C6 – 00

SPECIAL REPORT FOR GROUP C6
(Distribution Systems and Dispersed Generation)

by

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Introduction

Since the early nineties interest in using small generators (CHP systems, small hydro and fossil fuel generators, PV systems and fuel cells) connected to the distribution networks has grown rapidly in many countries, stimulated by a number of important drivers like: expected savings in network costs, improvement of efficiency in energy conversion, creation of open and competitive electricity markets, incentives for the exploitation of renewable energy sources (RES), and better environmental compatibility. Existing barriers to dispersed generation (DG) are mostly relevant to the present high cost of new technologies and to the technical-economic-organisational aspects of network integration.

SC C6 received the mandate *"to assess the technical impacts and requirements which a more widespread adoption of DG and which a larger proportion of presently not dispatched power generation could impose on the structure and operation of transmission and distribution systems"*. Rural electrification, demand side management methodologies, including management of the DG and application of storage are within the scope of this SC.

The SC decided to propose for discussion in the CIGRE 2004 General Session three preferential subjects dealing with:

- Distribution & transmission network development in a dispersed generation environment,
- Role of dispersed generation in power system reliability, security and quality of power supply,
- Electrification of rural areas.

19 reports were selected for discussion in the General Session. The main issues raised in the reports are summarised hereunder, together with some questions to solicit a lively and profitable discussion.

Preferential Subject 1

Distribution and transmission network development in a dispersed generation environment.

- **Rules for system planning and DG designing to maximise benefits and minimise impact.**
- **Impact of large share of non-dispatchable DG**

Electricity generation, transmission, distribution and utilisation form a technical system where changes in any part have its influence. Deregulation also contributes to dispersed generation. Large numbers of generating units are allowed to be connected in transmission and distribution systems. Several traditions will be broken and new people and technology involved. Both smaller units and large wind parks will be connected to the systems. A high percentage of DG in a certain area needs special attention from all

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players. Feasible and optimal solutions depend considerably on the conditions. Ten highly interesting papers have been allocated under this preferential subject. Important aspects and experiences on system planning and integration topics have been presented and will be discussed. The network effects of large wind parks, various planning aspects and new applications of distribution automation are covered by the papers. Only three papers were received from outside Europe, and only minor attention was paid to forms of DG other than wind power.

<u>DG development and integration in the liberalised market</u>

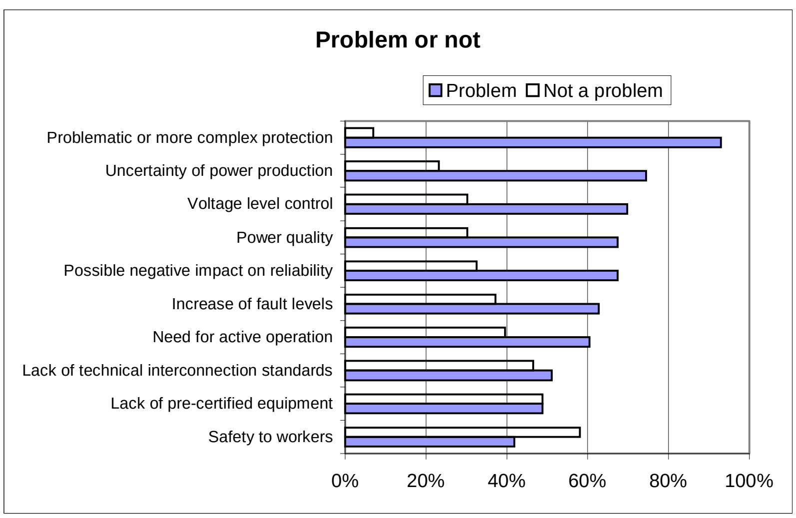
In paper C6-101 a consortium of seven European R&D organisations has developed modelling for business chains related to DG. The developed methodology assists in specifying and making the business idea understandable for all stakeholders. It also assists in finding out whether the case is commercially viable. A simple example of a 1 MW hydro power plant is demonstrated. The profitability for various players is shown for scenarios of network infeed tariffs.

