C6

GENERAL 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; a Special Report summarised the main issues and proposed some questions that raised a lively and profitable discussion. The main conclusions achieved in debating the three preferential subjects are hereunder given.

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

Preferential Subject 1 deals with issues associated with large scale integration of DER/RES on the transmission and distribution systems in both the planning and operating stages. Some of the issues include how to balance output fluctuations, how DER/RES can contribute to ancillary services, and market rules. Preferential Subject 1 received a total of 15 papers from Europe, Australia, New Zealand, USA and Japan in response to this subject. There was significant interest in this subject and 34 prepared contributions were presented.

1.1 Large Scale Integration of RES on the Transmission System

Role of interconnections in integration of RES. The main drivers for new high voltage ac/dc interconnections are:

- Economics,
- to exploit load diversity,
- to share reserves (gain access to flexible generation),
- to facilitate competition between generators,
- to facilitate integration of renewables.

Coordinated planning among TSOs is needed to optimally develop the transmission network. Good examples of this coordination have been given for Europe and North America.

The ability of a new interconnection to facilitate integration of additional wind generation depends on a number of factors including the diversity of the wind/load in each area as well as the generation mix (e.g. amount of available flexible generation or storage). New HVdc interconnections between Ireland and Britain (i.e. 500 MW in 2012 and 2-350 MW merchant links) were shown to facilitate the increased penetration of wind in Ireland by allowing surplus to be exported as well as allowing imports during low wind periods.

Given the challenge in siting new overhead transmission, a proposal is given to use new high temperature superconducting underground cable. An example is described where a 30 kV superconducting cable has similar capacity as a conventional 150 kV cable. The low voltage cable has the advantage that step-up transformation is not needed and reactive power compensation is not needed. The new cables have lower losses and potentially can reduce short circuit currents because of its inherent non-linear impedance characteristic, if this is an issue. A 6 km demonstration cable is being installed to downtown Amsterdam. There are concerns with the price of the cable and the feasible length of transmission that can be built.

As regards the comparison with storage option, only the existing level of pumped storage in Ireland was considered. The study acts as a base case for comparing the economics of new interconnections with local storage.

Use of fast power reversals in a high voltage dc interconnection or in the unit commitment plans of a remote balancing area. Most new HVdc interconnections are considering hourly schedules a day ahead based on wind forecasts. There are no technical issues with reversing power on this time scale. However, if the link were planned to provide primary or secondary frequency reserves, there would be limitations with traditional line commutated HVdc converters and oil-filled undersea cables. New designs incorporating voltage sourced converters and alternative cables would be required. In Britain, there would also be significant unbalance charges resulting from sub-hourly transactions that would need to be resolved.

Participation from wind plants in frequency regulation. Frequency regulation is one of the most critical factors in determining the penetration level of variable generation. Participation of wind in primary and secondary frequency control will become mandatory. In the near future, grid codes will be modified and ancillary services markets harmonized. Ireland's grid code has a requirement that all plants above 5 MW must have a frequency response capability installed and tested.

Due to the high cost of wind providing frequency reserves, other technologies may also be competitive in providing this service (demand, storage, interconnections, etc.). The most economic form of storage today is pumped hydro and compressed air storage.

The frequency control practices in Denmark, Ireland, Germany and France were described. It is a common requirement today to have wind generation curtail for over-frequency or other system conditions (10% rated output/minute) and remain connected for extended periods of under-frequency. Denmark has requirements for wind generation to participate in secondary frequency control.

Planning issues and methodologies. In many jurisdictions it has been noted that traditional deterministic planning methods are not adequate. Probabilistic methods are being proposed and used to better deal with the variable nature of generation, loads, contingencies and the uncertainty of future generation development because central resource planning is typically no longer applicable. A warning is given from Australia that probabilistic methods have led to some underinvestment resulting in blackouts. It is important to assess the level of acceptable risk in a probabilistic study.

Ultimately the consumer takes on the risk if congestion is higher than the models predict. The risk of curtailment is included in the transmission service costs (paid by market participants) in Ireland but the TSO is responsible for managing them. On the other hand, there is a risk of overinvestment in the transmission network when deterministic methods are used.

In France, the software tool ASSESS has been used to determine the wind penetration level on the French island network. PROMOD is used in Ireland and the U.S. to determine feasible market situations based on a variety of generation futures and wind hourly data.

