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Automatic Station for Monitoring a Microgrid

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***Abstract* – In the last few years there have been several changes in the electric energy sector, because of the need to have ever more energy and at the same time to reduce polluting emissions. These needs have led to the diffusion of renewable sources for the production of energy, which are often distributed throughout the territory. The concept of electric network has changed, leading to the introduction of the smart grid, in which energy consumption and quality are important information that allow a better management of the energy flows. To support efficiently smart grids in the management of bidirectional flow among the various nodes, they are needed smart meters and energy management systems. This paper aims to describe the design of an automatic measuring station, capable of simultaneously monitoring data from different smart meters distributed within a microgrid. Data acquired can be analysed and used, with the necessary methodologies, to implement a smart management of the energy flows.**

I. ENERGY FLOWS IN THE MICROGRID

The structure of a smart grid can be seen as a set of multiple microgrids interconnected with each other, at an electrical and IT level, with dedicated communication systems.

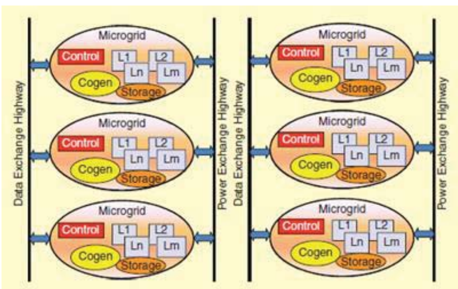

Fig. 1 Smart Grid topology example

The microgrid is defined as "*interconnected networks of distributed energy systems (loads and resources) that can function whether they are connected to or separate from the electricity grid*" [1].

The microgrid can continue to perform its functions even though completely disconnected from the main electric grid. In this case it supplies the various utilities, using only the energy produced inside by the renewable energy sources (RES), or uses the energy stored in the storage systems. Furthermore, the surplus energy in the network, can be re-directed to other microgrids that need it.

To fulfill all its inside functions, the microgrid needs a centralized control system. This analyses the information received from all the components of the network, monitors the energy flows in terms of quantity and quality, and makes decisions on the functioning of the microgrid, taking into account the presence of "*sensitive*" users, who need energy with a given quality and without interruption. In fact, it is essential to guarantee a continuous electricity supply, without power fluctuations and with good quality. Furthermore, with the recent spread of electric vehicles that require electric energy for their operation, another element has been added to the conformation of the network. With the diffusion of RES, randomly distributed throughout the territory, large amounts of energy are introduced into the network, not equally distributed, not constant in the supply, and often with suboptimal quality. The management of bidirectional energy flows has become very complex and it is necessary to treat this argument more in detail [2].

The microgrid is a cluster of different types of RES and different types of loads, it can operate in both grid-tied as well as islanded modes. In the latter case the management of energy flows is of primary importance, in order to match accumulations and needs. For example, a voltage drop, caused by the non-productivity of a photovoltaic plant, could be compensated by a flow of energy from a storage system. Different technologies are being developed on this line of research, such as new more efficient batteries and super capacitors [3].

Fig. 2 Microgrid topology

Inside the microgrid, a possible management solution is to have different RES that compensate each other, to have always a constant flow of energy, and to use storage systems when the need of electric energy is greatest.
A real-time system must be created to manage the flows from the different sources and storage systems used [4, 5]. Therefore, an energy management system (EMS) is necessary, as an integrating part of the microgrid for constant network monitoring. The smart EMS optimizes the usage of electric energy by integrating that produced from renewable sources, decreases pollution emissions, reduces losses, increases energy quality, and at the same time meets the user needs. The collection of data carried out by monitoring devices will be very useful, since it is possible to create consumption forecasts based on user behaviour and to create optimized consumption plans [6]. There are several works on this topic in the literature. In [7] it was developed a system to monitor the quality of electric energy in the network using smart meters and data transmission systems based on zig-bee technology. In the work described in [8], a real-time energy management architecture is presented, with several Smart Meters, which continuously monitor the connected loads and communicate with a central system using CAN bus technology. Users can remotely control their energy consumption using a web browser. The authors of the work [6] have developed an algorithm to control energy flows in the electric grid and to guarantee minimal power variations, considering both renewable energy sources and storage systems.

