Distribution Systems and Dispersed Generation: strategy, activities and future development

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Preface

CIGRE carried out in 2002 a radical transformation aimed at focussing CIGRE activity on the "Electrical System" as a whole, including all interconnected components. In particular issues relevant to electricity distribution and to integration of small size generators into distribution networks were integrated within CIGRE's scope and a new Study Committee was set up to work on this subject.

The scope of *Study Committee C6, "Distribution System and Dispersed Generation"*, encompasses primarily the assessment of the technical impacts, requirements and possible solutions associated with a more widespread penetration of Dispersed Generation (DG) and larger proportions of non-dispatchable power generation which could impose changes to the structure and operation of transmission and distribution systems. Electrification of rural and remote areas, demand management methodologies, storage application are also within the scope of the Committee.

Why a new SC dealing with Distribution and Dispersed Generation?

To-day three key factors:

- Contribution of PES to the Global Climate Change,
- High prices, physical and political constraints in the acquisition of primary energy sources,
- Concern towards PES security due to extension of interactions, at a continent level, among regional or national systems,

are calling for substantial changes in Power Electric Systems (PES). The utilisation and the integration into the distribution networks of small size generators (combined heat and power - CHP - systems, small hydro and fossil fuelled generators, fuel cells, photovoltaic - PV - sets, wind turbines) is considered one of the main option to face climate change and concern toward security of energy acquisition and of PES operation. The development of the DG concept is motivated by a number of important factors including:

- Capability to achieve higher efficiency in conversion from primary energy sources mostly by means of the diffusion of CHP and to reduce joule losses;
- Low environmental impact and capability to capture renewable energy sources (RES);
- No additional transmission costs and savings in distribution costs (although this depends on DG location);
- New DG technologies are intrinsically modular and a low scale factor to for both investment and running costs is expected in the future;
- Improvement in reliability and quality of power supply from the customer side. From the system side, possible improvements depend on DG features and performances and on changes in design and operation of distribution networks;
- Adoption of targets by international organisations/national governs and provision of subsidies, especially to support development and deployment of RES and CHP based generation systems;
- The creation of open and competitive electricity markets (even though DG participation is still a problem that has yet to be resolved).

Notwithstanding the above favourable factors the existence of some barriers like:

- High technology cost;
- Existing distribution networks are not designed or configured to support DG integration; criteria and

rules for the operation of distribution systems have to be modified;
- Contributions of DG to system security and the capability to provide ancillary services are currently not fully recognised.

is in some way constraining the development of the DG concept.

The definite success of DG is related with the development of so called Smart Networks, i.e. active distribution grids with widespread integration of small size generators and of distributed intelligence, able to support end users interactivity with market and grid operators.

Strategy applied by the SC

The development of DG concept is already in progress since early nineties, even though the diffusion it is not yet so wide as expected; moreover the significant incentives stated in many countries by national government boards often motivated by targets posed by international organisations raised the problem of integration into PES of large amounts of RES, i.e. fluctuating and not-dispatchable power.

The SC strategy undertaken in the first 6 years of activity was firstly driven towards three different directions. Firstly the SC studied actions to be undertaken in a short term perspective just to meet the immediate expectations of our Targets Groups: to get more and detailed information about DG and to investigate about the integration issues. Furthermore, considering the novelty and some revolutionary aspect of the DG concept, the SC also investigated about problems whose solution may be envisaged in a longer term perspective. Then attention was also given to the other topics included in the scope assigned by CIGRE TC: i.e. rural electrification, management of electricity consumptions and demand (DSM), adoption of electricity storage.

At the beginning of the SC activity an investigation was also performed just to assess the main expectations of our Target Groups from SC; the main requirements raised were as follows:
- Exchange of information (based on real projects) on problems and solutions relevant to "*connection, integration and operation of dispersed and renewable based (wind in particular) generators*": the aim is to identify and share the "*best practices*";
- Exchange of information on research projects;
- Support the development of internationally accepted rules and standards;
- Support the development of internationally accepted models and benchmarks;
- Identify the requirements for DG component manufacturers and provide recommendations for the technical content of Distribution Codes and Grid Access Rules.

