

## **DISTRIBUTED ENERGY RESOURCES**

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### **Driving forces**

The deregulation of the energy markets, environmental concerns (Kyoto Protocol), security of energy supply and quality of services considerations and emerging new technologies are contributing to the shift from centralised to de-centralised power generation, frequently with small-scale cogeneration.

Major opportunities for the development of Distributed Energy Resources (DER) are densely populated urban areas since the demand for power, heating and cooling concentrates there. 80% of the population of Europe, for instance, is indeed accommodated in urban areas where a major part of industrial and business activities is also found. Rural and peripheral regions can also prove to be interesting opportunities for DER.

Distributed generation has many benefits in terms of:

- reduced transmission and distribution losses,
- avoidance of investment cost and of public reaction when building new electricity transport infrastructure
- distributed generation technologies have low investment costs and can be build incrementally to match demand
- potential to use locally available alternative and renewable energy sources
- local exploitation of the heat produced for the case of CHP applications, leading to high efficiencies (75%)
- shorter planning and erection phases
- can be transported to other sites if need arises

There are also some potential drawbacks, including:

- high cost of the kWh for some fuels
- electrical quality issues in terms of voltage and frequency control, reactive power issues
- terms for connection to the grid could be still unclear in some countries

### **Key elements for DER**

For many years, power systems were operated in a top-down fashion. Thus, large power generation plants, such as a nuclear plant or a lignite-fired plant for instance, produced most of the power. This kind of generation is often located close to the required resources such as water for cooling purposes for nuclear plants or a lignite mine in the latter case. The power is then transmitted to large consumption centres

over long distances and using different high voltage levels. This operating structure was built on the basis of economic facts, security and quality of supply. This very centralized structure is operated by a hierarchy of control centres, which facilitate the constant monitoring and control of the system. Thus, generation is instantly adjusted to the load of demand (by monitoring the frequency and using well established load forecasting models). The voltage is also controlled to be within specified security limits by means of appropriate devices, which are usually coordinated (generators, on-line tap changer, reactive compensation devices, etc.)

However, this operating mode is increasingly changing due to technical, economical, social, environmental, and political factors. From the technical viewpoint, there are several reasons for these changes. Some are listed below:

- Saturation of the existing network and reduction of security margins,
- Geographical and ecological constraints,
- Stability and security problems (including the need to take expensive preventive measures and the increase of short-circuit currents),
- Continuous demand growth (in the E.U. accession countries, for instance),
- Need for investment to sustain the development in the power demand. This development has led to smaller “packets” of investment,
- Privatisation, deregulation and competitive environment of the electricity market,
- Emergence of new rational generation technologies with ecological advantages, which can be combined with heat generation.

In this context, we can anticipate the development of decentralised and autonomous generation in many countries all over the world. This energy will be produced locally close to consumption centres and is not intended to be transmitted over long distances. The size of this generation varies from kW to dozens of MW and can be coupled with heat generation and even cooling systems. Such generation is generally connected to distribution systems. Furthermore, it is encouraged by a regulatory framework favourable to co-generation and renewable energy sources as well as by the attractive cost of some equipment and the low cost and flexibility of some primary energy.

Distributed resources will introduce tremendous changes to the generation and distribution businesses, and to its distribution and management. This will require redesign of planning strategies and tools, design methodologies, operations and control of electrical networks. Indeed, these networks were not designed and built to interconnect large amount of distributed resources and the integration of such resources into the grid may have significant consequences on power transfers and hence on the philosophy of the management systems and their robustness.

On the other hand, this kind of power generation through its distributed and local nature has the potential to achieve increased security of the bulk power system. In fact, traditional power transfers depend heavily on the bulk transmission network. This network can be considered as the weakest link of the chain. A greater penetration of distributed resources into the grid will permit the whole network to be less dependent on the bulk transmission network. Therefore constraints such as transmission network congestion, cascading effects and large blackouts will have less

impact on the end user. Furthermore, it will be possible to redesign grid re-energizing strategies so that the distributed resources can play a major role.

