ANNEX 2: TEMPLATE FOR PROPOSAL UNDER DERRI

User-Project Proposal:

Use-Project Acronym	VOREGLOC
User-Project Title	Novel distributed network management with dispersed generation: VOltage REGulation based on LOcal Controllers
Main-scientific field	Electrical power system
Specific-Discipline	Smart grids and voltage quality

Lead User of the Proposing Team:

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Position in Organization	PhD student

* Higher Education Institution (1) – Public research organization (2) – Private not-for-profit research organization (3) – Small or Medium size private enterprise (4) – Large private enterprise (5) – other (specify)

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Position in Organization	Assistant professor

* Higher Education Institution (1) – Public research organization (2) – Private not-for-profit research organization (3) – Small or Medium size private enterprise (4) – Large private enterprise (5) – other (specify)

(Repeat for all Users)

Date of submission	30 September 2010
Re-submission	YES_______ NO___X__
Proposed Host TA Facility	KEMA – Arnhem, RISOE-DTU - Roskilde
Starting date (proposed)	1 February 2011

Summary of proposed research (about ½ page)

The research deals with dispersed generation (DG) connected to the medium voltage (MV) and low voltage (LV) distribution system.

In particular the proposed work is focused on a novel distribution network management in order to take advantages of this new form of generation. In this way it is possible to use renewable resources, that are spread on the territory, and to reduce gas emissions, resulting in environmental and energy benefits. Actually the network is designed to be passive system (i.e. without generation connected) so power injections at distribution level introduce new issues in network management.

An important issue is related to the voltage quality of the power supply. DG plants determine different power flow along distribution feeders modifying voltage profiles. In particular injections of power increase the voltage magnitude at the DG point of common coupling (PCC) with the risk to violate the voltage upper limits. Actually DG units supply energy at unit power factor (compliant with the Italian regulation) and they don't participate actively to the voltage regulation. A first simple approach for improving voltage profile on distribution network entails the exploitation of regulation resources based entirely on local measurements. In some circumstances generators have to operate at non-unitary power factor by injecting or absorbing reactive power from the network. In this way the distribution network is made up by two voltage control systems: the first is at the generators level and the second is the on-load tap changer (OLTC) at primary substation level. The aim of the research is to investigate local control strategies. Different laboratory tests are carried out in several network conditions (e.g. several conditions of power flow) to analyze the performance of this voltage regulation system. The expected results can raise awareness about local voltage control and the consequent behavior of the network in term of voltage profile and power losses. This project represents a cost-effective solution to the voltage control, moreover it is possible to obtain significant results in a short time period. The project could be the starting point for developing global control system that coordinates distributed resources (e.g. reactors and capacitors) and OLTC.

The expected outcome is an improvement of voltage quality thank to the active participation of dispersed generation to the voltage regulation.

State-of-the-Art (about 1 ½ page)

With respect to the voltage control, currently the regulation is usually based on on-load and off-voltage tap changing transformers and capacitors\reactors banks.

Automatic voltage control of the electrical network is implemented by use of voltage control relays which control motorised OLTC power transformers. The regulating point is the MV busbar that is usually far from the load centre of the network, which means that the load may not be delivered at the desired voltage level due to the voltage drop on the line between the load and the Primary Substation (PS). The greatest voltage drop occurs under the maximum loading condition. By means of load drop compensator the voltage set-point is modified according to the current that flows through the transformer (i.e. the entity of load); in this way voltage drop is compensated and load is delivered at the optimum voltage level. When generator is running the measured transformer current no longer represents the load connected to the PS; this involves a decreasing *in load compensation. The DG plants also effects the voltage profile along the feeder to which they are connected. As the generator output increases such that it supplies the entire load of the feeder, the voltage at the point of connection is greater than voltage at the MV busbar of the PS. This control strategy became ineffective for two main reasons described below. First the voltage at the MV busbar of the PS is not adequate to guarantee acceptable voltage profile along the passive feeder due to the reduction of load compensation; an under-voltage violation may occur. Second, DG plants increase the voltage at the PCC and over-voltage violation at the active feeder (i.e. feeder with DG units connected) may occur. In [1] a solution to estimate the generation output and to trace back to the true load is proposed, but the algorithm developed requires to know the amount of load of each feeder and in which feeders the DGs are connected. Information about load consumptions and generation injections could not be available and state estimation techniques are required.*

In [2] a multiple line drop compensation method is proposed. This method uses both the load diversity information of each feeder connected to the PS and the output power information of DG unit. In this way voltage regulation is more accurate and flexible than that of conventional load drop compensation method; but the tap changing operations of OLTC are more frequent. To have a more accurate voltage regulation it is necessary to involve DG units and others regulation resources; a cooperation between OLTC and these regulation resources can improve the voltage quality and, by a hierarchical voltage regulation action, reduce the tap changing operations.