Some tools are able to estimate the amount of future congestion. However, the TSO doesn't take the risks of errors in the models. The market participants can choose to invest in the transmission network to remove forecast congestion. Cigre WG C4.601 is preparing a technical brochure describing the current status of probabilistic tools and the need for future development.

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

Reliability penalties are in place in Australia and have a value between \$1000/MWh and \$10,000/MWh. This value is planned to increase to \$12,500/MWh in 2010. No other examples of equivalent reliability penalties were given.

Grid codes are being changed to ensure that resources remain connected over a wider frequency and voltage range to better coordinate with under-frequency and under-voltage load shed relays. Australia reported on a possibility of using rate of change of frequency to help coordinate load shedding. Cigre Working group B5.34 is investigating protection issues.

No specific examples of grid codes that limit the integration of DG were given. In Brazil, it was noted that long, weak distribution feeders could result in limited penetration levels due to stability concerns.

Islanding issues. As regards security issues with current methods of local anti-islanding protection, an example is given showing that severe over-voltages can occur with islanded systems containing inverter-fed PV installations and low load. It is recommended to modify the existing standards. However, in the short term proper surge arrester application at minimum is recommended. Conventional anti-islanding protection schemes were presented (e.g. under/over voltage and under/over frequency relays).

The current practice in most areas today is to apply 100% anti-islanding protection. However, there are many examples of pilot projects in Europe that have been designed specifically to operate in islanded mode. There is increasing interest in rural areas of Australia to develop micro-grids because of the very strict reliability rules and penalties. Also, investigations for small hydro, wind and biomass combinations may be feasible in Brazil.

Cigre WG C6.11 is preparing a document that will describe the development and operation of active networks, which will include suggestions of how to transition from an anti-islanding mode to a fully active network.

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

Demand Side Integration (DSI) implementation strategies. The level of adoption of DSI strategies are given for the U.S. The highest level of participation is in interruptible loads or direct load control. A significant number of loads are participating in ancillary services, demand bidding and emergency demand response. Real time pricing, critical peak pricing or time-of-use strategies have at present low participation.

Many countries are focused on developing DSI programs. New technology such as Smart Meters, Smart Grids etc. are being developed and installed. Demand response is being encouraged by providing consumers with peak demand pricing, for example.

Information or trigger signals to coordinate demand response with market conditions. An example is given in France where the system, PREMIO, is due to be implemented in 2009. The loads will be able to react to day-ahead hourly and real-time (10 minute) pricing information. This will be an experiment to test consumer response to dynamic tariffs. In Spain, the GAD project looks to allow intelligent loads and intelligent plugs. Work is still required on standard communication protocols to allow the interconnection of millions of intelligent devices.

The choice of trigger is related to coordinating the desired demand response with the system or market conditions. Several types of trigger signals being considered in the U.S. are summarized. The customer could receive a trigger signal from a retail operator who is demand bidding in the ancillary services market, for example.

Practical examples of application of the VPP concept. The aggregation of generation and load in a virtual power plant is possible. An example is given from Germany, where since 2004, the VPP is able to supply minute reserve power and optimize the use of electricity, gas and heat. Several other examples were given for Germany, Greece, Spain and France.

In Germany, the existing codes allow pooling of DG to provide minute reserve power. The rules for a reserve power market have been in place since Dec. 2006. The rules allow units with only 4 hours of reserve power to participate in the market, which includes CHP and predictable RES. Some changes in the German RES Act are to come in to effect in Jan. 2009. One change will result in small wind DG receiving a bonus if they participate in ancillary services.

In Germany, there will be an effort made to align the costs relevant to the communication infrastructure that permit real time voltage control with the market participants who caused them.

However, the large scale penetration of VPP is not economic today in Germany because:

- RES and CHP are subsidized at a higher than market price
- The current incentive is to maximize production.
- There is no obligation for RES to participate in ancillary services markets.

Several rule changes are proposed in Germany to overcome the above limits and are currently being discussed.

