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

David Jacobson (Preferential Subject 1) **Michael Buchholz** (Preferential Subject 2) **Kurt Kaltenegger** (Preferential Subject 3)

Special Reporters

Introduction

The scope of SC C6 is *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 integration of renewable based electric generators as well as of small size generators, the processes and technologies to support their operation and that of the whole electric power systems are subjects widely debated and still studied and developed within electric companies, manufacturers, universities and research institutes.

The SC decided to propose for discussion in the CIGRE 2008 General Session three preferential subjects dealing with:

- The impact of integration on system development and operation issues,
- The transition towards active distribution networks,
- The expected role of storage technologies.

26 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[1].

1. Preferential Subject 1 - Development and operation of power systems incorporating Dispersed and Renewable Energy Resources (DER/RES)

The European Union is strongly supporting the development of renewable resources. In 1997, a target of 12% was set for the level of contribution of renewable resources to energy supply by 2010. In March 2007, new commitments have been set:

- 20% less greenhouse gases in 2020 compared to 1990
- 20% savings in energy consumption compared to 2020 baseline projections
- 20% overall energy mix by renewable resources by 2020

Other countries are also setting ambitious targets.

[1] PS1: dajacobson@hydro.mb.ca; PS2: DrBuchholz@aol.com ; PS3: kurt.kaltenegger@cn.abb.com

Preferential Subject 1 deals with issues associated with large scale integration of DER/RES at both the planning and operating stages. Some of the issues include how to balance output fluctuations, how DER/RES can contribute to ancillary services, new business models and market rules.

A total of 15 papers were received from Europe, Australia, New Zealand, USA and Japan in response to this subject.

1.1 Large Scale Integration of RES on the Transmission System

Paper C6-101 reports on a practical study of high wind penetration in Greece. There is currently 870 MW installed and 3000 MW are anticipated by the year 2010. The study investigated the impact on dynamic stability, impact on production levels of conventional units, and the overall power system reliability. Some of the major problems that have been observed include:

- Ability of wind generators to withstand voltage dips
- Impact on load following capability when wind output is changing rapidly
- Ability of network to absorb high levels of wind when the load is low.

No issues were observed in terms of system damping and inter-area oscillations. Changing from power factor control to voltage control resulted in reduced number of on load tap-changer (OLTC) operations and is recommended. Fault ride-through (FRT) capability is required. Without FRT, anywhere from 1000-2000 MW of generation could trip for a single fault. The technical characteristics of thermal generators may limit the secure level of wind penetration (ramp rates, start/stop ability).

Paper C6-102 from Ireland reports on a large scale renewable generation investigation. At present, there is a peak demand of 7000 MW in Ireland and a single 500 MW HVdc tie with the British Power System. The paper examines various generation portfolios in a 2020 system (forecast 9600 MW peak load and 3500 MW minimum load). The portfolios examine the impact of renewables supplying 16%, 27%, 42% and 59% of the energy. The maximum wind capacity studied was 8000 MW. It was determined that beyond 6900 MW of wind capacity in 2020 that unit commitment was impractical (large number of hourly starts/stops of thermal generation) and a significant network redesign was required.

Paper C6-111 discusses how probabilistic models are used in Italy to determine the possible need for grid reinforcements.

Paper C6-112 takes a very broad view of the possible future developments needed to achieve a target of 50% renewable energy by 2050. The Netherlands is used as a particular example. The main drivers for high levels of renewable generation include climate change (greenhouse gas reduction), economics (oil and gas prices are expected to increase dramatically due to supply shortages), and geopolitical signals (desire to be self sufficient and less reliant on foreign reserves). Various transition paths are possible: Super grids (average generation unit size increase and are connected to the HV and EHV systems), local grids (average generation size decreases and is connected near the load), or a hybrid of the above two. High levels of wind and solar generation will require additional measures to ensure power balance such as sophisticated weather forecasts, fast responding storage facilities and additional demand management techniques. New technologies will be needed such as smart metering for load management, smart sensors for dynamic rating of equipment. Increased use of underground cables will require additional reactive power control.

