Special Report for Session 4
DISTRIBUTED GENERATION - MANAGEMENT AND UTILISATION OF ELECTRICITY

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There is little doubt that distributed generation and the change in role of the distribution system that it brings, continues to be a topic of great interest. This is reflected in both the large number and high quality of the papers offered for Session 4. Papers describing practical distributed generation schemes have been received from a number of countries and the conference will provide an important opportunity to share insights and experience. High penetrations of distributed generation radically change the way a distribution system is designed and operated and significantly expands the work of the distribution engineer. Thus, in addition to questions relating to the design and operation of the distribution network, there are a number of papers on new forms of generation, particularly large wind turbines, and how power electronics can increase the flexibility and controllability of such equipment. In addition to the technical issues, the Session will also address how distributed generation, with its important environmental benefits, can operate in liberalised markets where the power system has been re-structured. Of course, the effective management and efficient utilisation of electrical energy is a topic of equal importance to new forms of generation and, although fewer papers were received, these important topics will also be addressed.

Building on the success of recent CIRED conferences, the extended Session 4 format for 2005 is as follows:

- The main **Alpha** day (Tuesday 7th June) will start, (Block 1) with reviewing experience of distributed generation from a number of countries. Then Blocks 2, 3 & 4, will consider in turn: the design of networks with distributed generation, the operation of networks with distributed generation and finally the interaction of distributed generation with the network.
- On the **Beta** day (Thursday 9th June) there will be two **Round Tables** to discuss: "DFIG – Doubly Fed Induction Generators", and "Impact on the network of operating distributed generation". These will be followed by a **Research and Innovation Forum** discussing topical technical developments in distributed generation. A joint Session 5/Session 4 Round Table will be held on Wednesday 8th June to discuss "Planning tools for distributed generation".
- There is also the opportunity to discuss with authors on a one to one basis at the **Interactive Poster Session** on Wednesday 8th June. We encourage all authors to bring poster material to the conference and use this excellent opportunity for individual interation.
- Two **Tutorial** sessions on "An Introduction to Network Stability" and "Current Topics in Distributed Generation" will be held on Thursday 8th June.

Alpha Day blocks start with a keynote presentation, then invited authors will present the updated highlights of their work before all the authors form a panel to interact with the delegates in the discussion period. Papers to be presented orally are marked *. All delegates are encouraged to prepare in advance contributions to the discussion and answers to the questions below.

Block 4.1: EXPERIENCE OF DISTRIBUTED GENERATION

The **keynote presentation** for the first block is **Paper #1*.** This describes how the reliability of distributed generation (in this case wind turbines) can be evaluated and modelled. As distributed generation starts to become an important component of the power system, then its long term behaviour is of critical interest to distribution engineers. The paper uses data from Germany and Denmark collected over a 7-year period.

A number of other papers discuss details of the technology used in distributed generation. These include **Paper #145**, which deals with the electromagnetic design of disk permanent magnet generators for micro generators and **Paper #712** discussing new approaches to speed control of DC motors. It is clear that as more and more novel technologies are connected to the distribution network that an improved understanding of these new generators is required.

Question No 1:
Is our present understanding of the performance of distributed generators adequate? How should such knowledge be acquired and managed in a de-regulated commercial environment?

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Paper #54* then describes the 76 MVA connection developed for a large offshore wind farm. During intact network operation the wind farm is permitted to export its full capacity, depending on wind resource. However in the event of network outages the export capacity of the wind farms is curtailed. This will result in modest loss of generation over the life of the project but allowed a significantly (Euro 4.5M) cheaper connection scheme to be adopted.

A contribution from Malaysia (**Paper #209***) then discusses how the distribution utility in that country addresses the connection of distributed generation and describes the two-stage evaluation process it has developed. This process allows a comprehensive assessment of the impact of the distributed generation on the network.

Germany has a high concentration of wind energy (presently around 14 GW) but with very ambitious plans to expand this to 45-50 GW by 2030. **Paper #224*** discusses how this might be achieved and the requirements such an expansion in capacity will place both on the generation equipment and on the network.