1.4 Microgrids

Use of PV power conditioner in a microgrid demonstration project: the Hachinohe project. A three-phase PV power conditioner is used as the compensator. The negative-phase-sequence (NPS) current is calculated at Supply and Demand Controller from each phase. The values are measured at the both ends of the dedicated distribution line. Measurement at both ends is necessary in order to compensate both isolated and interconnected operation. NPS current is expressed by its amplitude and phase difference (i.e. direction) from phase-A voltage angle, which is regarded as a base angle. It is assumed that the voltage is well balanced at all points in the micro-grid. The controller can share the calculated NPS current to more than one PV power conditioner, although only one is applied at the Hachinohe project. Measurement, calculation and control are made every one minute.

Measurements have been taken and the NPS controller has been shown to be effective.

The permissible negative sequence limit is based on the rating of the gas engine generator, which can only withstand 20% negative sequence current (of generator rating) or 2.8 A. The controller has been designed to limit the NPS to less than 1 A.

Effect of natural fluctuations in load and in weather dependent generations on frequency and voltage variations. The largest observed fluctuation was 50kW+100kVar in 40ms, caused by an air-conditioner's start-up transients, while the rate of change of weather dependent generators were larger than that of demand.

It was expected that the maximum frequency and voltage variations would occur while only one gas engine was in operation, and when the sudden change of demand happened. The frequency variation was estimated as 2.6Hz due to the time delay of the gas engine governor, while our target was for the frequency to be within ±0.5Hz of nominal value. Therefore, a local controller was installed for the battery to control frequency every 10ms. The probability of the frequency deviation being within ±0.2Hz was 99.85% and the maximum deviation was 0.4Hz.

Cost of the controller and necessary communication network. Clarification on some of the control techniques of the existing microgrid in Japan was given. The cost breakdown was also provided and it was noted the control and communication costs comprised only 2.3% of overall costs. It was noted that storage was needed to meet the 50 Hz +/-0.5 Hz regulation needs and this cost was significant at 8%.

1.5 Conclusions - Preferential Subject 1

Large Scale integration of variable generation up to 20-30% of demand is technically feasible in many countries today because of changes to grid codes and equipment capability. Beyond this level, there are concerns with the ability to control frequency. The integration of flexible generation, load, storage or the aggregation of DG into virtual power plants will be required. A new Cigre WG C1/C2/C6.18 will investigate the network requirements of large scale integration of variable generation in both islanded and networked systems.

Additional work on defining probabilistic planning methods and acceptable level of risk is needed given the level of uncertainty in planning networks with high amounts of variable generation. Cigre WG C4.601 is taking initial steps in this direction.

It is unclear whether customers are willing to change their behavior to allow realization of DSI goals of peak shaving or peak shifting. Future work will require changes in load forecasting tools as the penetration of DSI increases.

Standardization of strategies and communication protocols for DSI, VPP, and other Smart Grid topics has not been realized to date. Improved project economics could be realized via standard open protocols.

Some work determining the sensitivity of modern loads to transient frequencies and voltages would be useful to determine if islanded networks can withstand wider excursions to reduce the cost of infrastructure such as storage devices.

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

Active distribution networks are supply areas containing a significant share of dispersed generation. Advanced technical solutions and concepts shall be applied to ensure the secure and reliable contribution of the dispersed generation to the power system operations.

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. Addressing this Preferential Subject 13 contributions were presented covering the 6 questions of the Special Report.

The discussion of the preferential subject 2 was opened by a report of the working group C6.11 "*Development and operation of active distribution networks*".

2.1. Concepts of active distribution

Answering the first question the definitions of such concepts for active distribution like “power cells”, “microgrids” and “virtual power plants” were clarified.

A **virtual power plant** (VPP) is a cluster of dispersed generators, storage capabilities and demand side management activities operated together with the target to offer energy and system services on the liberalised markets in the same way like the traditional power plants do.

A **microgrid** is a community distribution network that supplies electricity and heat to users in close proximity. It integrates generation from renewable energy sources, such as wind or solar, into a locally controlled electricity distribution network. A microgrid is able to supply all or a part of its consumers independently of the network in case of system disturbances.

Power cells, on the other hand, are self-contained, autonomous networks, of any economic size or voltage, managing and controlling their own renewable energy power generation, protection, storage and power distribution to loads. Voltage and frequency standards may be controlled locally but synchronised to a national standard. Individual or groups of cells may be interconnected, or meshed, to form a power network, importing or exporting power to their neighbours, or to a transmission grid, to balance generation and load demands.

Active transformers were recommended as an interface between a Distribution Network and a Transmission Grid or another Distribution Network to provide flexible means of network management and control.