Paper C6-113 discusses experiences in the German, Danish and Greek systems. Wind supplied 6% of the energy demand in Germany in 2006 and is predicted to supply 20% by 2020. Denmark is expecting 50% of the energy demand to be supplied by wind. The paper describes some of the operational issues being faced in these countries and measures that have been put into place. Some of the main issues include:

- Ensuring power balance between supply and demand. Accurate forecasting of wind plays a key role.
- Low voltage ride through. Grid codes have been modified to include LVRT.

- Reactive power and voltage control. Grid codes have been modified to specify the required range and control requirements.
- Frequency control. Offshore wind farms must be able to contribute to active power balance and frequency control. Wind plant output must be limited when frequency is high.
- Remote communication. The paper describes communication standards that enable remote generation to participate in ancillary services.

The paper also talks about how system planning is changing and how new tools are being developed. Developing equivalent models of large wind plants is a challenge.

Question 1.1 New interconnections are proposed to be added in C6-101, C6-102 and C6-111. What is the main driver for the interconnections? Will the new interconnections be able to increase the level of penetration of wind in each country? Were storage options also considered? Are fast power reversals a significant technical challenge in a high voltage dc interconnection or in the unit commitment plans of the remote balancing area?

Question 1.2 What level of participation from wind plants in frequency regulation is expected in the future? What other options are available (e.g. wind power management, demand management, use of interconnections, storage etc.) What is the practice in other countries?

Question 1.3 Paper C6-111 promotes the use of a probabilistic method for determining the need for grid reinforcements. Might this method result in transmission under investment? Who takes on the risks if the actual congestion is higher than the models predict? What other new planning tools have been used by other utilities/countries?

1.2 Large Scale Integration of DER/RES on the Distribution System

Paper C6-103 calculates the optimal amount of DG for a feeder assuming the goal is to minimize voltage excursions, lower line losses or improve supply security. Only dispatchable types of DG are considered in the analysis. The simulations indicate the optimum location of the DG is at the end of a feeder. If supply security penalties are low then the optimum amount of DG is less than 10% of total load. If supply security is penalized heavily then penetration approaches 80%. The authors haven’t compared the cost of DG to the cost of a second supply. Peak shaving tends to be the most economical control mode.

Paper C6-104 discusses the impacts of a large wind plant at the end of a radial 66 kV circuit in New Zealand. Initially a 200 MW wind plant was proposed but this was optimized to 58 MW to avoid new line construction. Several 66 kV network enhancements were included such as: 66 kV protection upgrades, 217 Hz ripple blocking filters, special protection systems, power factor correction at the main 33-66 kV grid exit point substation (4-5 MVAr), midpoint voltage control (2-2.5 MVAr), and a 6 MVAr Statcom at the wind plant. During high wind periods and low load, the distribution losses were expected to increase to 15%. A 70 MW wind plant was deemed to be uneconomic for both loss impacts and because of the cost of additional transmission network reinforcements required.

Paper C6-108 summarizes the European project EU-DEEP that deals with the integration of Distributed Energy Resources. Three main topics are identified that require improved coordination: anti-islanding protection, coordination of under-frequency and under-voltage load shed schemes, and voltage control coordination. The EU-DEEP project is concerned with distributed generation in the 1 kW to 10 MW range connected to the radial distribution system. At present, commercially viable projects are in the range of 1-3 MW and above.

Areas needing improved transmission and distribution coordination

- Islanding protection
- Underfrequency or undervoltage load shedding (UFLS/UVLS)

- Voltage Control

Finally the authors talk about "flexible" distribution networks. A fully asymmetric approach, where load and generation are on separate feeders is presented but not fully justified.

Paper C6-115 looks at two potential problems associated with high levels of distributed generation: the effect on network losses and voltage regulation. The paper describes an optimization technique using a genetic algorithm to reconfigure the network in order to minimize the losses (so called flexible network). Significant loss savings can be gained if the network is reconfigured every hour based on forecast generation. However, the number of switching actions required is extremely large. The authors are proposing weekly or seasonal switching perhaps. The authors also investigate coordinated control of multiple generators, OLTCs and capacitor banks. Some results are presented but further work is required to develop efficient algorithms for real-time application.