Paper #440* continues the theme of the impact of high penetrations of wind power on to networks and discusses a wide range of topics that are the subject of Grid Code requirements in many countries. It discusses the technical impacts including the effect of variations of the wind, fault ride through and the requirement for reserve and frequency response.

Question No 2:
Do the present Grid Codes and network rules encourage the connection of distributed generation? Are the approaches for connecting new forms of generation to the distribution network compatible with those for connecting similar generation to the transmission system?

A paper from Austria **(Paper #495*)** describes work undertaken as part of the CEU projects DISPOWER and DGFACTS. Results of Power Quality measurements at photovoltaic and wind installations are presented. Particular insights into the development of distributed generation in Austria are summarised and the use of design/assessment tools discussed.

The DISPOWER project also led to **Paper #503** which discusses the information requirements and methods for characterising distributed generation. Distributed generation places new burdens of analysis and information management on distribution companies and proposals on how data can be collected and managed are given.

The commercial incentives for distributed generation are discussed in **Paper #36** with particular reference to Brazil while the use of the Joint Implementation and Clean Development Mechanisms for encouraging investment in distributed generation in the Western Balkans is addressed in **Paper #16.** The financial instruments for supporting distributed generation in Portugal are discussed in **Paper #262** which also deals with how the capacity of the network is managed.

Question No3:
Are there sufficient incentives for operators of distribution networks to connect distributed generation so that the ambitions of energy policy makers to encourage renewables and low-carbon generation can be achieved?
Paper #631* discusses how large (DFIG) wind turbines respond to network faults and uses simulation to explore the phenomenon of voltage collapse. Approaches to improve the fault ride through capability of the generators are reviewed including the use of a crowbar on the DFIG rotor and isolating the generator in the event of a network fault.

Although much attention is presently focused on distributed generation and new energy sources, the area of demand reduction and energy efficiency both in the network and in load equipment is key to achieving a transition to a low carbon energy economy. **Paper #307** discusses how this important topic is addressed in Italy while energy efficiency in the residential sector in Romania is addressed in **Paper #404.** Egyptian experience of improving energy efficiency in Government buildings is addressed in **Paper #705.** This successful approach illustrates what progress is possible with a well-constructed energy efficiency programme.

Question No 4:
Is de-regulation of the power system making it harder to implement effective energy efficiency programmes? How can energy efficiency be encouraged, both in the network and in loads within the present and emerging commercial frameworks?

Several innovative approaches to control of loads were also proposed. **Paper #469** discusses how an advanced interface unit can increase the daily profit of a customer by optimising the use of distributed energy resources and controlling loads. In a similar manner, the optimisation of trading strategies for Combined Heat and Power plant is addressed in **Paper #337**.

A paper from Japan (**Paper #505**) shows how time-deferrable loads can be used for frequency regulation while an autonomous lighting system using PV is discussed in **Paper #642**.

Question No 5
What is the scope for load control to assist in the operation of the power system, particularly with high levels of distributed generation?

Block 4.2: DESIGN OF NETWORKS WITH DISTRIBUTED GENERATION

Interest in distributed generation is now moving beyond the relatively simple question of how distributed generation can be connected to networks to the more demanding question of how such generation can be integrated effectively into the development and operation of the power system. In addition, new concepts of active control of networks and generators give greater flexibility to the designer.

The keynote speech of this Block is **Paper #203*,** which discusses a study of how to develop a network "from scratch" for the connection of distributed generation. Such an approach gives important insights as to how networks can be constructed building on existing assets.

Question No 6:
How should the network of the future be conceived and developed? To what extent should designers consider future distributed generation when designing new networks?

Paper #137* then continues the discussion on advanced tools and demonstrates the use of unbalanced sequential power flow calculation to determine the voltage profile on a low voltage network supplied with distributed generation. The forward and backward sweep calculation technique is used with one-minute load data.

A methodology for the design of low voltage networks with small generators is described in **Paper #147*.** Particular attention is paid to compliance with limits on voltage regulation, voltage unbalance and short-circuit levels. The paper describes a design procedure that can be adopted and details the calculation techniques used.

