GRID IMPACT AND INTEGRATION OF MICRO WIND GENERATION

Vito CALDERARO  Vincenzo GALDI  Antonio PICCOLO  Pierluigi SIANO
Department of Electrical and Information Engineering, University of Salerno, Italy
vcalderaro@unisa.it, vgaldi@unisa.it, apiccolo@unisa.it, psiano@unisa.it

ABSTRACT
Full integration of Distributed Generation (DG) in the current electricity grids can be favoured by designing measurement, communication and monitoring (MCM) systems able to control power quality levels and to organize power systems in microgrids managed by Information and Communication Technology (ICT).

In order to cope with this, a MCM system for micro generation into microgrids is presented in the paper. The system consists of a Human Machine Interface, a communication system based on WiMAX technology and an acquisition system based on National Instrument technology and LabView software.

In this paper the electrical network of University of Salerno Campus is used in order to assess the issues related to micro wind integration into microgrids by carrying on experimental studies.

INTRODUCTION
The development of Information and Communication Technologies (ICTs) has impacted and will continue to have a major effect on meter reading, power usage recording, power reliability data collection and power quality monitoring. Furthermore, the large diffusion of ICTs allows to access remotely the energy systems and manage optimally power systems. Such as real and potential possibilities allow to face adequately the increasing levels of distributed generation (DG) that can lead to power quality problems in electricity grids. In particular, distributed energy renewable resources, like wind sources, often produce power and voltage changes with natural conditions.

Considering that wind generation is essential to alleviate the present day problems of the atmospheric pollution and the global warming, it is needed to investigate new ways to monitor and integrate a high penetration of wind turbines in distribution grid.

For that purpose, two important strategies can be followed: to design measurement, communication and monitoring (MCM) systems able to monitor power quality levels and to organize power systems in microgrids that offer the possibility of coordinating the distributed resources in a more or less decentralized way, so that they behave as a single, controlled entity. In this way, distributed resources can provide their full advantages in a consistent way.

Various power quality monitoring systems that integrate data processing automatically or manually have been proposed in literature.

A comprehensive system is the Signature System [1] or the proprietary system Carolina Power &Light (CP&L) [2] that incorporates functions to evaluate voltage variation, voltage transient, distortion and supply system status. Typically, monitoring units are distributed over the power networks and linked by means of internet, intranet or proprietary communication systems [3]. Although the majority of existing systems are proprietary, the engineering world is moving towards open systems in the interests of better interconnectivity and expandability [4].

The present work, that describes the use of advanced ICT in the design of a comprehensive power quality MCM system, moves in this direction.

More specifically, the electrical network of University of Salerno Campus is used to assess the issues related to micro generation integration into microgrids.

An accurate description of the proposed management and control system is given and experimental studies on a 20 kW variable speed wind turbine are presented in the paper. In order to cope with the open communication issues, a WiMAX technology is used allowing controlling and remotely monitoring via a graphical interface designed and realized by LabView programming.

The results are analyzed considering the power quality parameter indicated from standard international standards [5,6].

MICROGRID AND MICRO WIND GENERATOR
The micro wind generator is connected to the microgrid that supplies the University of Salerno Campus that extends over an area of about 800000 m².

The power system consists of eight MV/LV substations (20/0.23 kV) which normally feed the LV feeders in a ring configuration as shown in fig. 1.
The maximum total load is of about 4.5 MW. A 20 kW wind turbine is connected to the secondary side of a MV/LV transformer of a substation (Generic Load & Wind turbine bus), as shown in fig. 1. The generator is a synchronous permanent magnet generator (200 rpm), with a power electronic conversion system for power conditioning and grid connection. The wind turbine, installed on a tower of 18 m, consists of a three blade rotor with direct connection to the generator. A pitch blade control system, that drives an electric linear actuator, limits the generated power by controlling the rotor speed within the allowed limits and up to wind speeds of 35 m/s. The power provided by the synchronous generator is conditioned by a power conversion system installed at the base of the tower. The power conversion system consists of three conversion stages: a three-phase uncontrolled rectifier; a step up dc-dc converter; an Active Front End (AFE) inverter, which transfers the power to the three-phase line, at 400V, 50Hz. The rectifier supplies a front line dc with a voltage proportional to the speed of rotation of the rotor, varying as a function of wind speed between 0 and 200 rpm. The dc-dc step up converter is current controlled in order to ensure the maximum power production while the AFE inverter allows a power factor of 0.99 and keeps the dc-link voltage to a constant value of 620 V.

