Smart grid and Super grid

Traditional electrical grids are not able anymore to support the needs of a rapidly evolving electricity sector. The convergence of many factors –including the generation of electricity from renewable sources and distributed generation as a whole– promotes the development of smart grids and the related continental interconnections, the super grids

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In recent years, depletion of fossil energy resources and global warming problems have prompted international awareness about sustainability of energy supply on a worldwide scale. According to the latest forecast, the global electricity demand will outstrip the supply by 2020, due to several key trends, such as migration to cities, increasing levels of wealth, and growing number of appliances and equipment used. In such a context, there is a pressing need to accelerate the development of low-carbon energy technologies, in order to address the global challenges related to energy security, climate change and economic growth. Smart grids offer ways not just to meet these challenges, but also to develop a cleaner energy supply, which is more efficient, more affordable and more sustainable. A smart grid is an electricity network, which uses digital and other advanced technologies to monitor and manage the electricity transport from generation sources to meet the end-user electricity demand. Smart grids coordinate the needs and capabilities of generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, by reducing costs and environmental impacts, while increasing system reliability, resilience and stability. The main characteristics of a smart grid are summarized in the following:

- Allows active participation of consumers, based on their increased interaction with the grid. This active participation brings tangible results for both the grid and the environment, while reducing the cost of the delivered electricity.
- Offers the possibility to involve several generation and storage options, which represent new opportunities for a more efficient, cleaner power production.
- Supports the process for a larger penetration of renewables into the transmission and distribution networks, thereby promoting the transition towards a low-carbon energy system and its sustainable economic development.
- Enables new products, services and markets, by offering new consumer choices such as green power products, and a new generation of electric vehicles.

- Optimizes asset utilization and operates efficiently. Desired functionality at minimum cost guides operations and allows fuller utilization of assets. More targeted and efficient grid-maintenance programs result in fewer equipment failures and safe operations.
- Anticipates and responds to system disturbance through self-assessments to detect, analyze and respond adequately to restore grid components or network sections.
- Operates resiliently against cyber-attacks.

The smart management of the grid is the key point, allowing significant development perspectives of smart grids at local scale, and super grids at continental scale. This key point faces several challenges related to grid strengthening, enhanced intelligence, communication technologies and standardization, interoperability between different components and systems, integration of intermittent generation, moving offshore, and capturing the benefits of distributed generation and storage.

ENEA Research activities

In order to deal with the challenges mentioned above, the ENEA research activities mainly focus on three specific areas related to smart grids and super grids, as discussed in the following. All these R&D activities are carried out within several National and European projects, and in national and international organism and networks, working in the field of energy technologies and systems, integrated energy networks and renewables.

Smart grids and microgrids

In the context of smart grids and microgrids, research focuses on the modeling, operation and design optimization of Distributed Energy Resources (DER) (shown in Figure 1), in presence of renewables, polygeneration systems such as Combined Heat and Power systems, and electrical/thermal storage, through multi-objective approach, by considering both economic and energy savings/environmental aspects [1, 2, 3, 4]. The main goal of this research is to investigate configurations and operation strategies of DER systems through multi-objective approach, in order to provide decision support to planners and/or operators based on short- and long-run priorities. The developed optimization models are both deterministic and stochastic. In this latter case, uncertainties of supply side, including renewables and demand side, are included.

Demand side management (DSM) is also integrated in smart grid modeling through Demand Response (DR) programs. These latter allow to transfer the customer load during periods of high demand to

off-peak periods, with the aim of managing the required demand to match the available energy resources, without adding new generation capacity. By reducing the peak loads on the electricity network, DSM has various benefits, including the mitigation of electrical system emergencies and the increase in the system reliability. Benefits also include the reduction of dependency on imports of fuels, as well as the reduction of energy prices and environmental impacts.
The research interests also focus on the technologies, systems and strategies, which allow to promote an active electric network and the transition from the "fossil-fuel-based" energy generation system to a distributed and smart "renewable-based" scenario.
The most important outcome of this research activity is the POLISTAR (POLIgeneration and STorage for smARt green islands() Project, based on the collaboration between ENEA and the University of Palermo's Department of Energy, Information Engineering and Mathematical Models(DEIM). The goal of the project is to design a smart grid for Pantelleria island (South Italy), based on renewables (solar photovoltaic, wind, geothermal), power generation from urban waste, and electrochemical storage, with the aim of reducing the dependency on fossil fuels, thereby increasing the island energy autonomy.
Moreover, research activities also address the management and control of combined systems based on renewable (solar photovoltaic) generation plants, and electrochemical storage, integrated into smart grids and energy networks, in order to foster a larger penetration of renewables into the electric grids, as well to offer ancillary service for the network and end-users.