Question 1.4 A very high penalty on reliability is applied in some of the simulations in paper C6-103 ($10,000/MWh for an outage). Is this penalty applied to utilities in Australia or is this an approximate societal cost number? Are there reliability penalties applied in other countries?

Question 1.5 What efforts are being made in various countries to coordinate UFLS/UVLS schemes when there are high penetration levels of distributed generation?

Question 1.6 Are there grid codes that limit the integration of DG to achieve certain objectives or are the distribution grids open to permit DGs to use the full thermal capability of the lines in the reverse direction? Are there security issues with current methods of local anti-islanding protection? What schemes are in use in other countries? Are utilities planning on eventually transitioning from an anti-islanding to a micro-grid philosophy?

1.3 Market Rules for DER, Ancillary Service participation and Virtual Power Plants

Paper C6-105 identifies DSM concepts and implementation methods that are relevant in a restructured environment. Industry restructuring has resulted in changes in commonly used terminology. Load management is being replaced by Demand Response. Flexible Load Shape is being replaced by the concept of Demand Energy Management. Demand Side Integration (DSI) encompasses all ideas related to Demand Response, Energy Efficiency and Strategic Load Growth. DSI implementation methods are broadly categorized by type: alternative pricing, direct incentives, outreach and cooperation, regional codes and standards.

Paper C6-106 summarizes the main results of the European project, FENIX that deals with Virtual Power Plants (VPP). The VPP is a distributed system control architecture used to aggregate a large number of small distributed energy resources (DER) into a virtual unit that has similar flexibility and controllability as a conventional generating unit. The general FENIX architecture has been customized to show how it could work in the Spanish and French networks.

Paper C6-107 points out that there is a disincentive for DG to participate in the ancillary service markets because of the high feed-in tariff rates currently in place and the current fit and forget approach to installations. The paper discusses the need for a new legal and regulatory framework to permit high penetration levels. DG will be expected to make the following mandatory contributions to ancillary services at the distribution level:

- Primary, secondary and tertiary reserves for regulation and frequency control
- Power balancing and dispatch
- Reactive supply and voltage control
- Black start and islanding capability

Paper C6-116 talks about the technical consequences and infrastructure requirements of the future distribution grid where significant distributed generation penetration is expected. The authors

examine various 2020 development scenarios in the German network with varying levels of RES and controllable power from combined heat and power (CHP) units. Demand for heat is expected to decrease by 50% due to various regulations on the quality of building insulation.
Intelligent Energy Management Systems will be required to deal with small DG using local decision strategies as well as aggregated DGs forming a virtual power plant. Standardized communication protocols will be needed. At present there is only limited communication for monitoring and control. High penetration levels will also require the DG to participate in ancillary services. Additional measures will be required to meet power deficits during periods where renewable generation is not available such as demand side management and use of storage.
The studies show advantages to using power-controlled CHP units rather than heat - controlled. Geothermal energy also has significant advantages. Based on the study results, distributed systems can be more effective (cost, energy, CO_2 emissions) than central supply.

Question 1.7 Can utilities comment on the level of adoption of various DSI implementation strategies? Are there practical examples where information signal are used to coordinate demand response with market conditions? What types of trigger signals are being used or are under development?

Question 1.8 The virtual power plant concept and DSI strategies are proposed to improve system operation, security and economics. Are there practical examples? What efforts are being made to change grid codes or retrofit existing installations to permit remote control of DER/RES? Real time voltage control and extensive communication is required; how will this be planned and who will pay for the infrastructure and maintenance? What progress has been made in developing a new legal and regulatory framework that would require DG and RES to participate in ancillary services?

1.4 Microgrids

Paper C6-109 describes a microgrid demonstration project that has been built and tested in Hachinohe, Japan. The system is able to operate within limits in both grid-connected and islanded modes. The microgrid is roughly 600 kW in size and includes gas engines, PV, wind and battery storage. The renewable generation (PV and wind) accounts for about 25% of total demand. The integrated energy management system is designed to minimize operating costs and environmental burden while maintaining a constant power flow at the coupling point. The battery system is used to maintain frequency when the system is islanded. The authors found that the gas engine generators were sufficiently fast to deal with frequency variations and the batteries could potentially be modified to supply energy when demand is low. The system has been in operation since October 2005.