DG: what is it? Impact on PES

At the beginning of the SC C6 activity, *WG C6.01* investigated about "*Development of Dispersed Generation and Consequences for Power Systems*". The principal focus of study for this Working Group was the present status of DG and its impact on power systems.

The actual status of DG penetration in PES as well as the development of technologies, rules and methods of DG connection to the power grid was firstly studied by examining the situation in a number of different countries. Next, the influences of DG on the power system and relevant countermeasures to face them as well as the benefits of using DG to provide solutions for customer requirements were examined with reference on example case. The results gained by the WG confirmed the feeling that DG installations will increase steadily and remarked the need for power grids to coexist in harmony with DG, setting appropriate standards just to gain mutual advantages. Three topics to be further investigated were pointed out:
- **Revision of standards:** it is important to oversee the development of technology and the • • •

capabilities of the different types of generators and to revise accordingly standards.

- **Data management:** data on DG, such as classification, penetration level, type of connection to the grid and type of operation differs among the examined countries. Data on DG must be consistently classified and maintained in order to evaluate its impact on the grid and timely revise the standards. Well-organized data from many countries will contribute to the exchange of information on problems and solutions just to identify and share best practices.
- **Technology development:** main technological challenges for DG are the increasing as more as possible of conversion efficiency and the development of appropriate interfaces for proper connection to the grid.

DG integration issues

The subject of rules and practices of *"Connection of Generators and Other Customers"* was firstly deeply studied by *WG C6.02*. The study, mostly focused at the whole power system level, covered the definition of connection, procedures for connection, ownership, tariffs and contractual agreements; furthermore the transmission service was examined as well as the impact of the connection on the transmission network. The connection of dispersed generation was considered separately. The study remarked that while there have been major developments in distributed generation over the past couple of decades, the electric industry is not yet mature. Pnshed forward by policy strategies which favour the deployment of RES, new technologies are only now been adopted, with many new planned wind projects worldwide, many of the new turbines, like many DG, employing power electronics as a means of interfacing with the grid. Utilities, governments and regulatory bodies have addressed this growth by developing interconnection requirements aimed specifically at these types of generation. International standards, such as those developed by IEC and IEEE, are now in place, that dictate conditions which interconnecting DG must abide by covering normal operation and contingencies. However, the majority of these standards have been developed from the point of view of ensuring DG does not negatively impact the grid rather than integrating DG and making it a functional unit of the modern power system.

The subject of *"Connection Criteria at the Distribution Network for Distributed Generation"* was deeply studied by *TF C6.04.01*. The study was focused on the current connection criteria and protectiou practices applied in various countries for DG: a review of existing iuternatioual standards and of simplified methods applied to DG connection in various countries was performed. The study identified inadequacies in existing connection practices (that may unnecessarily limit the penetration of DG) and indicated appropriate connection analysis techniques that could be applied for connection evaluation. Recommendations for further standardization activities that will lead to integration of DG were also provided: these include a clear procedure for the determination of DG installed capacity, the operation of Active Distribution Networks, the prevention of unintentional islanding and the conditions for controlled intentional islanding, the DG behaviour during network disturbances and the limits of direct current (DC) injection into the LV network by DG Inverters.

The need for a correct evaluation of DG connection calls for the development and the utilization of appropriate analysis techniques; therefore the *TF C6.04.02* investigated about *"Computational tools and techniques for analysis, design and validation of DG systems"*. The scope is to examine existing computational tools and techniques for the dynamic simulation of DG systems and to evaluate the significance of these tools for DG systems design. The TF is also developing some DG benchmark system models aimed to study wind farm integration to HV transmission networks and DG integration to MV and LV distribution networks; the developed benchmarks include models of wind farms, fuel cells, power electronic equipment and connection to networks through appropriate equivalents. Studies on the DG benchmark with common simulation programs, including comparison and evaluation, will also be performed. Based on the outcome, recommendations for improvements will be provided as well as ideas for future researches and development works on computational techniques. Publication of results are expected by mid year.