Question No 7:
Is the connection of micro-generation to LV networks likely to be a problem? If so, when? To what extent should unbalanced loading be considered or is unbalanced loading of LV circuits merely bad engineering?

A US approach to the modelling of networks with distributed generation is described in **Paper #161***. US distribution practice differs considerably from that found in most of Europe and the paper includes a discussion of using Step Voltage Regulators for voltage control on MV circuits with distributed generation. Such devices are now emerging as useful tools for the connection of distributed generation to MV networks and are in service in a number of counties.

Paper #257* describes a radical approach to the use of distributed generation in networks without connection to a large power system. In this case an autonomous 200-customer power system supplied by small CHP units is studied. As expected, there are considerable practical difficulties in maintaining operation of such a small system but the study gives useful insights into how very high penetration of distributed generation might be managed. Another advanced concept of self-controlling autonomous power networks is addressed in **Paper #280***. Simulations are used to investigate both the normal operation and behaviour during faults of the system.

Question No 8:
Is the "MicroGrid" autonomous network concept useful? Is it likely to become commercially attractive? Does the study of such networks shed light on system performance with high penetrations of distributed generation connected to distribution networks?

Including distributed generation in distribution network planning is discussed in **Paper #499***. The authors describe tools that they have developed to investigate both the technical and economic performance of networks with distributed generation. Example outputs are shown and discussed. An advanced technique to evaluate a multi-objective performance index to decide the preferred location on the network for the connection of distributed generation is discussed in **Paper #584**. Such an approach allows evaluation of various aspects of the contribution of distributed generation to system performance.

Paper #271 discusses the verification of models for distributed generation. There is a marked lack of validated models for distributed generation and so any simulation results will contain considerable uncertainties. In addition, without experimental or site validation it is not possible to ascertain if the models capture the important effects.

Question 9:
What can be done to validate distributed generation models and to ensure the results of tests and site experiments are widely available?

Paper #392 investigates how small CHP units can be modelled. An interesting feature is the consideration of thermal energy storage as well as the combination of the MATLAB simulation with the electrical program Eurostag. The use of thermal energy storage is shown to result in lower voltage variations due to the reduced number of switching operation of the CHP units. Detailed modelling of photovoltaic systems is demonstrated in **Paper #573.** The operation of the Phase Locked Loop and Maximum Power Point Tracker is represented.

The particular issues associated with connecting induction generators are discussed in **Paper #482**. Induction machines have been used for many years in small hydro plants, and the case studies shown in the paper confirm that, subject to careful assessment, this form of generation is attractive.

Results from another CEU Project, EU-DEEP, are presented in **Paper #490**. Here the emphasis is on determining how much distributed generation a particular network can host. The capacity of distributed generation that a network can host may be increased by a number of measures, including network reinforcement, but also by moving to more active control of network voltages.

An integrated design of a section of a city using a combination of small CHP and photovoltaic generators is discussed in **Paper #524**. Implementation of the scheme will begin this year using sophisticated control and communication equipment.

Block 4.3: OPERATION OF NETWORKS WITH DISTRIBUTED GENERATION

The papers in this Block relate mainly to how networks with significant penetrations of distributed generation may be operated. There is no particular keynote paper as the papers selected for oral presentation each deal with specific aspects of network operation.

The performance of Loss-of-Mains relays continues to be a topic of interest to many distribution engineers and **Paper #111*** describes test results which indicate how both ROCOF (Rate of Change of Frequency) and Vector Shift type relays perform when subject to secondary data taken from real network incidents.

The influence of distributed generation on system frequency was studied as part of the CEU CRISP project and is addressed in **Paper #371.** A deterministic criterion for the limit of DG (with and without instantaneous disconnection protection) on to system is proposed.

Question No 10:
Is the performance of Loss-of-Mains relays on distribution networks now well understood? Given the requirement to isolate generators in the event of Loss-of-Mains, while maintaining stable operation for remote disturbances, is Loss-of- Mains protection still a cause for concern? Is there progress on resolving the conflict between rapid Loss-of-Mains protection on distribution networks and maintaining overall system frequency stability?