II. AUTOMATIC STATION FOR MONITORING ENERGY FLOWS

The work described in this paper consists in the design of a station for monitoring the flow of electric energy. This serves to identify a solution for electric energy management in a microgrid. The graphical user interface created, allows to simultaneously control several smart meters connected in the microgrid, to monitor energy parameters and to exactly know their position on an interactive map.

A. Smart meters and synchronization

To monitor the energy flows in the microgrid, they are used measurement instruments for monitoring energy in terms of both quantity and quality, in particular smart meters developed on the model described in [9]. The Smart Meter is made using a NI Single Board RIO with two modules, NI-9225 and NI-9246, mounted on board to acquire the voltage and current signals. This system is able to monitor all the parameters reported in the Standard IEEE 1459 [10], and it is connected to the network and remotely controllable by a dedicated application, created with the LabVIEW software.
The smart meter developed is a stand-alone device that operates automatically, it is equipped with an internal memory for local saving of measurement data and can be continuously monitored or can be interrogated only when needed. It provides real-time measurements of multiple parameters, useful for monitoring the quantity and quality of electric energy and consists of a single instrument, very easy to install and remotely controllable using an Ethernet connection.
To monitor energy flows, a certain number of smart meters should be positioned in the nodes of the microgrid. So, another very important aspect for the network management, is the synchronization of the distributed measuring devices, it is essential to ensure synchronization accuracy.
To monitor the energy, in different parts of a grid, is required synchronization accuracy on the order of hundreds of microseconds or less [11-14]. Considering the specific case of this application, the computer synchronization systems can be used to ensure the adequate synchronization of the devices, so minimizing implementation costs [15]. In this work it has been implemented the protocol reported in the IEEE 1588 Standard [16], the Precision Time Protocol (PTP), which allows to synchronize devices connected to a network with the precision of the microsecond.

B. Graphical interface of the control station

A server-based monitoring station has been developed to manage all smart meters distributed in the microgrid. The user interface of the control station (Fig. 3) was created in the LabVIEW environment and with it the user can communicate and control all the devices on the network simultaneously.
The control station program is installed on a central server, which coordinates the entire electrical network and each smart meter, that can be reached through an IP address. The graphical interface of the control station allows the user to read the data in real time from each smart meter, to observe the status of each device, to monitor operations and to check for any measurement errors or faults. In this way, the remote control station can perform a real-time supervision of each node of the grid and read all the parameters: the voltage and current waveforms, the harmonic content and all values of the Std. IEEE 1459. Indicators are available on the front panel to show the operating status of the selected smart meters and possible errors. Furthermore the user, setting the proper controls, can choose the data to be displayed, has the possibility to save the measurement data locally or if necessary may decide to switch off a measuring device.
On the front panel there is also another feature, the "*Localize*" button, which allows the user to get the position of the specific node in the microgrid where the smart meter was installed. To select the device to be

monitored, the user has to click on the drop-down menu of the front panel (Fig.3) and, knowing the relative IP address, has to select the desired smart meter.