In addition and beyond the distributed resources, the whole distribution network should be redesigned using innovative equipment, more automation, new control and supervisory functions, specific network architectures and intelligent protection systems where information and communication technologies can achieve low costs. Hence, the whole electrical system and its philosophy of planning, design and management is subject to a profound change.

It is urgent to develop DER to arrive at the target of sustainable development and security of power supply for the next distributed generation electrical network, such that it is able to survive amongst fierce market competition. This requires intelligent interaction between the decentralized grid of the future, new electrical energy technologies including renewable generation and storage devices, smart and self-adapting power interfaces (conversion), the system operator, the market and, last but not least, the customer. An innovative approach is needed for the planning, design, management and operations of distributed power systems of the future with high reliability and quality performance requirements, targeted at creating benefits for the end-user and for industry competitiveness. Key to this strategy is distributed intelligence, self-adapting components, a decentralized grid, global piloting, and smart use of Information and Communication Technologies (ICT).

It is anticipated that:

- DER shall become a “normal” profitable business thriving in a competitive market. Currently, DER is introduced through government-level policies and subsidies. Ultimately, however, DER has to stand on its own feet within the market without such measures.
- Exploiting advanced ICT will be the prime mechanism to manage the new grid and its many decentralised players. There is simply no technological way to manage a new and heavily networked power system other than taking advantage of all the new opportunities and capabilities of ICT. This demands a stream of innovations that will be cutting across the traditional boundaries currently separating the power and ICT industry sectors.
- The customer will no longer be a passive “load”, but a pro-active player in the new utility value chain. In today’s power grid, customers are in fact mainly passive end nodes. In the new decentralized grid, they will be among the many decentralized players and may even help to co-produce the required energy services such as demand-side management and load shedding. Customers will have a choice to select and collaborate with their preferred supplier. So, they will gain the opportunity to be active market players. The future active role of the customer in the decentralized grid operations and energy services has to be completely rethought.

## The Players

The common types of distributed generation technologies are:

Diesel gensets. Commonly used for emergency back-up till today, can now be used as peaking or base load units. Power from 50 kW to 6 MW and efficiency of the order of 33% to 40%

NG gensets. If a Natural Gas network is available a Natural Gas engine would be suitable for CHP applications. Their power range would cover ranges similar to the diesel genset.

Gas Turbines. Commonly used in industrial applications for power of CHP or as peaking units by utilities. Their power can range from 1 MW to 100 MW and their efficiency from 30% to 40%

Microturbines. A technology that has recently been made commercially available, where the turbine, compressor and generator are on the same shaft that spins at very high speeds, that can be as high as 120,000 rpm for small units. The power produced is of high frequency and is rectified to 50/60Hz through power electronics. Their power ranges from 25 kW to 500 kW. The electrical efficiency is of the order of 25% and can be increased to an overall efficiency of 80% if the heat is also exploited. Microturbines can be operated on a variety of fuels, like natural gas, propane, diesel or kerosene. With no or few modifications the microturbines can be operated with low calorific value fuels like landfill gas or biogas.

Fuel cells. In principle, a fuel cell operates like a battery, producing energy in the form of electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes sandwiched around an electrolyte. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water and heat. The ideal fuel for fuel cells is Hydrogen but some types can operate on gaseous fuels (Hydrogen carriers) that are internally reformed into Hydrogen. Fuel cells operate at temperatures that vary between 80 and 1000 °C. Depending on the electrolyte used, fuel cells can be divided into the following types:

- *Proton Exchange Membrane fuel cells:* Operate at low temperatures, require high purity Hydrogen, good load following characteristics, suitable for transport applications.
- *Alkaline fuel cells :* Used in space applications, requiring pure Hydrogen.
- *Phosphoric acid fuel cells:* Commercially available today for CHP applications running on NG, typical power range 200kW<sub>e</sub> and 200 kW<sub>th</sub>.
- *Molten carbonate fuel cells:* Some prototype units manufactured with power ranging from 250kW to 2MW. High temperature operation.
- *Solid Oxide fuel cells:* High temperature operation, tolerance in Hydrogen purity, power ranging from 1kW to 250 kW, significant market potential for stationary CHP applications