Interactions among the voltage control operated in the MV substation and the possible voltage control operated by the DGs connected to the distribution system is also analyzed. In [3] a novel voltage and reactive power controller for the dispersed generators is proposed. With this controller, when the voltage profile at the feeder remains into an acceptable range DG operates at unit power factor, otherwise the DG gives an additional contribution to control the voltage of the system by injecting or absorbing reactive power (according to voltage violation) until the under/over voltage excitation limits are reached. The techniques presented is very interesting because DG plants are use as ancillary services in order to keep voltage along the feeders in an acceptable range. It can represent the starting point to develop a control system that exploit all control resources connected to the feeder (e.g. active and passive users, reactors/capacitors, OLTC). The control strategy described are local control; it means that each device operates independently. In an electrical network each regulation action affects the voltage of all buses of the system; for this reasons it is essential to coordinate all regulation resources. This problem is faced in [4]; coordination between OLTC and capacitors is achieved through the maximization of a fuzzy objective function. In order to improve the quality of the supply voltage in the distribution network this approach can be introduced to coordinate local control of DG voltage and OLTC.

Voltage regulation strategy to coordinate all the available on line voltage regulation resources have to be designed at a global level [5] [6]. The voltage regulation strategy can control several device types in real-time by computing voltage set-points on the base of electrical state of the network (all system is supervised and regulated). Therefore it arises a need for improvement of measuring, data preprocessing and communication techniques.

References

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[5] J.Tlusty, "Management of the voltage quality in the distribution system within dispersed generation sources", 18th international conference on electricity distribution CIRED, Turin, 6-9 June 2005.
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Detailed Description of proposed project : Objectives – Expected Outcome – Fundamental Scientific and Technical value and interest (2-3 pages)

Objectives

- *To built a local voltage regulator that modulates the reactive power injected/absorbed by the DG plants proportional to the voltage deviations. An appropriate voltage control function is defined.*
- *Implementation of the voltage control strategy in a facility test and analysis of the behavior of the DG regulator in case of network events (e.g. load event or tap event). In this way it is possible to test it and to define a sort of benchmark for a practice implementation.*
- *The simulations are exploited to fix data parameters and control strategies that are in agreement with grid constraints. It is possible to obtain a standard local controller that can be used in software simulations.*

Expected Outcome

It is expected that the experimental validation of the voltage control regulation gives the foundation for improving the distributed network management. This is the first step to actively involve DG plants to voltage regulation. Dispersed generations can inject power without technical limits (it is possible to use all "green energy" available) and they can also be used as ancillary services in order to support the network in critical conditions and improve the power quality of the energy supply.

Fundamental Scientific and Technical value and interest

The project is related to the local voltage regulation in a MV & LV distribution network with dispersed generation plants connected.
The main kinds of dispersed generation are combined heat and power (CHP), wind farms, PV, and waste burning. As these generators become more and more compact, the wish to connect them at lower network voltages is increasing. However, Distribution Networks have not been designed to connect a significant amount of generation. Without any medium voltage (MV) networks adaptation, this fast expanding can affect the quality of supply as well as the public and equipment safety.
This project suggests a technical solution which would permit to connect more generators on the network without violating technical constraints, in particular the voltage constraints. This solution can reduce the voltage increase due to the power injections and at the same time take advantage of the regulation capacity to improve the lower voltages in case of high amount of load. Referring to the Italian standard, the voltage limits in the distribution system (including both MV and LV network) are +10 % and -10 % of the nominal voltage (CEI EN 50160). Today, two main voltage setting devices are available: the HV/MV transformer OLTC allows the automatic regulation of the transformation ratio according to a selected voltage level which is constant or proportional to the secondary current and the MV/LV transformer off-load tap-changers.
In a passive network (no generators connected at the MV and LV levels) the voltage profile along

the feeder is monotonous: it decreases along the feeder. The OLTC has to act with the goal to maintain the voltage in all nodes of the network into the upper and lower limits. In practice, it regulates the voltage in order to maintain the voltage upper to the lower voltage limit at the end of feeder in case of maximum load and to avoid over-voltage in case of minimum load.

However, today, with DG connected, the voltage profile is no longer monotonous and the introduced generation increases the voltage at the PCC. Depending on the power mismatch (both real and reactive) between load and generation at local level, the generator can either leads serious over-voltages to other customers connected to the same main feeder, or contribute to improve the feeder voltage. It happens because the OLTC acts according to local measurement (voltage in the MV bus of the PS) and it doesn't know the power injections of the DG units. Indeed, if the OLTC is set to the upper level in order to respect the required lower voltage level in case of peak load, the generator introduction creates over-voltages during minimum load times. On the contrary, if the HV/MV transformer voltage level is decreased in order to connect a generator to one of the MV feeder, it can create an under-voltages during peak load; these under-voltages occur on the feeders without generator.