The contribution of wind in the power balance of some countries has increased significantly in recent years, notwithstanding intermittency and variability. In Germany (2006) the installed wind power capacity has already overcome the amount of 20000 MW, and achieved approximately the share of 5.6 % of the total electric demand. In Denmark the installed wind capacity got through the amount of 3100 MW and the relevant electricity generation arrived at about 17 % of the total electric demand. Other significant programs for the exploitation of the wind energy are in progress in many countries like Spain, USA, India, UK, Ireland, Portugal; in the world, 49 countries have installed more that 10 MW of wind generation capacity. Wind turbine installations are relevant to both on shore and off shore installations that allow higher utilisation of wind generators to be achieved. At present, the wind power plants are connected to the HV, MV and LV distribution networks. However, as the extent of on-shore and off-shore wind power penetration increases their impact on the transmission grid becomes stronger. In some countries system operators already encountered difficulties to face the effects of wind fluctuation, like network congestion, wind generators shut down during network emergencies, etc. Furthermore, large wind farms with rated power over 100 MW will be connected directly to the transmission grids. *WG C6.08* is now working on the subject of *"Integration of large share of fluctuating generation"* with the aim to share system operation experience gained so far, to identify the most important issues related to fluctuating generation, to study conditions and generators design requirements (i.e. protection and control) to face experienced drawbacks just to allow growing fluctuating power penetration. The final report, that shall be ready by the end of the year, shall be focused on:

- Dispatching issues (power flow congestion and control);
- Priunary, secondary and tertiary frequency control;
- Voltage stability;
- Transient phenomena and ride-through capability;
- Reactive power and voltage control;
- Protection issues.

Information & Communication Technology (ICT) role

The development of ICT in the last years is really astonishing and further achievements are expected in the future. The full utilisation of such technology shall allow the bi-directional communication among PES and Distribute Electricity Resources (small size generators, storage units, controlled loads, power electronic devices) spread into distribution networks. ICT will make it possible to efficiently use the existing distribution network and facing future problems by providing capabilities for the monitoring and control of all network equipment, including DG, and the provision of additional customer services. *WG C6.03* investigated about *"Operating Dispersed Generation with ICT"*.

The WG performed a survey about the status of ICT utilisation. The results remarked that ICT has been already in use in many countries, but the communication networks have yet to be fully installed. Regarding the significance and priorities of the various issues for applying ICT two biggest obstacles are the cost of constructing the communication networks and the absence of any institution to define the cost-bearing structure and shoulder the administrative responsibility for network operation. All countries, however, accept that ICT is eminently important for the rapid prevalence of DG. Utilities are therefore expected to steadfastly install communication networks as a means of ensuring that DG can be diffused more widely, by using generating systems able to assure stable and reliable operation and adequate power quality. Given that communication infrastructures generally have a high value-added, they can be used for purposes other than operating DG: the survey results confirmed that in some countries projects have already started with the aim to support a set of functions like voltage control, automated operation of distribu- • • •

tion system, management of customer services, power quality monitoring. The development of such projects is supporting the transition of existing distribution systems towards active distribution networks. The WG indicated also some suggestions to promote the widespread dissemination of DG through the use of ICT:

- **Communication infrastructure availability:** development of low-cost, huge-capacity, high-speed, reliable and secure communication infrastructures for the distribution systems.
- **Standardization:** a unified information interface based on the plug-in method may help to facilitate cooperative operations, such as connection and disconnection of DG with distribution networks. A standardized interface and a stratified set of standardized core algorithms for control and protection on the respective layers will make it easier to connect devices provided by different manufacturers. Though research on ICT should certainly be promoted as a means of improving network operation, it will also be necessary to define requirements of information transfer and to coordinate with the standardization of DG interface.
- **Information security:** the widespread uses of versatile communication infrastructures will allow the network to receive a steady flow of signals from the operation and control of PES; namely information about the status of lines and substation of distribution network, information from the customer side on electricity consumptions and appliances status. Information security will therefore be critical. It will be essential to secure the secrecy of the information and signals transmitted and to build networks capable of giving and receiving information rapidly and smoothly.