Renewable Energy Source Technologies. Renewable energy technologies could work in grid-connected mode or as stand-alone units in combination with some energy

storage device like a battery. Their realisation potential is site specific, depending on resource availability. Such technologies include,

- *Wind turbines*: World market increasing by 25% last year, commercial machines reaching 5MW in capacity and price (installed) dropping below 1000 Euro/kW.
- *Photovoltaics*: Technology that converts direct sunlight into electrical energy, requiring large spaces and having a high cost (6,000 to 10,000 Euro/kW).
- *Small Hydro*: A mature technology that can be well integrated at the distribution level, with power ranging from a few kW to hundreds of kW.
- *Biomass*: boilers or IC engines used to convert biomass or waste into electricity and heat can be made at a suitable scale for distributed generation.

## The Grid

DER has the potential to improve the security of the bulk power system by limiting congestion, loop flows, high losses, cascading effects and avoiding building new transmission lines. In particular, distributed resources, by their decentralised nature, may significantly improve the reliability of the system as a whole by making power supply less dependent on the bulk transmission network.

However, the presence of a large number of small generation units on the distribution grid leads to technical challenges. Some DER sources (micro-turbines, fuel cells) are easily controllable, and others (wind and solar energy) have a more unpredictable power output. This will require the distribution system to be more flexible and more automated with faster responses. With a high penetration of DER, the distribution grid would resemble the transmission systems.

Here are a few technical challenges:

- Assuring the balance between production and demand, it will not be possible without the assistance of DER. Consideration is under way in several European countries on having the distribution system operators (DSOs) provide system services to the transmission system operators (TSOs); a high penetration of DER would reinforce this trend and change the way things are done. It will also make economic sense for DER to provide system services to the distribution system.
- DER will imply bi-directional flows between independent entities that cannot be handled by today's distribution systems. Protection will have to be redesigned in order to adapt to distributed generators connected to the distribution system. This will require distributed intelligence that will rely heavily on multi-party communications. The architecture and reconfiguration methods may have to be radically changed in order to ensure that the grid is optimally operated. The notions of total black-out and black-restart will probably have to be revised, and the concept of a self-restored system will need to be introduced.
- The functions of the DSO (flow control, current limitation, voltage control, reactive control, harmonic filtering) may not be able to be fully met by traditional technologies. Combined power electronic and storage technologies will enable cheaper and environmentally friendly alternatives to be provided.

A high penetration of DER would also mean significant developments in gas infrastructures (including storage) to supply fuel cells, micro-turbines and Stirling

engines. This will cause a high interdependency between gas, electricity and communication infrastructures and will affect other fuel supply structures as well. It is important to account and make sure that energy and intelligence are being distributed with an adequate level of reliability and security.

### **The Market Places**

In a deregulated market, production is scheduled through an open wholesale market where large amounts of electrical energy are traded daily. European market places are today organized over one or several countries, and each market place presently has its own set of rules. With a high penetration of DER, these market places will have to interface both with the transmission operators and with distribution operators.

The development of DER on Low Voltage and Medium Voltage levels will probably bring changes to the present wholesale market structure through the emergence of new energy service providers on large wholesale market, representing aggregations of DERs or consumers, or the creation of local (or regional) market places focused on lower voltage grid participants.

Currently, each market sets the rules for participant interaction separately, and negotiates other interactions (e.g. market to market) on an as-needed basis, with no real supervising organization. This was a necessary measure in order to get markets functioning quickly, however this is very undesirable in the long run because it creates both extra work and the inevitability of different models for the same grid in different markets. The restructuring of market places with the likely emergence of new market places on lower voltage levels will require all markets to be able to access a common registry of grid data.

Current market systems have effectively implemented real-time and day-ahead markets, as well as interaction with operations systems (EMS/SCADA) and settlements. Record keeping for support of auditing and market monitoring is less well developed, as is the ability to simulate market operations, either in training or analytically. A vision for the future needs to include improved methods for managing time, archiving information, and making archived information useful.