At any moment, the impact of the generator on the voltage profile depends directly on power injection and its power factor. The under-voltages occur during peak load times without generation, the over-voltages occur during minimal load times with generation.

*The research aims to develop and test a local voltage control regulator that modulates the reactive power injections in order to increase/decrease the voltage at the PCC. The local control strategy comprises two conditions (*Fig. 1*): a normal operating situation, where no control action is required, and a situation where first voltage thresholds are violated. In the latter case, the generator operates at a not-unitary power factor injecting/absorbing reactive power from the network.*

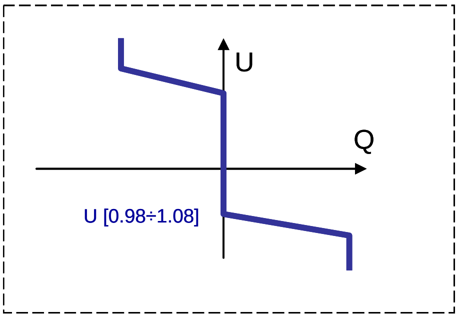

Fig. 1: Regulation control strategy

The proposed voltage control limits the participation of the generators to the voltage control of the distribution system only when the network voltage is out of a pre-defined range. In this way, the reactive power generated by the dispersed generator is null when the network voltage is at acceptable levels, limiting the current generated and lowering the power losses.

The control function is introduced in a test facility and different network events could be simulated. The control function in term of transfer function is realized by means of a software that guarantees the implementation to the physical component of the tested grid.

According to the DG unit type available in the laboratory, the algorithm will be implemented in the inverter interface (for wind turbines or PV solar panels) or in the automatic voltage control (AVR) of synchronous generators. The impact of different local strategies (e.g. different voltage thresholds, different generators size, different control performances) can be tested by means of software interfaces.

Several network scenarios have to be taken into account: DG units connections in several points of the feeders, different load conditions and different network configurations. In this way different voltage profiles are studied and the real behavior of the network is analyzed. The results obtained during testing can be used as a reference for software simulations.

This research allows to analyze the impact of the local voltage regulation at the PCC on the voltage profile of the entire feeder and the consequences on the OLTC actions. By connecting

more than one generator is possible to evaluate the feasibility of a lot of regulator actions at the same time and point out possible critical situations.
The benefits of this method are represented by voltage improvements. The voltage at the PCC is kept at acceptable values, furthermore DG doesn't impact directly to the OLTC regulation at the PS level. This technical solution permit to connect more generators to the network without violating voltage constraints.

Originality and Innovation of proposed research – Broader Impact (1-2 pages)

The voltage regulation system in the distributed network take place traditionally in the PS and voltage at MV busbar is monitored and regulated at set-point value. Dispersed generation is not coordinated with the OLTC and in some circumstances can create hazardous voltage conditions. The voltage regulation strategy proposed reduces the probability of this critical conditions.

Furthermore, t*his solution allows to increase the hosting capacity of the network: all the available renewable resources spread on the territory can be used for conversion in electrical energy in small power plants. It is important because DG penetration will increase in the near future; the network has to be ready to receive a large amount of plants.*

DG resources exploitation for ancillary services represents the peculiarity of the research. The generators are adopted to locally control voltage and to improve the voltage profile. The voltage regulation is performed in many points along the feeder and the distribution network can be consider as an active part of the electrical system.

The improvement expected in network operation is mainly the enhancement of voltage regulation (i.e. fulfillment of limits related to supply voltage variation, within the range set by EN 50160).

The results represent the first step toward a voltage regulation at global level (i.e. a coordination between several regulation resources).

At present there is a lot research on communication techniques to be used for the construction of an intelligent communication network. This interactions between devices is the basis of the smart grid of the future; in this new context there is an exchange of information: a central unit sends logic signals to the voltage regulation resources and DG units sends local measurers to the central unit. This research Involves high cost whereas local control system, that represents the first viable step toward a smart grid, is feasible in a short term scenario.

Whit this technical solution it is possible to reduce the voltage variations at the PCC. It eliminates the technical limits due to the voltage variation and it guarantees a better exploitation of renewable resources.