This model might offer a chance to analyse the situation more deeply from the network point of view, e.g. to compare additional network investments caused by DG to the income collected through network tariffs. The acceptable profit in the regulated network business is usually limited so this type of method might also be applied for determining relevant network tariffs for distribution systems where DG is connected.

Question 1.1: What kind of calculation tools are in use or planned for determining acceptable transparent transfer tariffs for distribution networks including considerable amounts of DG?

Paper C6-102 describes the work of a European network for promoting the use of DG+RES, including eight work packages covering various aspects of practices and benchmarking. The paper summarises one of the reports finished so far and focuses on barriers to DG interconnection. DG developers' interests are reflected. In summary, business and regulatory type barriers were considered the most severe constraints.

A Nordic survey, not involved in these papers but referred in the figure (courtesy: CODGUNet project) reflects attitudes among distribution system operators:



Additional requirements for protection and uncertainties in power generation variations are found most difficult among that group of companies.

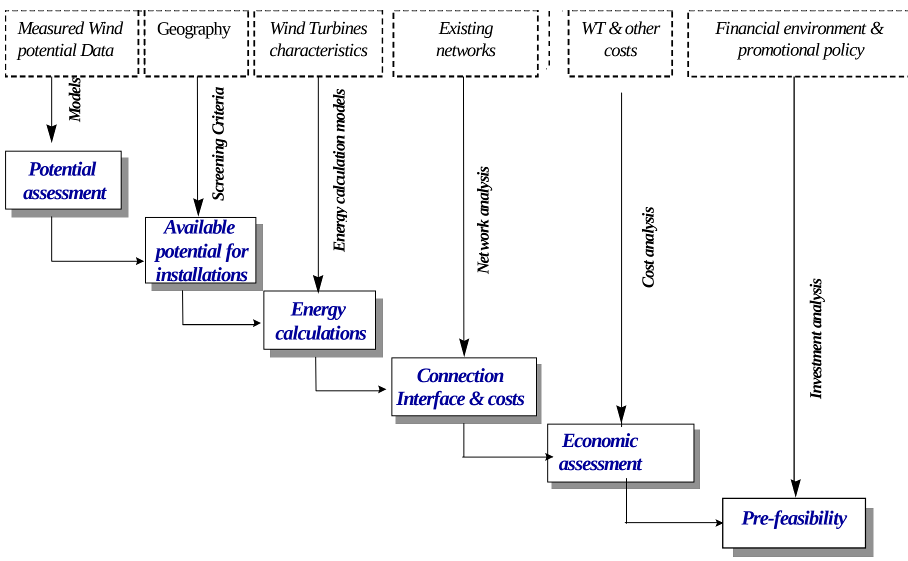
Especially in towns CHP has traditionally been operated by the same organisation that owned the local sub-transmission and distribution network. Thus contacts between people and practices for integration inside the same organisation have been close and solutions case oriented. Now organisations are often separate and resources for local developments more limited. Various recommendations and even regulations are increasingly centrally developed and applied for many kinds of conditions even in a whole continent.

Question 1.2: Unbundling of ownership of power plants and distribution networks has on one hand contributed liberal access of power producers to the distribution network but on the other hand weakened contacts with network engineering people in connecting and operating DG. Are there experiences of this latter, negative effect, and how it could be mitigated? There are many differences in electric power systems (e.g. underground/overhead, automation practices) and electricity market (free or regulated; subsidies) in different countries. How far are common integration rules and regulations possible and relevant?

Question 1.3: The current price of electricity reflects market conditions and if a potential DG producer does not have generation costs low enough or is not subsidised satisfactorily the chance for penetration into markets will disappear. Generation costs depend significantly on type of power plant and local conditions, and forecasts of future costs vary. Are there experiences of DG having already achieved low generation costs, and expectations of other DG that will very soon become profitable or are unlikely to ever reach profitability?

Planning issues

A comprehensive decision support system for the evaluation of the technical-economical potential of wind power and small hydro is presented in paper C6-104. It includes a geographical information system (GIS) for RES potential, infrastructure including electrical networks, etc. Combining this with techno-economic data the profitability of investments can be estimated. Versatile data of transmission and distribution systems can be included into GIS, so that the network analysis tools can be used to determine the effects of RES penetration on the networks.