Paper C6-110 discusses the development and performance of a 200 kW test network used to verify the microgrid concept. The test network was installed on a 30 kV network in Spain. The distributed energy resources included: wind (6 kW), fuel cell, microturbine (50 kW), photo voltaic (6 kW), diesel (2x55 MW), flywheel (250 kVA), battery (1925 Ah) and ultra capacitors (5 kW). The main control strategies tested included “peak-shaving” and “load-following”. Currently the connection rules in Spain prevent distribution generation backfeeding into the transmission grid. A test was conducted to demonstrate no negative effects occurred during backfeeding.

Question 1.9 Can the authors of C6-109 explain how the power conditioner of the PV is used to eliminate negative sequence power? Have measurements been taken to show the effectiveness? What is the permissible negative sequence limit?

Question 1.10 Natural fluctuations in load and in weather dependent generations give rise to frequency and voltage variations; what ranges have been observed and are considered acceptable? What performances are expected from dispatching and control systems? What is the cost of the controller and necessary communication network?

2. Preferential Subject 2 - Concepts and technologies for active distribution networks

Preferential Subject 2 received 5 papers addressing various aspects of the transition from passive to active distribution networks. Authors were drawn from 8 countries reflecting the international interest and cooperation in this field.

Active distribution networks are supply areas containing a significant share of dispersed generation. They are able to provide a new quality of system services on the distribution level, including for example:

- Power balancing based on day-ahead schedules,
- Frequency stability, primary and secondary control power, tertiary reserves,
- Voltage stability, local provision of reactive power,
- Restoration of supply after disturbances, islanding and black-start capability.

Advanced technical solutions and concepts shall be applied to maintain the above mentioned services:

In the framework of the **virtual power plant** concept various dispersed generation units with controllable/ secure and with intermittent/ not secure power output, storage capabilities and demand side integration are managed in such a way that the provision of system services will become possible with a similar quality to the one provided by traditional power plants.

Smart metering implies the automation of all metering services from data acquisition up to the billing based on dynamic tariffs, reflecting the market prices for energy and motivating the customers to participate on the market through demand side management. In this context, smart metering provides the gateway to home automation with small automation devices for shifting controllable loads like air conditioning or wash machines.

Enhanced automation and remote control will lead to self healing distribution networks and significantly improve the reliability of supply in the context of **microgrid concepts**.

All three concepts require a deep penetration of information and communication technologies in distribution networks down to the low voltage customers.

2.1. Historical development of distribution networks and future needs

Paper C6-201 briefly describes the evolution of distribution networks since the late 19th century. The integration of significant amounts of dispersed generation may bring a fundamental change to the network architecture. A new architecture based on power cells containing generation, energy storage and loads has been proposed by some authors. An active transformer consisting of a resonant, supply side converter, a high frequency transformer and a resonant load side converter is considered the novel interface between the power cells and the network. Its function is providing a continuously controlling bi-directional power flow. Different types of controllers are investigated by means of simulation and recommendations are given.

Question 2.1 Which are the main differences between the term "Power cell" and the ones already used like VPP or micro grids? What are the economical and functional drivers for an application of active transformers? What are the features of the declared "greater control" in comparison with the traditional transformer?

2.2. Methods for planning network transition

The integration of a growing amount of dispersed generation and their active management should already be considered in the planning level of the distribution networks to exactly assess investments in the medium/ long term perspective. In this context, **paper C6-204** describes a special multi-year dynamic programme for distribution network planning taking into account the outcome of an active energy management. In the planning algorithm the "active network operation module" is activated to reduce power flows when a network configuration does not meet technical constraints. Consequently, in operation the power flow has to be reduced by re-dispatch of the dispersed sources and demand response whenever the calculated congestions occur. A case study is demonstrated and cost savings up to 50 % are estimated.

Question 2.2 What is the long term impact of such a planning approach on the reliability of supply? Should the reliability assessment not be a part of the planning procedures? How dispersed generation and demand will follow the control signals of the active operation management? Is there a need to introduce incentives or changes in present regulation?