Active distribution grids

The development of the new DG concept is based on the integration into distribution networks of small size generators, storage devices and controllable loads (i.e. Distributed Electricity Resources, DER) connected to LV or MV distribution feeders. A section of distribution network integrating a significant portion of micro-sources is considered as a micro-grid. In order to support the convenient penetration of DER and micro-grids into the liberalised electricity market the adoption of standard technical and commercial protocols is necessary. Technical requirements deals with defining standards for interfaces between the electrical equipment and the network at several levels, ranging from substation to distribution management systems for monitoring and control. IEC 61850 is one of the reference standards for this purpose. Commercial standardisation is more complex, since market regulations vary throughout the world. The existence of a unique European energy market would help define staudard data structures and communication protocols. Like any new product, DER/micro-grid technology penetration in the electrical market will strongly depend on the ability to overcome current technical and commercial barriers. Thus, standardisation at several levels is paramount in this process to fully gain the DER/micro-grid benefits and to avoid negative impacts on the electrical network reliability and safety. The *WG C6.10* recently started to study the "*Technical and commercial standardisation of DER/micro-grid components*"; the aim is to propose guidelines to allow easy installation of micro-sources, looking mainly to their integration in a micro-grid. The preparation of the guidelines is focused on the issues that follow:

- Standardisation of interfaces to connect the micro-generator to the distribution network. Also, connection requirements of the DG equipment and the Microgrid itself will be agreed. Plug and play performance for the generators will also be considered.
- Harmonisation of standards supportiug the certification of the different MicroGrid equipment (generators, inverters, control and protection devices, etc.).
- Protocols for negotiating sales and purchase of electrical energy and ancillary services, access to network, communicating status and control data between components, or dealing with faults and abnormal conditions.
- Standardised tests must be formulated for the installation evaluation and even for periodic assessment.

The technology development of small size generating systems, the new requirements of efficiency, security and quality of power supply, the liberalisation of the electricity market are driving the evolution of electricity distribution from passive to active distribution networks. The evolution is strictly connected to the possibility to allow Distribution Companies to integrate, operate and control distribution electricity resources (DER) within the network under their responsibility. Distribution Companies may act on both the demand side and the generation side. The *WG C6.11* is now studying the "*Development and operation of active distribution networks*"; the aim is the assessment of the various requirements from the Distribution Companies (relevant to con-

trol, protection, communication, etc.) to allow and support the transition towards active distribution networks. In particular, strict co-operation among manufacturers, ITC solutions providers and Distribution Companies will be necessary to achieve the assigned scope. The WG is proceeding by developing the steps that follow:

- Assessment of network and generators requirements for the integration of DER (e.g. islanded operation criteria, black-start capability, ancillary services, etc.);
- Identification of enabling technologies both for demand and generators (e.g. on the demand side: electronic meters, flexible tariffs, load reductions; on the generators side: voltage control, power factor regulators, reactive power regulating generators, etc.);
- Definition of limits/barriers (costs, infrastructures, conflict of interest, DG control, investment remuneration);
- Evaluation of cost/benefit analysis methods (referred to the whole electric systems);
- Identification of evolution requirements in regulatory aspects (e.g. possibility to dispatch local energy, Distributor's control on DER and loads, market constraints, etc.).

Interaction with electricity consumptions - Demand management initiatives

The pressure of increased consumption of electricity manifests itself in many ways. The electrical infrastructure installed to meet the required demand must be adequate within the generation, transmission and distribution systems to supply the requirements in a safe, secure and economical manner. Demand management initiatives are increasingly being examined with a view to lower customer energy costs and reduce impact on the environment, with a view to minimising the extent of the traditional expansion of the generation, transmission and distribution systems. The drivers for demand management are essentially grouped into four categories:

- **Environment:** reduction of energy consumption, improvement of efficiency and reduction of greenhouse gas emissions.
- **Network:** avoid that network congestions may constraint capacity of generation.
- **Economical:** inclusion of demand in the deregulated market to help avoid high pool prices and price spikes.
- **Customer choice:** ability of customers to have flexibility in demand, possibly in combination with DER, to locally trade their energy needs in a deregulated environment (Local Trading Strategy).