Proposed Host TA Infrastructure/Installation – Justification (about one page)

The Host TA Infrastructures proposed are: TA7: KEMA - Arnhem (The Netherlands) and TA10: RISOE-DTU – Roskilde (Denmark). By the information provided by the DERri website it seems that in these two infrastructures there could be the possibility to implement and test the voltage regulator proposed in the project. In this two TA there is the possibility to use the voltage regulator on a real test facility.

KEMA is considered suitable to host this project. The laboratory infrastructure has a test facility in which a variety of electrical circuit can be tested. One option is to connect the virtual grid back to the feeding grid with off-load tap changer (0.4/4kV). Alternatively a large diversity of passive loads are available in the lab and an islanded grid can be simulated to analyze performance of the voltage regulation system.

The DG plan is a power electronic converter that is able to feed grid at MV level; the four-quadrant operation can be exploited to inject or absorb reactive power and to satisfy the voltage control signal.

The research is in agreement with the future development of Flexible Power Grid Lab to create a connection to a Real Time Digital Simulator located in Delft University of Technology in order to facilitate the interaction between DG units and the power system.

DTU SYSlab is considered suitable to host this project. The facility is a LV power grid with an Ethernet based communication network. The communication system is fit for the research purpose: it allows an intelligent control by implementing the voltage control function in the computer which interfaces with the DG units. The flexibility of the power grid guarantee a range of different network topology.

Synergy with ongoing research (about ½ page)

The project proposed is in synergy with two project listed below.

- *The project RicercaDiSistema of Politecnico di Milano in collaboration with RSE. The purpose of this activity is to develop a local control regulator with the same characteristics of that proposed. In particular different control strategy and different transfer functions are considered and simulated by using the software DIgSILENT Power Factory. The results of this research can be exploited to define the practical tests in laboratory and they can be use as reference for the simulations.*
- *Milano Wi-Power is a project that tests advanced communication technologies in order to interface primary substations (the electricity distribution network) and active users of the distribution system. The project involves the participation of: The Polytechnic of Milan, A2A, Thytronic, Selta, ERSE, Mobimesh, and is followed with interest by the Authority for Electricity and Gas and Comitato Elettrotecnico Italiano (CEI).*

Dissemination – Exploitation of results (about ½ page)

The results of the experiment will be used to write papers for journal publication. The papers will be obviously focus on local voltage regulation of DG plants. The work will be presented to IEEE conference.

This project will be insert in the SmartDGLab site (http://www.fondazionepolitecnico.it/pagine/SmartDGlab.aspx).

SmartDGlab is an interdepartmental laboratory of the Politecnico di Milano; it was born with the aim of finalizing research in the context of active networks (smart grids). The current technological frontier follows the need to integrate the electricity network with appropriate channels of communication and logic innovative planning, programming, supervision, control, regulation and protection of electrical distribution. The Fondazione Politecnico di Milano supports SmartDGlab by providing their own infrastructure.

Time schedule (about ½ page)

The time schedule can be organized as follow:

- 6 days: first visit at the laboratory for checking the test facilities, for the simulation definition and for laboratory tests on the network, one person
- 4 days: second visit at the laboratory and tests after a check of the results, one person

Transport: 2 Journey (round trip)

Room and board: 10 days in Arnhem or Roskilde

Use of the laboratory: 10 days

	Start	Finish	Febbruary 2011	March 2011
First visit at the Lab and check the test facility	01/02/2011	01/02/2011		
Simulation definition	02/02/2011	02/02/2011		
Laboratory test on the network	03/02/2011	06/02/2011		
Check of the result and analysis by software simulation in DIgSILENT	07/02/2011	21/03/2011		
Second visit and tests	22/03/2011	25/03/2011		

Description of the proposing team (as long as needed)

The proposing team is made up of:

- *1 phd student: Gabriele Monfredini,*
- *1 assistant professor: Marco Merlo.*

Gabriele Monfredini

He received the degree in electrical engineering from the Politecnico di Milano, Milano, Italy, in 2009. Currently, he is a PhD student of Power Systems in the Department of Energy at Politecnico di Milano, Milano, Italy.

Publication:

M. Merlo, G. Monfredini, M. Ambroggi, "Protezioni della generazione diffusa sulle reti MT", AEIT pag. 12-19, Maggio-Giugno 2010.

Marco Merlo

He received the Ph.D. degree in electrical engineering from the Politecnico di Milano, Milano, Italy, in 2003. Currently, he is Assistant Professor of Power Systems in the Department of Energy at Politecnico di Milano, Italy.

Publication:

I. P. Marannino, F. Zanellini, A. Berizzi, D. Medina, M. Merlo, M. Pozzi, "Steady state and dynamic approaches for the evaluation of the loadability margins in the presence of the secondary voltage regulation", IEEE Transactions on Power System, vol 19, issue 2, maggio 2004,pp.1048-1057
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