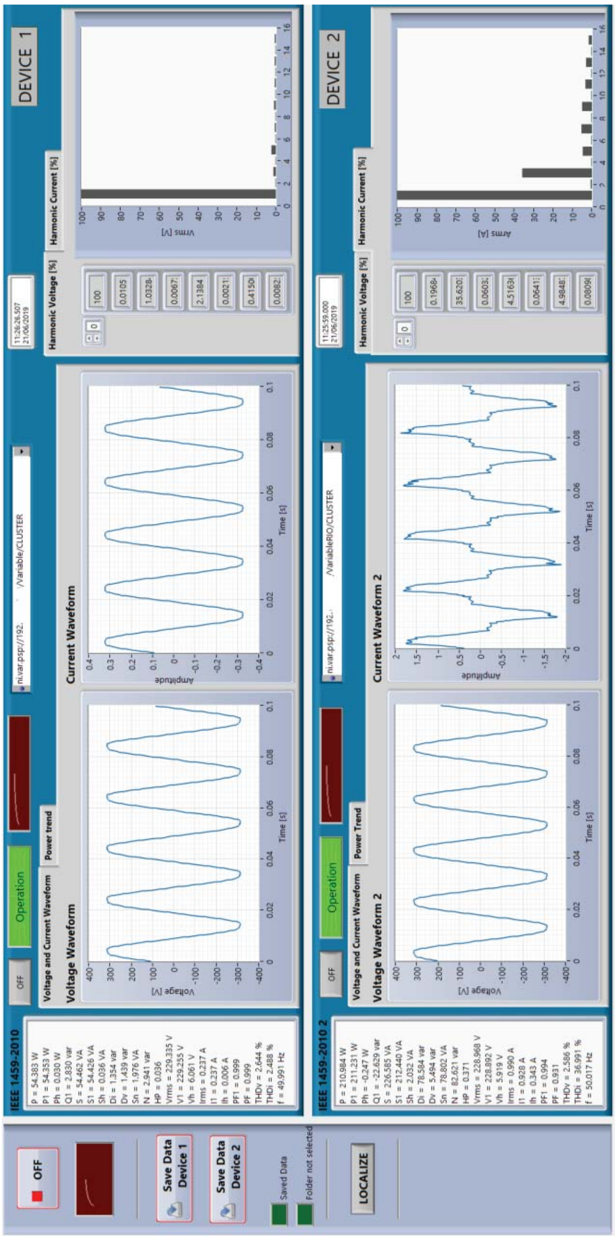

Fig. 3 Graphical interface

Field tests were carried out with two smart meters located in two different points of the electric grid of the Mediterranean University of Reggio Calabria (Italy). The tests let to verify the correct functioning of the monitoring station, the synchronization of the data measured by the several smart meters and the absence of interruptions or instrument failures.

In compliance with the PTP protocol, the first connected smart meter has been set as a master device, and it has to provide the clock signal for synchronization, while the second device has been set as a slave. Other smart meters can be added to the measurement network through the control station, which automatically sets them as slave devices.

C. Management system

The control station developed can be used to monitor and control energy flows in a microgrid. We look forward to create a network with a smart meter and an actuator system in each node, as shown in Fig. 4, to monitor and control the energy flows from the renewable sources, the storage systems and the national network, in order to match energy production with the requests of different users.

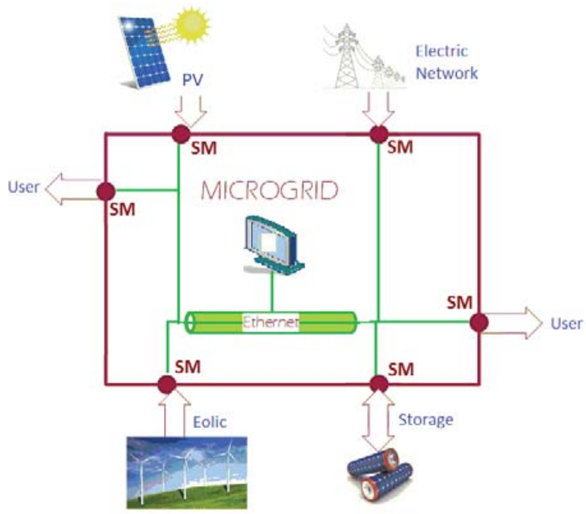

Fig. 4 Graphic pattern of monitoring system

Analysing the information acquired, especially for what concerns the quality of the energy transported, some algorithms can be implemented for the correct distribution of the energy flows in the network. Those algorithms should take into account the needs of the users, in terms of quantity and quality, and try to satisfy them distributing the energy available in the microgrid.

From the User Interface (UI) shown in Fig.3, it is possible to monitor the energy consumed by the users, in terms of quantity and quality, by analysing both the voltage and current waveform.

To monitor the electric energy in the microgrid, in particular the quality of this energy, it is important to constantly monitor the voltage at the input nodes. Since considering any industrial or domestic load, the grid has to guarantee an adequate quality of the energy provided, the final target is the maximization of the quality of energy, and of the overall energy efficiency [17].

To achieve this, and then to have a complete picture of the energy flows in the microgrid, both for the incoming energy and energy used by the users, which are an active

part in the new network [18], an automatic measurement system has been implemented. This system monitors the voltage quality parameters of the incoming flows to the microgrid and analyses, in real time, the voltage quality indexes of the various input nodes to the microgrid.
In Fig. 5, it is shown the UI panel of the monitoring system, which has been added to the station reported in Fig. 3. It reports to the user the voltage status and the voltage quality level, of the incoming energy at the microgrid nodes. In this first implementation, only two energy sources are monitored, but the system is scalable.