2.2. Planning of active distribution networks

The planning process of active distribution operation was considered in two presentations from Italy and Germany.

In the current context of distribution networks, novel methods and tools to evaluate the reliability of distribution systems are necessary to plan economic sound investments and to find the optimal priority of the reliability-oriented actions. The traditional planning techniques need to be revised also to take into account ageing concern in order to avoid the underestimation of system risk and incorrect conclusions in system planning. Active distribution management has to be considered in the long term network planning. It was underlined that active distribution management including dispersed generation is able to postpone investments into the grid.

Security management is a further opportunity to increase the reliability of supply. Network security management systems (NSM) are applied to limit the power output from DER / RES in the case of grid parameter violation. The introduction of the NSM systems has generally a negative effect on the utilization of DER / RES since the “green energy” is lost. However, this solution seems to be an optimal way that can be immediately applied to allow for further development of DER / RES taking into account the existing barriers However, to reach the positive aspects it is necessary to change the regulatory framework to create incentives for an active management of dispersed generation. Further more, the penetration of communication into the distribution level is the pre- requisite.

2.3. Management of active consumers

Examples of coordinated forecasting of load an dispersed generation in a German pilot project were demonstrated and the high accuracy of the applied tools could be presented.

The Italian concept of the “Energy Manager” in secondary (MV/LV) substations was considered. The Energy Manager influences the load flow by price signals from the traders and by network signals from the distribution system operator.

Bi-directional communication is required for the active management of customers. It is probable that a hierarchy of communications will be possible with local “intelligent agents” able to communicate to optimise loading of local distribution substations and the substations communicating with other substations on the feeder to the zone substation.

2.4. Standards for data management

The communication using innovative technologies like S-TEN was discussed. It provides a more generic Control, Metering and Communication infrastructure based on Semantic Web technologies. The information about the capabilities of different dispersed resources is exposed using web services with annotated semantics. The needs of standards, the items to be standardised and the expected time frames of standard publications were presented.

The development of an ontology for observations and measurements is currently a preliminary work item within ISO TC184/SC4. A working draft is scheduled to be submitted in November 2008. This should then become a standard as a part of ISO 15926 within three years.

Within the European research project "More Microgrids" the Common Information Model CIM based on IEC 61970 has been used in order to create a formal ontology.

2.5. International field experience

Different concepts developed in four European and American projects were compared in a French contribution accordingly table 1:

- Virtual Power Plants in the FENIX European project
- Active Demand in the ADDRESS European project
- Energy Manager in the PREMIO French Regional project
- Intelligent Grids in the IntelliGrid EPRI program.

Table 1 – Main concepts used in the projects

FENIX	ADDRESS	INTELLIGRIDS	PREMIO
Virtual Power Plant (VPP): flexible representation of a portfolio of small generation and demands. Commercial VPP: commercial aggregated profile for the DER portfolio. Technical VPP: technical aggregation of DER from the same geographic location - Influence of the local network on the DER portfolio output - Included in the Distribution System Operator (DSO) local system management.	Aggregator: mediator between the consumers and the markets and the other power system participants. Interactions based on real-time price and volume (mainly Power) signals "Demand" approach (in contrast with the "generation" approach): consumers not motivated by purely economic aspects Distributed intelligence and local optimisation.	IntelliGrid architecture, a methodology to develop information architectures Customer portal that provides the foundations of Advanced Metering Infrastructure (AMI) and customer empowered functionalities Fast Simulation and Modelling that provides a computerized engine to intelligent devices Standard objects models for DER.	Local centralized energy controller to optimise the electric generation and demand at the level of the LV feeder and ensuring the performance of the local network. Controllable intelligent generation, storage and load processes at the consumers/producers premises able to optimise locally their operation and take into account the requests from the centralized controller. DSM signals received by the central controller from external commercial (e.g. retailers, aggregators) or technical (e.g. DSO) operators.

The definitions of several concept terms used in the different projects help to make the understanding clearer.

First time concrete benefit figures of the participation of a virtual power plant in the markets for energy and for reserve power were presented.

The benefits include:

- Saving of balancing group deviation costs,
- Profit from sales of tertiary (minute) reserve power,
- Possible benefits of a direct energy market access (avoiding subsidised feed-in prices) in periods of high energy prices.