Super grids
ENEA is also involved in research on super grids . In detail, research activities are aimed at testing, implementing and demonstration of a VSC-HVDC (Voltage Source Converter - High Voltage Direct Current) pilot plant, with the aim of promoting the creation of interconnected Pan-European Network (super grid).
High voltage direct current (HVDC) transmission systems can transport enormous amounts of electricity. Such systems have been widely introduced in European countries in order to stabilize and strengthen power grids and also respond to the increased use of renewable energy. The main challenges are related to their realization, reduction of operation and maintenance costs, increase in operation reliability and security, and reduced environmental impact.
This research activity is based on a scientific alliance between ENEA, Toshiba Corporation and Toshiba Transmission and Distribution on advanced technologies for electricity grids and renewables, and on a Memorandum of Understanding signed by ENEA and NEDO (New Energy and Industrial Technology Development Organization of Japan). The new HVDC interconnection employs innovative multilevel converters based on the VSC technology, and provides a higher efficiency, flexibility, security and grid stability, as well as lower environmental impacts [5].
The high-voltage VSCs allow to reduce energy losses and mitigate carbon dioxide emissions, which is difficult to attain with conventional VSCs. It is estimated that the high-voltage VSC devices can reduce energy losses on the transmission lines by about 60%, as compared to the conventional VSC devices. In addi-

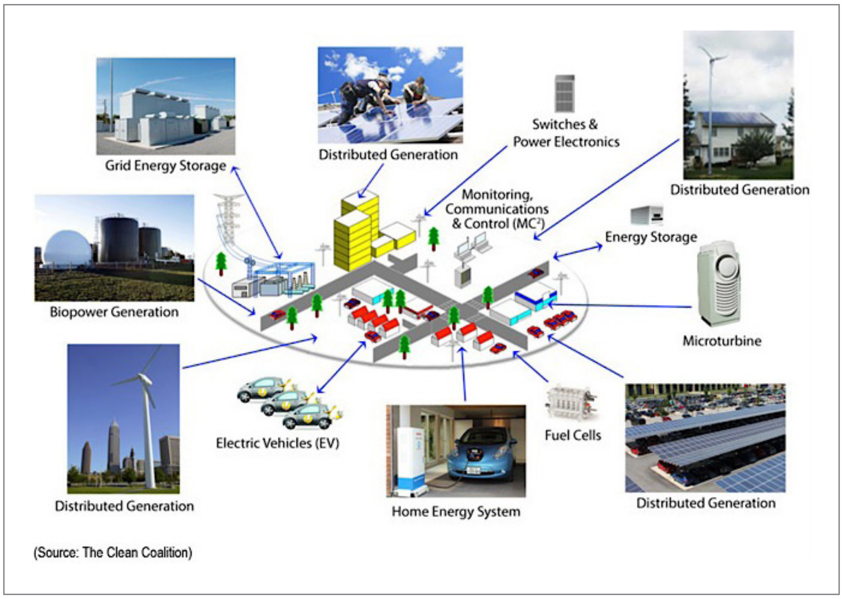

Fig. 1 Example of DER systems analysed

tion, using superconducting cables allows to increase the carrying capacity and reduce power losses.
The demonstration plant, to be set up at the ENEA Casaccia Research Centre, concerns an innovative technology considered among the most promising for long-distance electrical power transmission. The objective of the demonstration plant is to promote the dissemination and expansion of HVDC transmission systems in such areas as offshore wind power, which are promising end-use areas for the VSC's project, as well as to experiment and validate advanced solutions to modernize the existing grid, by promoting a new energy system based on distributed generation, the use of renewables, smart grid and super grid.
The experimental results will be also integrated in an European impact analysis with the purpose to demonstrate the applicability of the proposed solutions and their potential for replicability in the Pan-European electric power transmission network.

Smart PV systems

In the context of smart PV systems, research activities focus on the study, modelling and design of innovative components and solutions for photovoltaic applications in residential/industrial construction and micro-grids contexts. The aim consists in taking advantage of PV plant capillary distribution in the whole country for the creation and development of new energy contexts. These new energy models base their success on communication and cooperation among various devices and technologies. ENEA pursues this objective carrying out modeling, designing and experimental activities concerning innovative devices capable of constituting a constellation of "talking" nodes and of providing ancillary services useful to the PV plant users and/or grid operators.
In this area, research activities are organized into three lines:

- Distributed Maximum Power Point Tracking converters
- Smart Maximum Power Point Tracking Converters
- Microinverter and Multilevel Converters.