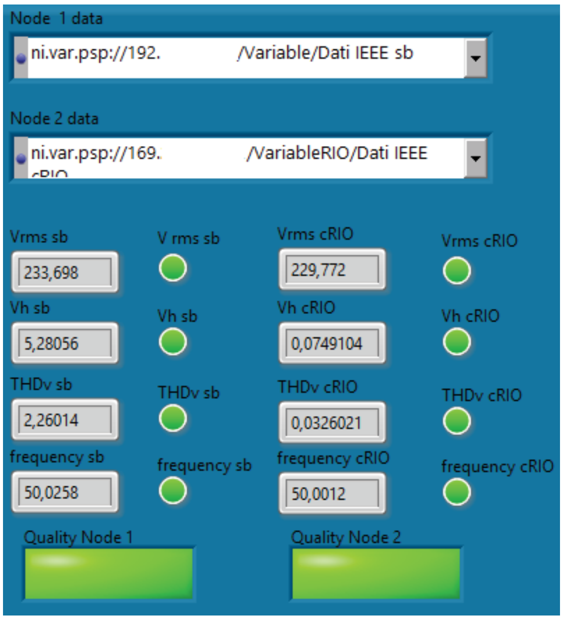

Fig. 5 Front panel

For each parameter analysed it is reported the numeric value and a light indicator, which gives informations on the degree of quality. Green colour to indicate good quality and red to indicate poor quality. Furthermore, the system analyses the parameters and reports a general indicator of quality, referring to the individual node.
Using this information and the output ports of the hardware used, it is possible to control a system of actuators to manage the energy flows and meet the best quality characteristics.
The parameters monitored for the analysis of the voltage quality and the ranges of values to be respected are chosen on the base of the sector standards [19, 21-24].
The parameters monitored are:

– the rms value of the voltage, calculated with the following equation [22]:

$$V_{rms} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} v_n^2} \tag{1}$$

with N = number of samples acquired;
v_n = sample

it must be greater than 90% of the nominal value [19, 20, 25], which is 230 Volt by the standard [21];
If during a rapid voltage change the voltage drops below a level of 0.9 x 230 V, it would be considered, under EN 50160 [19], to be a voltage dip.

– the rms value of the harmonic voltage [10]

$$V_h = \sqrt{\sum_{h=2}^{N} v_h^2} \tag{2}$$

with v_h = voltage value of single harmonic
N = harmonics number
It must be less than 10 V, based on several measurements [9];

– Total Harmonic Distortion of the voltage

$$THD_v = \frac{\sqrt{\sum_{h=2}^{N} v_h^2}}{v_1} \tag{3}$$

it must less than 5% [23, 24];

– frequency
It must be within the 50 Hz ± 1% range, for 99.5% of the year and for the remaining 0.5% of the year, in a range from -6% to + 4% around 50 Hz. For island networks, a wider operating range of 50 Hz ± 2% is required for 95% of a week. For the remaining 5% of the week, a range of 50 Hz ± 15% is specified [19].
To verify the operation of the automatic monitoring system some tests were performed, with two smart meters, the first connected to the National electric grid (node 1) and the second to a power generator (node 2). The generator employed is the *AMETEK Programmable Power California Instruments CSW series 5500*, used to generate, in the various tests, several voltage signals with quality problems.
The correct functioning of the automatic monitoring system has been verified, in fact, it always detected promptly disturbances in the quality of the supply voltage.
Figure 5 shows the results of a first test, in which the first smart meter (node 1) is connected to the electrical grid and the second (node 2) to the generator, which provides a perfectly sine voltage waveform, at 230 Volts RMS and with no harmonic content. As it can be seen, in this case the system reports no quality problems.
Figure 6 shows the front panel of the monitoring system, in the case that the generator provides a voltage signal with a nominal value lower than the limit imposed by the standard. Figure 7 shows the case of a signal with the addition of a harmonic content of the third order, in the value of 25% of the fundamental. In both cases, quality problems are promptly detected and reported, through the light indicator, on the graphical interface.

Fig. 6 Test Results-nominal value lower than the limit imposed by standard

Fig. 7 Test Results- signal with the addition of a harmonic content of the third order

III. CONCLUSION

The implemented monitoring station can control the quality of energy flows within a microgrid, both the energy used by users and the energy supplied to the microgrid at different nodes. Numerous local tests have been carried out to validate its operation.

The aim of this work is to create a network of smart meters to perform more accurate tests and to implement a control system for a network of electric actuators in order to automatically manage the switching of energy flows.

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