Step by step procedure giving the ability to focus on specific areas and resolve problems associated with wind energy exploitation. (Figure from paper C6-104)

In paper C6-105 the impact of DG on the distribution network has been studied by calculating the effects on losses, thermal limits of underground cables and deferral of investments. In addition to wind power, combined heat and power and photovoltaic systems are considered. Cases show that an even spatial distribution leads to lower losses than a concentrated generation. CHP seems to cut losses and delay necessary network investments considerably more efficiently than wind power. Effects of other constraints like voltage drop were not discussed.

Some papers indicate that the system impact of DG increases substantially when the penetration is high. Changes in network design, protection and operation may then be necessary. If the whole operating philosophy must be revised, there will be not only additional equipment and control system costs but also costs due to new configurations, staff education, etc.

Question 1.4: How should the costs due to increased complexity of distribution networks be allocated? Do you have any hints how to recognise the most important factor or constraint in planning or reinforcing distribution feeders including various types of DG?

Wind farm integration: techniques and system impact

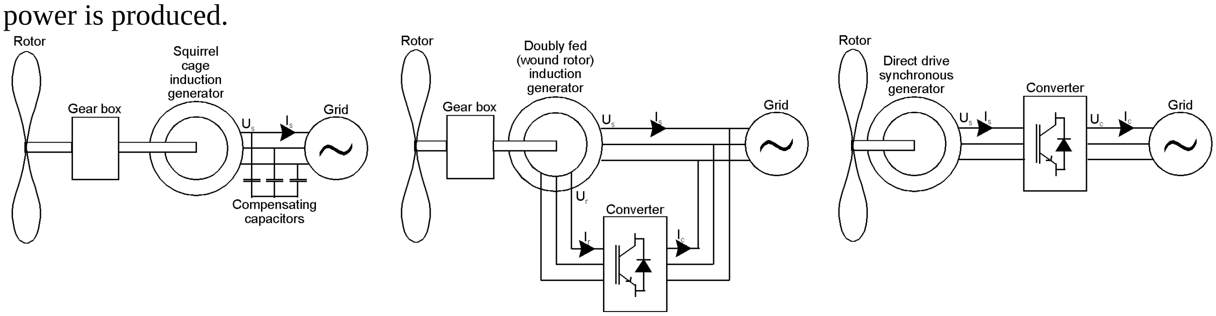
Shallow windy waters near densely populated areas offer good conditions for massive wind farms. They are considered more environmentally friendly but have higher construction and connection costs than conventional wind power. Paper C6-103 introduces typical concepts of conversion of wind power and a variety of specific topics concerning connection of offshore wind farms to a power system. They include power quality issues with special focus on power and voltage fluctuations caused by wind turbines and manners to eliminate these, and transient voltage stability and stabilisation possibilities of the internal networks of wind farms.

Different options of both AC and DC transmission from wind farm to grid are presented and compared. A Unified Power Flow Controller to control the energy transfer between two networks is introduced as well.

Paper C6-107 also discusses AC and DC transmission concepts for power transmission from offshore wind farms to shore. The conclusions are similar: AC is still recommended for distances up to about 100 km.

Question 1.5: The introduction of DC provides flexibility in a large variety of applications. Possibilities of power electronics in variable speed wind turbines and HVDC-concepts may be used beneficially and actively also for power system purposes providing reactive power, voltage control, stability, etc. How do you see their future related to DG?

Paper C6-106 presents the expected future development in the Netherlands, where as much as 6000 MW offshore wind power is set as a target for the year 2020. Both local- and system-wide impacts are explained: branch flows, node voltages, protection, harmonic distortion, flicker, system dynamics and stability, reactive power, voltage and frequency control. Paper C6-106 states that system load minus the wind power generation is far less smooth than without wind power. Time variations of wind generation compared to consumption depend both on the amount of generation and the geographical area where wind power is produced.



Commonly applied generating systems in wind turbines: squirrel cage induction generator, doubly fed (wound rotor) induction generator, direct-drive synchronous generator (from the left). (From paper C6-106)

Question 1.6: Can you mention useful results on time variations of wind power generation versus load curves? Please compare experiences on methods for smoothing the loads for various conditions and different targets.