As demand on network elements approach their rated capacity, the reliability and quality of supply deteriorates. When demand approaches the capacity of the network, either investment in additional capacity or some form of demand management initiative needs to be activated in order to ensure maintenance of service standards. To date, very little has been done to attempt to influence demand side behaviour of the market. The *WG C6.09 "Demand Side Management"* is now working with the scope to analyze a wide variety of demand-side integration issues. The initial name considered for the working group, *Demand Side Management*, was however regarded to be inappropriate as it tended to reflect a customer-managed environment driven by the electric utility industry. With the onset of electric power industry restructuring world-wide, many customers are not subject to an environment of centralized management. In order to reflect the market-driven aspect of demand-side behaviour, such as demand response to market conditions, the name *Demand Side Response* was firstly considered more appropriate. Nevertheless, this title too was sometimes perceived more restrictive in scope than intended. At the CIGRE Paris Session 2006, the term *Demand-Side Integration* (DSI) was adopted by the working group to better represent the overall technical area focused on the demand-side and its potential as a source of supply. That is, DSI refers to all activities focused on advancing the efficiency of electricity utilization, including demand response and energy efficiency. The working group's scope includes study of technical issues surrounding demand-side integration, such as:

- Identification of drivers for demand-side integration
- Investigation of the role of demand-side integration for impacting the drivers identified
- Assessment of the various forms of implementation of demand-side integration
- Methods for determining customer value of reliability and differentiation of reliability preferences through demand response
- Identification of roles, responsibilities, and economic drivers of network owners to support implementation of demand-side integration
- Improvements needed in distribution network planning to better integrate demand-side resources such as distributed generation, storage, and responsive load.

The final report should be ready by the end of the year. • • •

Electricity storage

Because of the small storage capability of the power system a secure and reliable power system operation requires a dynamic balance between demand and generation at all time. Especially the RES devices generate the electric energy in accordance with the availability of wind, sun or other resources, independently of the demand. Hence, energy storage technologies become important with growing renewable generation also in order to have electric energy available when needed. Different energy storage technologies have individual characteristics, which will make it more suitable for specific environments and application scenarios. The *WG C6.15 "Electric Energy Storage Systems"* is now starting to explore methods for evaluating scenarios of using storage technologies in an economic way and ultimately the feasibility of energy storage technologies. The scope is to evaluate different storage technologies and their commercial background, with special reference to support the integration in power systems of high penetration of dispersed generation and renewable based generation. For this reason representative scenarios of powers system networks with high penetration of uncertain generation will be established; the need of optimal storage capabilities and the relevant duties required will be analyzed and identified. The effect of on and off-shore wind power generation, PV generations and also CHPs fuelled with biomass will be taken into account as well as the operational issues of distribution networks integrating DER/RES. All existing and prospective energy storage technologies will be described; their technical and commercial characteristics will be included into a framework, from which the technical and economic benefit analysis can be performed for each selected scenario. As the central result of the investigations, recommendations for further development of the storage technologies will be given. The expected deliverable is a survey, which defines the current technological state and the needs for further development to reach economic benefits in the application of storage in the foreseen scenarios.