A combined planning approach considering the three contradicting planning aspects - technical, economical and environmental optimization was presented. The results of the combined approach are closed to the results of the economical optimization. However, technical constraints of the network (losses, voltage quality, loading) and environmental aspects (decrease of emissions) are taken into account.

2.6. Conclusions preferential subject 2

Active distribution network concepts are world wide investigated and applied in pilot projects. Active distribution management shall be considered in the planning phase. It improves the reliability of supply and can help to postpone investment.

On the other hand, active distribution management requires the wide spread penetration of communication infrastructure in the distribution level. The progress on adequate standards for communication and data management is still an issue.

Examples demonstrate the commercial benefits which can be reached by an active energy management on the distribution level targeting the markets for both, energy and reserve power.

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

Today’s experience with different energy storage solutions concepts are discussed, in the whole field from short term storage for Power Quality up to long term storage in stand alone and remote areas and applications in different topologies and combinations. Even cars with H2 fuel cell technology are considered in the storage system. It was shown that different solutions in different applications can be competitive if a sufficient over-capacity of power generation is available, regardless of the stochastic infeed. Besides economic arguments, the environmental impact, energy efficiency and reliability are considered, just to mention a few aspects.

A total of 6 papers regarding the Preferential Subject 3 have been selected for the 2008 session. 8 contributions were received for the discussion

3.1. Storage issues

Critical features for different storage scenarios from long term storage to peak shaving are compared in paper C6-301. The question raised, if there are significant disadvantages from one or the other battery solution could be answered in a way that today in most applications still strong subsidizing is needed and a strong improvement of technologies is needed – critical features of battery technologies are compared with target figures, including the costs of the solution. The example from Australia showed that limited knowledge can cause huge damage.

Practical applications of NAS sodium-sulfur battery systems in a Japan power utility case was presented. The proposed application of NAS for Power Quality as emergency power supply raised the question how voltage sags can be prevented. The answer given showed that fast detection of voltage sags and fast separation of the load from the grid is the key to avoid problems. The method was described and examples given. The answer addressing the advantages of NAS systems showed that many positive points could be collected in the field experience regarding economy, environment, reliability performance and maintenance.

3.2. Storage for DG and stand-alone systems

Economic considerations and optimization methodologies were presented regarding energy storage for a Canadian case studying the integration of wind energy into remote and isolated systems. The question regarding underlying models and assumptions for those stochastic variables like load and wind was answered by a spontaneous contribution in the session. The curves of the random variables had been shown. Regarding the economics, the interaction with storage devices was discussed regarding electricity cost reduction, positive environmental impact etc. For modeling, both deterministic and stochastic models are used together with sensitivity analysis.

Results of experimental activities with different storage concepts are presented with reference to different typologies in a LV DG system. The question regarding safety risks, loss of H2, embrittlement of material and maintenance requirements was answered. Risks can be reduced drastically if lower operating pressure for H2 together with a cooling system is applied. Further it is proposed to use stainless steel to avoid material aging. Experimental data underline that ZEBRA high temperature battery systems show very high energy density, energy efficiency and unitary coulombic efficiency, without gaseous emissions and providing simple system management.

The general model for a wind-H2-diesel energy system for a stand alone remote area was presented. Different scenarios represented by 100 households and 100 cars where considered. The question about impact of the load profile on the cost efficiency of the H2 storage is answered in a way that H2 can be cost-effective for energy storage in autonomous systems with a high share of wind power and high cost of conventional power supply.

Probabilistic tools were proposed for planning and operation of power systems with distributed energy storage (DES) and stochastic generations. The question regarding interdependence between individual stochastic infeeds was answered by two contributions, as well as the question how load uncertainty should be considered in the planning and operation of systems with stochastic generation. Non parametric transformation based methods for time-series analysis and simulation are shown to be well suited for identifying and reproducing the interdependence structure of multiple stochastic time series from power systems such as partially dependent wind generation or wind and load jointly. The correct modeling of the interdependences – not only correlations - has been shown important for the assessment of DES.

3.3. Conclusions preferential subject 3

Storage is assuming growing importance for DG and stand alone applications especially based on the exploitation of renewable energy sources; the use of probabilistic tools is recommended for planning and design purpose.

Batteries are to day commonly used, but improvement of technology is needed.

Use of H2 is now already studied just to identify load and generation scenarios in stand alone systems to be cost effective.