In open markets the transmission business is separated from generation business. In many countries DG is subsidised or privileged. Paper C6-107 describes such a situation in Germany where the network operators have to connect and then purchase all wind power that enters into the system. The paper sees problems arising from primarily the stochastic nature of wind and its poor predictability, and mentions the need for additional reserve capacity and network strengthening. The TSO's viewpoint is that construction of offshore wind farms in Northern Germany will require large reinforcements to the transmission network.

A locally high percentage of wind power has influence also at the transmission level. Thus, some network access requirements typical for conventional power plants connected to high voltage will have to be applied also for large wind farms. For example, the paper proposes the settings for under-voltage protection of wind turbines should be low in order to keep the turbines connected during network faults to avoid a disturbance evolving. Introducing new requirements gives challenges both for operators, owners and producers of wind power plants.

Question 1.7: Which impacts of large wind farms are relevant and most problematic in different types of transmission network and how can negative impacts be mitigated in economical way? What is the biggest difference compared to conventional power plant types? Opinions concerning requirements for DG in supporting the system in disturbances are invited. Are more strict connecting criteria in this respect needed or under development? How relevant is it to apply rules developed for the connection of large wind farms to smaller power plants connected at the distribution level?

Paper C6-110 describes a 50 MW wind park project in Mexico. Its IRR (internal rate of return) and displacement of different types of conventional electricity generation has been calculated by using different planning models. Reductions of CO_2 emissions are considered but no discussion on the preference topic - impacts to transmission and distribution networks - is included.

Question 1.8. What form of generation is DG replacing in an energy system is an important issue when estimating its benefits e.g. in saving fuel and reducing emissions. What, if any, is the relevance of such replacements from the point of view of transmission or distribution systems?

Advanced power supply systems with DG

New applications of IT and automation are welcome to support the operation of systems with DG. In the concept of paper C6-108 the medium voltage network is autonomously used as loops, and the intelligent management system controls the network, supply, and demand at customer interfaces both in normal and fault situation. Loop controllers with two AC/DC converters can control power flows and voltages at both sides of the terminal and they can also be used for isolation, reconfiguration and restoration of loops in fault situations.

Question 1.9: Are there any economic analysis or estimates available for the new system from different players' point of view. How does this concept fit with deregulation and competition where distribution and electricity supply are unbundled and where DG owners and customers can sell and buy electricity freely? Whose activity could it be?

In paper C6-109 urban 6.6 kV feeders including DG have been studied, the target being voltage control in feeders and simulation of power quality effects. A centralised voltage control scheme is proposed instead of the existing independent local control in primary substations and step voltage regulators distributed along feeders. The system settles a co-ordinated control of tap positions for all these devices by estimating voltage and load profiles on target feeders from current and voltage information measured by a limited number of sensors. Both simulation and field test results are described for a relatively simple single generator case.

Question 1.10: Does the central voltage control scheme cause more control actions and thus increase the number of stepwise voltage variations compared with a conventional independent local control? Can the authors give any cost information?

Acknowledgement: Experts from VTT Processes, Finland, have kindly contributed in preparing this part (Preferential Subject 1) of the Special Report.

Preferential Subject 2

Role of dispersed generation in power system reliability, security and quality of power supply.

- **Capability of DG in facing network disturbances.**
- **Capability of DG in providing ancillary services.**

Distribution networks with DG demonstrate all the characteristics of larger power systems, including stability, security, reliability and power quality. However, the relationships between the various system parameters, such as branch impedance, machine inertia and machine transient impedance, differ from those in large transmission systems. Also, many dispersed generators are induction machines, with very different transient behaviour from the synchronous generators of centralised power stations. As a result, the behaviour of distribution systems with dispersed generation is as complex as transmission systems, but has been studied less. As the unit costs of distribution systems are smaller than those of larger and higher voltage systems, generalised codes and application guidelines are needed to reduce engineering costs. Therefore, the work reported in this session is important in contributing to a better understanding of the behaviour of distribution systems.

Seven papers were selected, and their content addresses both parts of the subject - the capability of DG to face network disturbances and the related capability to provide ancillary services.