MEASUREMENT, COMMUNICATION AND MONITORING SYSTEM

A measurement, communication and monitoring (MCM) system is designed to actively manage the micro wind generator connected to the low voltage grid. The MCM system aims at keeping the operational conditions of the micro wind generator and of the grid within the range prescribed international standards [5,6]. The mandatory power quality limits prescribed by the standard EN 50160 are shown in table 1. The designed architecture of the MCM system for the micro wind generator allows to:

- acquire voltage and current waveforms along the conversion ac/dc/ac chain and perform appropriate processing on them;
- acquire transient events with high-frequency;
- provide a series of digital and analog input/output signals for the management of the breakers and of the contactor;
- manage and store events and any occurred anomalies;
- authenticate remotely access to all features of the management system by means of a communication link.

The control panel, shown in fig. 2 and placed under the wind tower, can generate control signals for both the motorized breakers and the contactor. The system is connected to the MV/LV substation by means of power and signal cables while an uninterruptible power supply has been installed in the substation, in order to feed the acquisition and monitoring system. The system is endowed by a WiMAX connection on a Virtual Private Network (VPN), allowing the remote control of all the features of the measuring station. The remote control can be carried out by means a National Instrument system and LabView software. The National Instrument system is based on PXI controllers with embedded PC and Windows XP and allows to connect to a local area network.

The PXI architecture combines the power features of the PCI bus with a special bus to synchronize in real time the acquisition modules, enabling synchronous acquisition of most signals on different acquisition modules operating in parallel.

The simultaneous sampling acquisition PXI modules allow acquiring synchronously up to 24 signals with sampling frequency of up to 500 kS/s per channel. The integration into an embedded PC platform enables the implementation of custom post-processing routine of the acquired signals. In addition, the embedded PC platform allows interfacing the measuring station with traditional computers and networks based on the most common data transmission protocols, such as TCP/IP.

More specifically, the acquisition system is composed of 3 cards with simultaneous sampling, with a maximum sampling rate of 500 kS/s per channel. They are able to ensure the acquisition of fast transient phenomena lasting 100 µs. With regards to the output signals a card able to provide 8 analog and 8 digital Transistor-Transistor Logic (TTL) signals has been chosen: the former are used to control the power conversion stage, while the second to check the breaking devices. This solution allows the synchronization of fast acquisition time with the opening and closing of the contactor or motorized breakers.

A LabView based monitoring system and Human Machine Interface (HMI) were developed to assess and record the wind generator and electrical network performances.

CASE STUDY AND DISCUSSION

The designed MCM system has been used to carry out a series of experimental measurements on the described micro wind generator in order to investigate both its steady-state performances and to assess compliance with power quality requirements. Steady state performances are shown in fig. 3 and in fig. 4, where the one second average values of the active power versus the wind speed and versus the rotor speed are respectively shown.
### Table 1: Mandatory Power Quality limits in standard EN 50160