2.3 Network control with active customers

The distribution systems with a high share of dispersed generation will have to be highly automated. On the other side, active customers will be able to offer services to the network. New market roles such as "energy manager" will occur which enable a seamless interaction between active customers and the network.
Paper C6-202 provides analyses of load patterns in Italy, where the peak load appears in summer time because of a large contribution of air conditioning systems. It is shown that the Heat Index based on temperature and relative humidity together with "temperature drop at night" allows load predictions with high accuracy. The forecasting of load patterns is used to avoid critical situations in the low voltage network with supply interruptions as a result of overloads. The tools for influencing the demand in such situations are described in detail, for example "critical peak pricing", or alert signals in case of exceeding the contracted power consumption. International experiences show that devices for "home automation" have to be promoted together with a variable tariff policy.

Question 2.3 Could generation forecasting coordinated with load forecasting improve the effectiveness of the energy manager? Dynamic tariffs, price signals, network signals: a lot of information needs to be exchanged between the active customers and the energy manager; which extend of communication infrastructure is required for this purpose? How large is the share of communication costs?

Two applications for active distribution control are described in paper **C6-203**. The "Microgrid control application" allows an intelligent and distributed reaction to disturbances and avoids subsequent constraints in the microgrid operation. Experiments with a microgrid containing several dispersed generators, storage units and controllable loads are presented.
"Demand Side Bidding" enables the provider to adjust his spot market bids and enables a wider participation of smaller customers. A more generic Control, Metering and Communication infrastructure based on Semantic Web technologies is considered. The information about the capabilities of different dispersed resources is exposed using web services with annotated semantics. This S-TEN ontology increases the representation capability of the components of the microgrid and supports the intelligent behaviour of the system.

Question 2.4 The benefits of the S-TEN technology can only be broadly used if various vendors will use the same approach. Are there currently international activities for standardisation taking place? What should be the scope to be standardized for enabling "plug and play" of different components?

2.4. International field experience

Paper C6-205 describes the international field experiences regarding the implementation of new hardware and software solutions for active management of distribution grids with a high penetration of dispersed generation. Experience was gained with developing the Multi Agent System (MAS) for real microgrids in Kythnos (Greece) and Mannheim (Germany). A further microgrid in Bronsbergen (Netherlands) is at its planning phase.
The main element of the MAS concept is the agent. An agent is an entity that has the ability to take autonomous decisions as well to communicate with other agents forming societies. The tasks of an agent are separated into three main control levels: "Local" (all local control), "Coordination" (simple tasks for two or more agents) and "Multi agent level" (all tasks related to the optimization of the microgrid as a whole). The ability of expressing complex data structures which include description of action sequences is one of the main parts of the intelligence of the agent.

Technical and economical benefits of active network operations concerning losses, loading and voltage quality are described in a qualitative way. It is stated that the future network planning has to consider the potential of the dispersed resources as an important factor.

Question 2.5 Has there already done any quantification of technical and economic benefits of active network operation seen from different stakeholder point of view? What will be the economic impact of active network operation? What are realistic/ estimated time frames within active networks that will be realised?

Question 2.6 There are various solutions for active network management such as "Agent technologies", "Virtual power plants", "Energy manager". Has there be done any comparison of these approaches? What is common, what is different? Is it possible to benchmark different solutions?

3. Preferential Subject 3 – Storage to support DER and RES integration in distribution grids and stand-alone systems

Paper C6-301 investigates the application potential of available energy storage technologies in future power supply systems. The study summarizes those critical characteristics and features of different energy storage systems and compares their cost effectiveness and technical feasibility regarding to three typical application scenarios: Long-term storage, Load Leveling, Peak-shaving at distribution level. Compressed Hydrogen and adiabatic compressed air have the potential to compete with pumped hydro storage and new battery technologies have the potential for peak-shaving, especially in DG systems, without the disadvantage of geographical limitation featuring all the long term storage concepts.

Question 3.1 The advantages of different battery technologies are often stressed: are there significant disadvantages of the different battery solutions? How can the future energy storage systems be integrated into existing power system infrastructure, with added value in term of both security improvement and economical enhancement?