Reliability and security

The authors of paper C6-202 have analysed the effect of the introduction of various capacities of wind generation on three composite system reliability indices (loss of load expectation, and energy and demand not served). The effects vary according to the water state (high, medium or low) of the associated hydro generation capacity on the Egyptian system. While the system reliability indices generally improve for the introduction of 300 MW of wind generation, all the indices deteriorate for 900 MW of wind capacity, representing 6% of the system capacity.

In contrast, the authors of paper C6-204 describe a smaller system in which the wind power capacity is about 15% and the instantaneous wind penetration reaches nearly 30%. The assessment of dynamic security is based on the calculated frequency response to three pre-selected disturbances.

The first question in respect of these papers relates to the assessment of security.

Question 2.1: Can composite indices, as calculated for the Egyptian system, represent the general effect of DG on system reliability in a suitable way, and does the faster technique of the dynamic security assessment provide an adequately representative indication of security? Are various techniques needed to represent the system security for different applications?

The proportion of wind power on a system also appears to affect security. On the Egyptian system (C6-202), more than 6% of wind power decreases system reliability. However, in Crete (C6-204), capacity of 15% appears acceptable, despite a high probability of under-frequency load shedding in the event of a disturbance, depending on the spinning reserve. Paper C6-205 also identifies the importance of the spinning reserve, particularly the size of the reserve needed when the extent of the DG is uncertain.

Further, the experience reported in paper C6-206 demonstrated the need for decentralised reserve strategies to compensate for errors in day-ahead forecasts.

Question 2.2: What is the limit of wind power capacity before security deteriorates, how is the security determined in those cases, and how is the reserve related to the security?

Paper C6-206 identifies a need for supplementary rules for the reliability and dispatchability of DG.

Question 2.3: Are such supplementary rules required for DG? Contributions are invited that share experience, derived from analytical studies or practical demonstration, that can guide the development of the supplementary rules for reliability and dispatchability.

Power quality

The authors of C6-206 describe the development of a microgrid with several sources: network injection through an MV DC network coupler, wind generation, photovoltaics, fuel cells and storage batteries, supported by a multi-component communications system. The cluster provides the load-following capability of central power stations, and has been shown to improve the voltage quality in the microgrid by providing only active power, with more significant voltage regulation possible through the DC coupler. The cluster offers higher reliability for the microgrid, provided that the components themselves have a high reliability, which was not achieved by all the components. However, the authors do not comment on their experience in respect of the flicker and harmonics limits defined by the German rules.

Question 2.4: The authors are invited to contribute further information on flicker and harmonics.

In common with many voltage or quality improvement schemes, no mention is made of the quality and reliability effects of improvement (in this case, for the microgrid) on the supplying distribution system.

Question 2.5: Do microgrids or similar approaches to using DG to improve power quality have undesirable effects on the remainder of the connected distribution systems?

Paper C6-207 presents the results of an investigation into the effects on power quality of adding eight 550 MW wind farms to the Nordel system. The authors report that the effects on voltage fluctuation are very small. The variation of wind farm power output arising from wind speed fluctuation and wind shadow on the rotor blades is shown to affect the power generation of the various other machines in the system according to their position and parameters, and can excite the oscillation modes of some generators. However, the oscillations were well damped by the frequency controllers, so the system remained stable.

Question 2.6: Does a system's frequency controllers need to be adjusted to achieve the stable control represented in the Nordel system, and are similar system studies needed in all cases of DG development to ensure acceptable power quality? Further, the authors are requested to give some information on the proportion of wind power of the total system represented by these studies.

Ancillary services and fault performance

Synchronous DG machines can supply and control reactive power transfer into a system, but induction machines need the system to supply reactive power. This aspect is raised in several papers, including C6-201, 205 and 206.

Paper C6-205 describes how the synchronous DG machines' ability to supply reactive power contributes to improving voltage stability, in contrast with induction machines that may reduce the voltage stability of a network.

Question 2.7: To what extent is the capacity of synchronous DG to provide ancillary services (reactive power) taken into account in the planning and operation of distribution systems with DG?

The differences between the synchronous and induction machines extend also to fault currents and the angle stability of systems. Paper C6-206 indicates a short circuit contribution of only 320 A from a doubly fed induction wind generator, on a system where the network contribution is 8.4 kA. Paper C6-201 shows how a region with a high density of wind generators gives rise to severe voltage dips and possible impairment of power system protection because of the small contribution to fault currents.