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>MEASUREMENT</th>
<th>VALUE LIMITS</th>
<th>TIME LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>10 s average value</td>
<td>50 Hz ± 1%</td>
<td>99.5% of average values of a year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 Hz ± 4% - 6%</td>
<td>100% of average values of a year</td>
</tr>
<tr>
<td>Slow voltage fluctuation</td>
<td>10 min average of RMS value</td>
<td>230 V ± 10%</td>
<td>95% of average values of every weekly range</td>
</tr>
<tr>
<td></td>
<td></td>
<td>230 V ± 10% - 15%</td>
<td>100% of average values of a year</td>
</tr>
<tr>
<td>Long term flicker intensity (P₁ₜ)</td>
<td>Calculated on the basis of twelve 10 min averages of short-term flicker, P₁ₜ 10 min averages of RMS</td>
<td>P₁ₜ≤1</td>
<td>95% of all P₁ₜ of every weekly range</td>
</tr>
<tr>
<td>Voltage asymmetry</td>
<td></td>
<td>Opposite phase sequence system component ≤2% of positive phase sequence system component</td>
<td>95% of average values of every weekly range</td>
</tr>
<tr>
<td>Single harmonics</td>
<td>10 min averages of RMS value</td>
<td></td>
<td>95% of average values of every weekly range</td>
</tr>
<tr>
<td>THD</td>
<td>Calculated on the basis of 10 min averages of RMS values of harmonics from the 1th to the 40th order</td>
<td>THD≤8%</td>
<td>100% of the time</td>
</tr>
</tbody>
</table>

**Figure 2** Control panel

**Figure 3** Active power vs wind speed

**Figure 4** Active power vs rotor speed
The cut-in wind velocity is of 3.5 m/s and it can be noted that the variable speed-turbine reaches the maximum power of 20 kW at 12 m/s while, when the maximum power level is reached, the turbine sticks to it very well until the maximum rotor speed of 200 rpm is reached. In any case, the pitch blade control system, that drives an electric linear actuator, limits the generated power by controlling the rotor speed within the allowed limits and up to wind speeds of 35 m/s.

The power curves shown in fig. 3 and in fig. 4 are due to the current controlled dc-dc step up converter that ensures the maximum power production. The measured step up dc-dc converter output voltage has a maximum percentage ripple of about 1% with a mean value varying from 618.5V to 621.6V, in correspondence of a generated power of 5kW and 20kW, respectively.

On the contrary, the dc-dc step up converter output current depends on rotor speed and varies accordingly to its value thanks to the converter current controller. The input to this control is the rotor speed that is derived by the measured rectifier output voltage that has a mean value varying from 318.7V to 429.5V, in correspondence of a generated power of 5kW and 20kW, respectively. The measured rectifier output voltage exhibits a maximum percentage ripple of 17% in correspondence of a generated power of 20kW.

Harmonic voltages and currents have been investigated at this stage in order to verify compliance with power quality requirements.

The phase grid voltage and the phase current injected into the grid have been analyzed for different values of injected power. As the wind turbine is equipped with a IGBT inverter with PWM modulation at 10kHz, harmonic currents are injected into the grid. In order to reduce current harmonic injection, the inverter is interconnected to the low voltage grid by means of a transformer and a condenser, together acting as a filter. Harmonic voltage level on the grid and the injection of harmonic currents as a function of power level have been evaluated. The voltage harmonics have been expressed as percentage of actual grid voltage while the current harmonics are presented as percentage of the grid current at the nominal power of 20kW.

Measurements evidenced that the total harmonic distortion (THD) of the voltage varies between 0.9% and 1.3%, reaching its maximum value in correspondence of a generated power of 20kW, while the European standard CENELEC - EN 50160 allows 8%.

The harmonic current injection is below 5% of the grid current at its nominal power, in compliance with the limit of 5% recommended by the IEC [6].

The phase grid voltage and phase current injected into the grid at its nominal power during a time interval of 100 ms are shown in Fig. 5 and in Fig. 6 respectively.

CONCLUSION

Experimental tests carried out on a 20 kW variable speed wind turbine connected to the low voltage distribution network of the University of Salerno Campus have shown the effectiveness of the proposed measurement, communication and monitoring system. It has been designed in order to control power quality levels and to organize power systems in microgrids managed by Information and Communication Technology (ICT).

REFERENCES