In detail, Distributed Maximum Power Point Tracking converters (DMPPT) are able to optimize the energy extracted from a single PV generator, also in presence of continuous variable operating conditions and mismatch phenomena. They are DC-DC converters capable of adapting the impedance in order to ensure the maximum transfer of power from the photovoltaic generator. Each converter is equipped with a digital control type for tracking, instant by instant, the Maximum Power Point of the photovoltaic module. In this way, there is improvement of performance even in those hours of the day when the yield of the photovoltaic generator decreases due to shadowing phenomena. In such a context, the research focus is on the circuital study and the benefit-cost trade-off analysis of applicable simple, hybrid or interleaved topologies [6,7]. The goal is to obtain optimized solutions both in terms of efficiency and reliability performances and in terms of necessary economical budget. The attention is also concentrated on affordable DMPPT control techniques for tracking the PV generator Maximum Power Point.
The research interest is also in Smart Maximum Power Point tracking Converters (SMPPC), as innovative solutions to enhance renewable integration in new energetic contexts such as Net Zero Energy Buildings (NZEBs), DC microgrids and smart grids [8,9]. In addition to DMPPT features, the SMPPC integrated approach allows to implement some auxiliary functions on board, such as data communication, alarms, di-

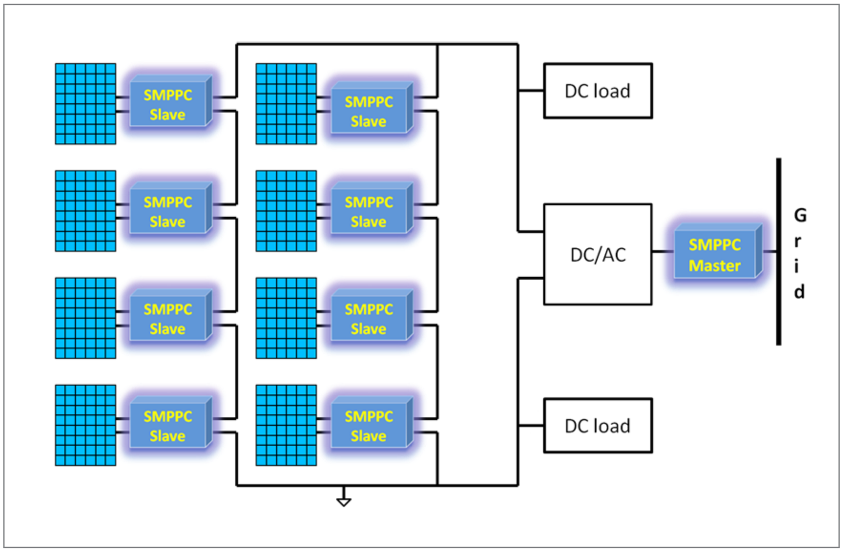

Fig. 2 SMPPC Master-Slave architecture

agnostics, monitoring and plant reconfiguration. In detail, a hierarchical SMPPC architecture (Figure 2) is presented. Each SMPPC Slave is dedicated to optimize a specific PV generator power and to provide suitable information to the higher architectural level. Each level is equipped with data acquisition and communication boards able to monitor and transfer data by suitable interfaces. Similar slave devices are dedicated to DC loads to acquire data about their power consumption and their interruptible capacity. The data exchange among SMPPC Master and Slaves nodes permits to implement services useful for both PV plant users and grid operators. Actually, in the future electricity grids (smart grids), data exchange and transmission will play a decisive role to decision and action making. The research focus is on the analysis and application of communication protocols to transfer necessary information for balancing the delivered and the consumed energy, ensuring the security and reliability of the whole system.

This research line is concentrated on the development of a SMPPC Master operating as an energy manager. It could be able to continuously receive microgrid generation and consumption data and make appropriate decisions to match and optimize supplies and load requirements. For instance, depending on the specific scenario, it could improve the micro-grid service quality and reliability deciding to immediately provide the generated energy to high priority and uninterruptible loads, to use it for storage devices recharge or to feed it into the grid. In addition, analysis and application of suitable digital techniques are carried out to improve microinverters performances and to develop multi-level converters ancillary services.

Open research issues

Beyond the research activities described above, open research issues regard several aspects in the context of smart grids. Among others, smart grids interoperability is a key point allowing the diverse devices and systems to interoperate within the smart grid. A key requirement is the interoperability of the cyber systems used to manage the power system. Interoperability among disparate devices and systems can only be achieved through the use of internationally recognized communication and interface standards. Another open research issue regards the need for a high number of demonstration plants to test and validate the technological and technical solutions found through the optimization models, as well the upgrading of technologies, components, and methods developed. Last but not least, open issues also concern the development of a capillary information/formation campaign for customers, with the aim of promoting and fostering their active role within the new energy scenario, based on smart grids and distributed generation from renewables.

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