Question 2.8: The small contribution to fault currents and post-fault recovery from induction generators imposes additional system requirements. What provision is made in grid codes or DG connection licences for the distribution systems to operate reliably under fault conditions, and who is responsible for providing the services needed to ensure acceptable performance?

Paper C6-201 presents a concept to supply reactive power by phase-shifting operation associated with a synchronous generator. Simulation studies show that the generator provides high short circuit currents and, after fault clearance, reactive power input into the network. In large wind parks, the transient response is smoother than for a conventional DG machine, because of the high inertia of wind turbines.

Similarly, the practical experience reported in paper C6-206 found that the control system of the MVDC coupler to the adjacent distributor required adaptation to allow fault ride-through and contribute reactive power to the wind generator after faults on the microgrid.

Question 2.9: These two techniques offer very different ways of overcoming the disadvantages of DG under fault conditions. Is one approach more suitable or effective than another, what other techniques have been developed, and what characteristics need to be considered in assessing the alternatives?

<u>Modelling of DG</u>

Several papers give details about modelling of DG. Papers C6-201 and 207 make assumptions about the consolidation of several generators in an equivalent model. Paper C6-206 describes some basic aspects of modelling DG over short and long-term. Paper C6-203 describes models of six different types of DG, but some of the controls as modelled may be more complex than expected on small generators. Paper C6-205 identifies that the desired accuracy of a simulation affects the modelling of the DG units. The various papers show that there are already several software packages that can analyse distribution networks, but standard or generally acceptable models are needed for incorporation into existing and new software tools.

Question 2.10: To what extent are the various modelling approaches suitable or useful to adopt as standards? What advantages do some of the models have, compared with each other? Is another simulation tool (software package) needed for analysing small power systems?

Preferential Subject 3:

Electrification of rural areas.

- **Opportunities offered by advanced grid based concepts and renewables.**
- **Financing schemes, service delivery methods.**
- **Experiences with relevant partnerships and initiatives**

Electrification is a new area of interest for the CIGRE Session, although CIGRE has participated in various study groups and joint symposia with other organisations such as CIRED and UPDEA. The SC C6 has established a new WG on rural electrification, considering load modelling and characterisation, supply technologies, associated organisational and financial aspects, and the effects of electrification on power system development and operations.

Rural electrification is a broad field, including equipment, systems planning and design, management and regulation. The boundary between rural, urban or peri-urban electrification is not easily defined. Electrification systems are characterised by changing feeder topologies as networks and loads develop. Although only two papers were received for this preferential subject this year, they represent very different aspects of electrification, and provide a useful basis for discussion.

Paper C6-301 describes an advanced grid-based concept of supplying loads along or near the routes of high voltage lines, by operating insulated shield wires at medium voltage (20-34.5 kV). The technology of shield wire schemes (SWS) has been applied in several countries and in this paper the authors describe in detail some installations in Laos. Care is taken to achieve a balanced supply voltage by appropriate compensation. The analysis of the steady state and transient behaviour must allow for the coupling between the phase conductors of the main line and the MV conductors/shield wires.

Paper C6-302 describes a large programme during which rural electrification costs were reduced by 50% over seven years by adopting alternative network technologies, including single-phase feeders, and capacity more closely matched to the needs of the customers as determined through load research. Information is provided on the relative costs of the components of distribution systems, as well as parameters to assess the suitability of project plans.

Question 3.1: What are the factors that limit the use of the low cost technologies described in these papers for rural electrification?

Question 3.2: What are the implications for the design and operation of the main line along which SWS feeders are built? What are the approaches to reinforcing supply when the loads develop to the capacity of the SWS line?

Question 3.3: How do the parameters presented in the two papers (for line design, component costing, performance indicators, etc) compare with electrification programmes in other countries?

General discussion of rural electrification

Electrification is being adopted in many countries because it meets social and political needs, even if it is not immediately financially viable. The programmes require new approaches to the technology and management of electricity distribution, and will affect the large power systems that are the concern of CIGRE.

Question 3.4: What aspects of electrification are expected to have the most significant effects on large electric power systems of the future?