Although power transformers are, fundamentally, bi-directional devices, there are well know limitations on some tap-changers when the direction of current flow is reversed. This can give rise to a limitation on the connection of distributed generation. **Paper #149*** presents an analysis of the reverse current flow capability of a single-resistor on load tap changer, the type frequently used on Medium Voltage distribution transformers.

A study from Holland investigated the impact of distributed generation on the operation of tap-changing transformers controlled with current compounding (**Paper #114**). The results of a comprehensive investigation indicate that with a modest degree of compounding, distributed generation does not lead to voltage control problems and that this control arrangement gives a better voltage profile than a simple voltage control strategy without compounding. Implementation of the results of the study is now in progress.

Paper #95* records Power Quality measurements made on two Medium Voltage networks with distributed generation in Norway. The work was undertaken as part of the CEU DGFACTS project. The period over which the data was collected was 3-4 months and the data indicates that, the level of distributed generation presently installed does not appear to cause a power quality problem.

The impact of the fluctuating output of loads and photovoltaic systems is addressed in **Paper #425*** from Japan. The load variations are significant and the results indicate the possibility of reducing the stability and quality of the network. In response to this the authors propose a system of distributed compensation.

Question No 11:
Is there evidence that distributed generation is resulting in reduction of network Power Quality? If so, under what circumstances is Power Quality reduced?

The use of modern control and communication technologies to improve the manner in which distributed generation is integrated with the network is the subject of much work worldwide. **Paper #142*** from Australia, proposes the use of multi-agent technology for the control of generators below 5 MW and 11 kV. The objective is to address the volatility of the wholesale electricity price and also network constraints.

An approach to the active control of distribution network voltages in order to increase the connection of distributed generation is discussed in **Paper #93***. Two approaches are described: the first being suitable for smaller networks with simpler control approaches working on transformer tap change controls, the second using an optimal control concept that can interface with both network and generation assets. A companion **Paper #506** describes the impact of the availability of communication channels on the operation of a state estimator algorithm. At present the cost of communication channels for the automation of distribution networks is significant and so their use must be assessed carefully.

A case study of active network management on the Island of Orkney is presented in **Paper #520**. The studies show how the implementation of the scheme would increase network security as well as allowing increased connection of distributed generation. The paper also contains a useful review of active management of networks with distributed generation and current topics of interest.

Question No 12:
Is active management of distribution networks for the increased connection of distributed generation a useful idea? Are schemes now being considered for construction or do these concepts remain in the research/investigation domain?

From the research community, **Paper #278** describes a technique to optimise the reactive power support of a network fed with distributed generation using an "Ant Colony algorithm". The authors demonstrate improved performance of this technique over more established approaches. In contrast, **Paper #368** uses an evolutionary algorithm to control the despatch of generators in a distribution network, taking into account system capacity, network voltages, electrical losses and generation costs.

The important aspect of how controlling the demand of a network can contribute to its controllability is discussed in **Paper #120**. This contribution deals with how load control can contribute to controlling network voltage rise and minimising export of active power to the network from small distributed generating plants. The speed of autonomous renewable energy generators can be controlled by varying the load applied to the generator and this concept is explored in **Paper #513**. Here a fixed pitch, wind turbine system is controlled by varying power through an AC/DC converter so avoiding complex mechanical governor systems.

Question No 13:
What is the role of load control in the operation of distribution systems? Under what circumstances is it appropriate to consider controlling load?

Finally in this Block, **Paper #72** from China discusses the development of a training simulator for the regional electricity network. Functions include training of operators, investigation of network incidents, playback of recorded data and familiarisation training of administrative staff.

Block 4.4: INTERACTION OF DISTRIBUTED GENERATION WITH THE NETWORK

The last Block of papers (Block 4) takes a broad look at how distributed generation interacts with the network. Both commercial and technical issues are considered. The technical topics include both power quality and stability while how distributed generation can contribute to ancillary services is also discussed.