Rural electrification

The CIGRE community considers the subject of rural electrification and the provision of electricity to remote areas with very low load densities, as a key challenge to be addressed by the industry and relevant stakeholders. The SC responded to the challenge by creating a new international Working Group, *C6.13 "Rural Electrification"*, aimed to address problems, difficulties and opportunities to extend electricity supply to rural and remote areas. Considering the extent and the complexity of the subject a first colloquium on *"Electrification and Dispersed Generation"* was successfully organised in South Africa in 2005; the colloquium was intended to effectively gather inputs for the purpose of redefining, realigning or re-focusing the initial scope of the Working Group with emphasis on understanding electricity demand, cost effective supply alternatives and organizational issues. During the gathering in South Africa the unanimous decision was reached to organize a second Colloquium in the Far-East region, following the kind invitation of the Malaysian National Committee of CIGRE. The Working Group received the mandate to collaborate with the local organising committee and to prepare contributions. For the colloquium in Malaysia the theme *"Electricity for Rural Socio-Economic Development"* was chosen to focus not only on discussion of technical aspects but also to get understanding and create awareness about the development impact. The theme is consistent with the urgent requirement for all stakeholders to consider and share local, regional and global issues on rural electrification and to offer possible solutions that could ultimately improve socio-economic well being of many deprived rural communities. This colloquium understandably dealt with technical, economic, social and organisational issues related to rural electrification. During a special panel session key national and international industry experts together with the audience discussed the particularities of rural electrification in the context of social-economic development. The results of the previous South Africa Colloquium and this second one shall permit CIGRÉ's International Working Group C6.13 "Rural Electrification" to prepare by 2008 a scoping paper for decision making in SC C6 and subsequent publication in ELECTRA. This paper, available by the end of the year, will also address possible additional actions that could be undertaken by the CIGRE commnnity to contribute to the provision of electric services to rural and remote areas of our world that still lack or have only limited access to electricity.

A look into the future

Since its creation SC C6 studied the several aspects of DG integration into the power system. Looking into the future the search for new subjects to be examined shall take into account the remarks that follow:

- There are still additional aspects to be studied related to the connection and the integration of dispersed generators and of related devices such as

storage, electronic base interfaces and systems. The concept of Dispersed Energy Resources (i.e. small size generators integrated into distribution networks, storage units, controllable loads, power electronic interfaces) has been definitely adopted;

- The application of the DG concept has also to be studied as a part of the medium long term evolution of distribution systems, i.e. creation of active distribution networks able to contribute to the improvement of the overall performances of electric power systems;
- Considering the increasing importance of electricity distribution SC C6 should study the evolution of distribution networks including subjects that are not strictly related to the application of DG concept up to the study of the role itself of electric distribution systems within PES.

The future activities of the SC shall be addressed to deal with subjects as those that follow:

- Analysis of demand evolution aimed to identify DG and demand side initiatives requirements. The new concept of Demand Side Integration adopted by WG C6.09 could be further investigated in the future.
- Contribution of distributed energy resources to energy policy objectives; role assigned to DER/RES and relevant strategies for the policy implementation. Revision of the distribution planning process and related techniques considering DER/RES, DSI, etc. Market rules and business models for DG implementation and exploitation.
- Methods applied in many countries to develop benchmarks for the evaluation of the performances of distribution systems (integrating DER, RES, DSI, etc.): issues considered, indices adopted, comparison methods, etc.
- Distribution utilities/operators requirements for the integration of DER, i.e. Distribution Grid Code, DG fault level contribution and technical specifications of DER components (to preserve distribution network reliability), requirements on DER performances during transmission and distribution failures, proposal of new standards (imposing, for example, field tests).
- New role of distribution networks, integrating DER and DSI, to improve system security. Ancillary services that DER may provide.
- Plug and play distributed energy resources to facilitate the use by end user and system customers: functions, technical characteristics and requirements.
- Use of distributed intelligent technology to develop advanced management and control systems of active distribution networks integrating DER and microgrids. Main topics are: management and remote control of power sources, storage and demand, control of power flows and voltage profiles, network reconfiguration and intentional islanding operation, power quality control; Extended use of ICT, sensors and actuators.
- Technical, economical and organisational issues relevant to electrification extension or to electricity supply in areas with very low pro-capita consumption. The activity should go on considering the suggestions indicated in the scoping paper under preparation by the WG C6.13.

- In 2008 more than half of human population is expected to live in urban areas and account for more than 75% of world energy use. In addition to rural electrification *"Urban electrification"* shall be an important subject to be studied with special attention to the case of mega-cities where the growing density of population is creating the conditions for high electricity consumption growth. ■