Paper C6-302 reports on NAS battery systems and their practical applications in a Japan power utility. The paper summarizes the characteristics of NAS technology, such as high energy efficiency and little loss of charging. The main usages of NAS systems in utility is introduced in detail. Firstly, comparing with pumped storage hydro power plants, NAS was used as a better alternative for daily load-levelling, especially as a distributed storage in DG systems. After improving AC/DC converter capacity and response speed, NAS showed good performance for power quality as an emergency power supply. Load levelling and stand-by power supply can be combined as demonstrated by the NAS battery system in closed grid application. A practical project showed NAS with high speed control could effectively suppress the fluctuations of wind generator output.

Question 3.2 For preventing voltage sags a few milliseconds response is required: what kind of the control unit together with sensor is needed? From the utility point of view, can NAS be compared with other storage power sources, on investments, environment impact, reliability, performances and utilization prospect?

Paper C6-303 reports about economic considerations, value stream and sizing optimization of energy storage systems, particularly battery technology in remote DG systems and for the case of peak power with high spot pricing. A methodology is presented, applied in some cases in Canada, facilitating the integration of wind energy into remote communities with diesel powered isolated systems and into distribution systems. The main topics include:

- Discussion of the negative impact of intermittent generation on existing power supply power quality and the potential benefits of energy storage systems.

- Demonstration of the methodology for energy storage economical analysis and sizing. Application regarding remote communities and distribution systems are described.
- Description of a real-time simulation tool used to validate the performance of overall energy storage systems, including the battery model and two-level storage control.

Questions 3.3 Wind and load, both stochastic variables, are two important inputs for the storage sizing methodology: what are the underlying models and assumptions? Value stream is essential to the economics of energy storage system: how many benefits are considered? What is the corresponding calculation method?

Paper C6-304 presents the results of an experimental activity on different typologies of storage systems in LV DG systems, based on electrical energy storage and fuel storage in combination with conventional and innovative renewable power generation. Tests and reported results include:

- A Vanadium Redox flow battery system for peak shaving in power supply systems when the grid can not supply the required energy.
- A ZEBRA^{TM} high temperature battery in DG systems for power supply under islanding operation conditions.
- A low-pressure hydrogen storage system based on metal hydride technology in combination with fuel cell technology.
- An on-line state-of-health diagnose tool for lead acid batteries.

Question 3.4 What are the safety risks (related with possible H_2 losses, if any) and maintenance requirements for hydrogen storage system based solutions? Are there problems expected with long time storage? What are the advantages of the high temperature ZEBRA^{TM} system compared with other electro-chemical storage solutions?

Paper C6-305 proposes a general model of a wind-H_2-diesel energy system located at a stand alone remote area, implemented as a linear programming problem. A general case study represented by 100 households and 100 cars is studied based on two scenarios: 1) electrical load only, 2) electric load & H_2 load. A 10 years sample of wind speeds is used in the study. Results show that a high diesel power cost (higher than 0.2~0.3 €/kWh) is necessary to make H_2 cost effective as energy storage for wind power. In addition the long-term variability of the wind resource used in the study strongly indicates that fully renewable energy systems, based solely on wind power as the energy source and H_2 as the long-term energy storage, are not cost-effective, mainly due to a requirement for a very large (seasonal) H_2 storage capacity.

Questions 3.5 How load profile affects cost effectiveness of H_2 storage? Considering wind variability, may need for long term H_2 storage be considered an occasional requirement? May other remedy measures be taken to deal with it?

Paper C6-306 gives a general overview on the probabilistic tools utilized for planning and operation of power systems with distributed energy storage (DES) and stochastic generations. This paper points out that different potential owners (grid operators, generation companies, and energy traders) of the DES systems may have different objectives, which in turn results in different goals of probabilistic tools for stochastic generation modeling. The properties of stochastic generation are summarized and various probabilistic tools for stochastic generation modeling, from time-domain modeling method to forecasting and scenario development techniques, are briefly introduced. Then the utilization of these probabilistic tools in planning and operation considering DES are demonstrated and the results show that these tools are well developed for assessment of DES in planning and operation of power systems.

Question 3.6 In time-domain simulation, how to decide the interdependence between individual stochastic infeeds? How the load uncertainty should be considered in the planning and operation of power systems with DES and stochastic generations?