As part of the CEU EU-DEEP project an investigation was undertaken to investigate the impact of distributed generation on the number of voltage dips experienced by end-customers (**Paper #104***). The results indicate that as large central generation is displaced, the number and severity of dips at transmission levels are likely to increase.

A number of papers address the issue of Power Quality and how this is affected by distributed generation including **Paper #281** from the Czech Republic and **Paper #562** from Brazil. Although the work is, in some cases, still in progress it would appear that variation in power quality of networks with distributed generation is a complex matter critically dependent on the type and location of the distributed generation as well as on the conventional generation that is displaced.

Question No 14:
What is the impact of distributed generation on network short-circuit levels? How does this effect power quality?

The commercial environment for distributed generation is likely to influence significantly the rate at which it is connected into the power system. **Paper #666*** from the UK discusses how ancillary services might be provided from distributed generation. **Paper #585** then addresses how networks with distributed generation can be reconfigured to reduce losses. A graphical simulator is demonstrated to show how a number of techniques for loss allocation can be implemented. Similarly **Paper #688** discusses how distributed generation with and without local capacitive compensation effects losses and the voltage profiles or the connecting circuits.

Question No 15:
How can distributed generation contribute to ancillary services? How can distribution companies deal with the possibility of the distributed generation not delivering the services when required?

Hardware test facilities are an important resource when investigating new concepts for distributed generation **Paper #311*** from Italy describes how simulation and hardware testing may be combined. A similar approach is described in **Paper 611*** from the UK. In both cases very major facilities have been created.

Question No 16:
What is the role of hardware testing faculties for investigating new distributed generation concepts? What are the advantages of hardware testing over simulation?

Distributed generators increasingly utilise power electronics for their connection to the network and this introduces the possibility of very flexible control. **Paper #672*** describes how doubly fed induction generator wind turbines may be controlled and demonstrates how this class of machine can be controlled. The paper also raises the interesting question as to whether voltage or power factor control of distributed generation is more desirable.

Question 17:
How should distributed generation with power electronic interfaces be controlled? For example should generators be operated on voltage or power factor control?

Paper #652 discusses the impact of a distributed generator on the network protection system. The case study shown concludes that good coordination of the protection could be maintained without large additional cost.

A more radical approach to the operation of distributed generation is discussed in **Paper #372***. Here, intentional islanding is proposed in order to prevent blackouts. This leads to significant requirements for integrated control and communications facilities. The work described was part of the CEU CRISP project.

From the university community, a number of papers describe simulations and investigations of particular distributed generation technologies. These include **Paper #341** from Iran describing work on Micro Generation and **Paper #498** from Slovenia looking at the response of photovoltaic generators to voltage sags. Continuing with photovoltaics, **Paper# 560** describes the design of a photovoltaic power converter able that produces a high power quality output. Finally **Paper #295** discuses the physically based modelling of induction lamps.

RIF4: Research and Innovation Forum

The papers listed below have been selected to be inputs into the discussion on topical Distributed Generation developments in RIF4 on Thursday 9th June. In the Forum new research ideas, concepts and challenges will be welcome along with views on innovations that could, or indeed, should be introduced into distribution networks with Distributed Generation.

Paper #189 Optimal allocation of embedded generation
Paper #192 Impact of DG on voltage control
Paper #258 Intentional islanding - effect on reliability
Paper #283 Benefits of active management
Paper #608 Enhanced capacity from intelligent generators
Paper #314 Network re-configuration for loss reduction
Paper #541 Security contribution from DG
Paper #348 Stability with low inertia generators
Paper #358 Fuzzy logic control
Paper #382 Statistical modelling
Paper #394 Wind-to-power model
Paper #552 Dynamic simulations of wind generators
Paper #653 Dynamic Modelling of Microturbine generator

Paper #171 Stability of DFIG wind farm
Paper #172 Transient analysis of multiple DFIG
Paper #342 DFIG modelling & model simplification
Paper #343 DFIG voltage control strategies
Paper #433 Dynamic behaviour of DFIG wind turbine
Paper #463 DFIG control performance

Contributions from the authors of the second group of papers (DFIG related) will also be very welcome in RT4a.