New solutions are needed (the required market place structure and the associated software) to allow any market participant, such as energy service providers (ESP), utilities, energy traders, or other resource schedulers to bid and schedule DER in multiple regional electricity markets. This will reduce the risks to the ESP and customers by automating and integrating wholesale market signals with customer operations, allowing significant cost and energy savings to end-users. This function in essence would extend to owners and operators of DER the opportunity to provide valuable services to energy markets (for example peak load reduction, reduced risk of network congestion and clean energy management), and in turn allow them to be compensated for the services provided. Enabling DER to tap into the potential revenue stream available from energy markets will improve the economics of DER, leading to greater penetration and the application of innovative technologies

## **Distributed resources and ICTs**

Beyond new generation technology, and in particular distributed generation, information and communication technology (ICT) is going to be an essential component of the power system, both on the industrial and the business sides.

Indeed, ICT is going to be at the heart of the forthcoming system architecture, as only ICT makes it possible to exchange immensely increased amounts of data, to control an increasing numbers of components, and to make it possible for new business actors to smoothly interact and go into markets, whilst maintaining the overall safety and security of the system.

At the same time, technology has reached a level where all this becomes possible: hardware is becoming cheap enough to be embedded within even simple electrical objects; software platforms are becoming standardized and support the necessary distributed control and intelligence; the Internet, relying on efficient networking and broadband technology, makes it possible to connect in continental digital networks the millions of objects of the electrical system - including generation units, grid components, and consumption sites - together with business actors, and marketplaces.

## **European Long-term Research Programme on DER**

The EU 6<sup>th</sup> Framework Programme (FP6) for long-medium term energy RTD identifies the following as strategically important areas for DER, where research should be concentrated:

New approach for large-scale implementation of Distributed Energy Resources (DER) in Europe (design, development and validation of novel components and DER solutions needed for future interactive energy service networks),

Energy storage technologies and systems for grid-connected applications (innovative energy storage concepts to facilitate the large-scale penetration of DER) and

Development of key enabling technologies (for distributed energy networks with high power quality and security of service, including development of low-loss cables for transmission systems and high temperature superconductor based components for electrical applications, such as fault current limiters, motors, transformers etc).

Along these lines, the first call of FP6 invited proposers for Integrated Projects on:

- *New demand driven solutions for large scale implementation of Distributed Energy Resources (DER) in Europe.* The objective is to design, develop and validate systems and approaches allowing the large-scale penetration of DER incorporating the needs of future market requirements. The work should be based on a demand driven approach and cover research and technological validation of solutions for the optimal operation and integration of a large number of distributed generators, including renewables. The main expected results should be a set of specifications for distributed generators and their control interface to the distribution network of the future and to

formulate, develop and test new tools and techniques for the management of distribution networks with a high penetration of DER.

- *Novel concepts and advanced components for power transmission and distribution networks with high Distributed energy Resources (DER) penetration.* The aim is to develop and test new concepts and components for future intelligent electricity networks (for mainland and island systems) based on a DER mode, integrating advanced power electronic components and new Information and Communication Technology (ICT) concepts. Results should enable operators of advanced networks to start planning the utilisation of innovative grid management tools in their businesses, increasing quality and reliability of supply and reducing environmental impacts. Furthermore, delivered specifications should allow manufacturers of equipment to plan and validate industrial production of new grid control and management devices.
- *Advanced energy storage systems for RES.* The objective is to develop technologies and systems for the storage of electricity for grid-connected applications enabling the increased penetration of renewable and distributed generation of electricity in new distributed electricity networks. RTD should also consider the analysis of storage system performance (in terms of lifetime, system lifetime cost, reliability, safety and recyclability of materials, including life cycle analysis), the benchmarking of technologies (such as batteries, reversible fuel cells, supercapacitors, flywheels and SMES, for storing electricity in grid-connected applications) and pre-normative research.

In addition, specific targeted research projects were invited in the following areas:

- *Electricity – transmission systems.* (advanced systems for stability and control, as well as the development of low-loss cables).
- *Electricity – innovative energy storage technologies for grid-connected applications.* (new concepts for energy storage technologies, where applicable exploiting the synergies with transport applications).
- *Electricity–development of devices based on high temperature superconductors (HTS.)* (development and validation of HTS based components for electrical applications, such as fault current limiters, motors, transformers, etc.).