems. A massive DG installation, typically based on Renewable Energy, completely changes power flows and, consecutively, network voltages and energy losses.
Focusing on MV network, we can say that today DG normally exchanges only active power to the grid, i.e. it works at unitary power factor. However, due to the MV grid resistance/reactance ratio, voltages are also influenced by active power injections. Therefore, in case of high active power injection, high voltage levels may occurs so potentially causing DG disconnection by means of interface relay tripping. Controlling the grid voltage, the above mentioned problems should be solved. Moreover, voltage regulation allows to increase the network hosting capacity.
In this PhD Thesis, which has been developed in collaboration with Enel Distribuzione S.p.A. (the major Italian DSO), an MV grid Voltage Control Criteria is proposed, discussed and analyzed using a Real-Time Digital Simulator (RTDS, see Fig. 1). The Voltage Control Criteria consists in three control strategies, which work in correlate way:

1. MV busbar voltage regulation in Primary Substation
2. "Local" Voltage Control, along feeders
3. "Centralized" Voltage Control, which involves the entire MV grid

The MV busbar voltage regulation in Primary Substation allows to maintain the MV busbar to the minimum admissible voltage set-point. It is based on "daily load flow" calculation performed by the Distribution Management System (DMS) by means of load curves derived from the Electronic Meters.
The Local Voltage Control allows to control voltage along feeders, at the DG delivery point, varying the exchanged reactive power as a function of the delivery point voltage. Two local regulation functions will be presented: the UPG and the RQV.
The "Centralized" Voltage Control allows to support the Local Voltage Control. In case of Local Voltage Control is not able to maintain the voltage between pre-defined limits, the Centralized Voltage Control try to help generators "in difficulty" asking the "closest" generators to operate. The "closest" concept is based on a Sensitivity Approach particularized for radial distribution feeders.
The proposed Voltage Control Criteria has been applied to the "Ciccalento" MV line, located in the Italian Puglia region, and fed by the "San Giovanni Rotondo" Primary Substation. This line has been taken into account for the "POI-P3" Pilot Project (the Italian acronym of "Interregional Operative Project") on Smart Grids, funded by the Italian Ministry of Economic Development, which involves some GD plants in four Regions of the South of Italy.
Before the real field application in the pilot project, Real-Time Digital Simulations have been used to validate the presented criteria. Analysis have been performed using the Real-Time Digital Simulator installed in the Enel Distribuzione Test Center of Milan (Italy).
Moreover the MV network Sensitivity Approach has been generalized for a four-wires LV network, in order to extend the Centralized Voltage Control to LV application.
The PhD Thesis results can be summarized as follows:
Using the actual voltage control, without involving new voltage control criteria, generators G1, G2, G3 and G5 daily violate, for about two hours, voltage limits imposed by the European Standard EN 50160 (± 10 %).
It is important to note that the generators nominal power that should be disconnected amounts to 3.814 MW, referred to a total 3.974 MW connected to

1. The Real-Time Digital Simulator used in this PhD Thesis.

the grid. The presence of DG decrease active power losses from 2.99 MWh to 1.74 MWh. This phenomenon occurs because generated energy is quite close to the load so reducing power flows along line sections.
Activating the new Local Voltage Control criteria all generators do not violate EN 50160 limits. In this conditions, daily grid losses increase, passing from 1.74 MWh to 2.57 MWh (UPG voltage control function) or 2.41 MWh (RQV voltage control function) due to the reactive power exchange necessary to the voltage control. It is worth noting that the UPG and the RQV have quite the same effect, even if the UPG function seems to be more efficient in terms of hosting capacity. In fact, it is able to decrease the voltage to some percent less than RQV function.
Further analysis showed that up to 5 MW can be connected to the network without violating EN 50160 limits, which corresponds to +28 % hosting capacity more.
Modifying the criteria actually used for the MV busbar voltage control the nominal power that could be connected reaches 6.95 MW so increasing of +75 % the grid hosting capacity. In this conditions daily grid losses increase significantly, passing from 1.74 MWh to 5.77 MWh (UPG voltage control function) or 5.51 MWh (RQV voltage control function) due to great amount of reactive power exchange necessary to the voltage control.
On the other hand, daily energy flowing through HV/MV transformer is quite zero due to the high DG penetration compared to the load.
Finally, activating the new Centralized Voltage Control function, different condition have been considered. In particular, a condition where two generators (G4 and G5) don't activate any local voltage control has been considered. In this condition, G1 voltage exceeds voltage limits and local voltage control is activated. Nevertheless G1 voltage reaches the highest value so requiring an help to the central Voltage Control System (VCS). The VCS call the "closest" generators to operate, at first G5 and then G4. It's important to note that the closet generator firstly called (G5) is geographically farer than G4 but more efficient from the Sensitivity Table.
Results showed in this PhD Thesis have been obtained analyzing a real MV line (named "Ciccalento"). They demonstrated the effectiveness of the proposed voltage control criteria that can be therefore used for an efficient voltage control of MV grids.
The proposed criteria can in fact be applied on every MV lines because they are base on reactive power exchanges, which influences voltage variations, due to the network inductive reactance presence.
However it is important to note that numerical results obtained for the "Ciccalento" line can't be used in order to evaluate the effect on different lines. For example, the obtained hosting capacity increment (+28 % or +75 %) could be different in other lines because it strongly depends on network electric characteristics, network topology, load and generation power and their point of connection. In addition similar consideration can be done about the effect on voltage regulation.
In other words, only analysis on the considered line (characterized by network characteristics, topology, load and generation power) could give numerical results to quantify the effect of the proposed criteria on voltage control and hosting capacity.