Special Report - Session 4
DISTRIBUTED GENERATION AND ENERGY EFFICIENCY

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Introduction

Papers were invited for session 4 from a wide range of topics in areas involving the integration of distributed energy resources within distribution networks (including distributed generation, storage systems, responsive load and electric vehicles) and also involving opportunities for more efficient and lower carbon distribution and end-use of electricity. Contributions relating real experiences of integrating distributed energy resources into distribution networks and examples of technical, commercial and regulatory solutions were welcomed. Papers describing developments in low carbon generation technologies and their assessment and techniques for improving the efficiency of delivery and end-use of electricity were also welcomed.

A large number of papers were submitted to Session 4 and from the selection process based on abstract review 135 full papers have now been included in this session. The volume and quality of abstracts and papers submitted and selected in this session show a vibrancy, depth and breadth of activity in this area that has taken a further step forward since the last CIRED conference in 2009. The papers have been allocated into four blocks as follows:

Block 1: DG/DER planning and studies

- Analysis and planning techniques and results from studies

Block 2: Control of networks with DG/DER

- Operation and control of DG/DER, active network management, new smart grid concepts and demonstration projects.

Block 3: Customer side developments

- Demand Response, smart meters and AMR/AMI, energy efficiency, load modeling, Electric Vehicles network integration.

Block 4: DG/DER technology

- DG/DER technology development, DG/DER system testing, EV technology, Energy storage, grid interfaces, other enabling technologies.

Five papers in each block have been selected for oral presentation in the main sessions and a further six papers in each block are selected to give a brief presentation at the research and innovation forum (RIF) session. The main session provides the opportunity to engage at a deeper level with some of the more significant papers and topics. The RIF session provides the opportunity to appraise several new and innovative ideas (often fresh from research and development programmes) in a dynamic and interactive environment. All papers are invited to present posters at the conference and this is a good opportunity to meet authors, discuss topics further and participate in the discussions on these topics.

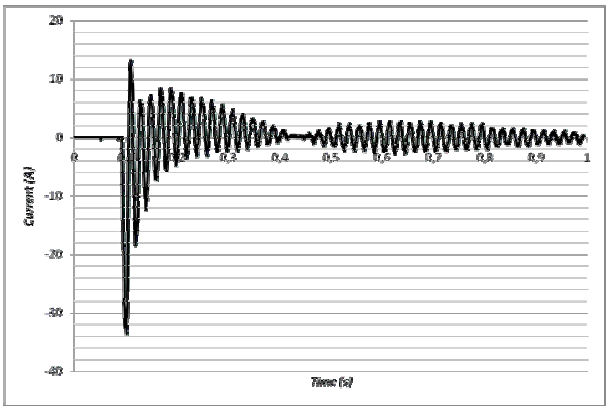
This special report provides a summary of each paper in the context of a coherent discussion of the main topics in each block and provides an ideal way to assess the breadth of the field. This special report also provides a good way to identify the papers on a given topic and then dig deeper through the papers and the conference sessions and poster events.

Block 1: DG/DER planning and studies

This block brings together a relatively broad set of papers that deal with distribution network analysis that involves distributed energy resources (DER) such as reactive power and voltage control, power flow management, losses, network reliability, protection, stability, faults and synchronisation.

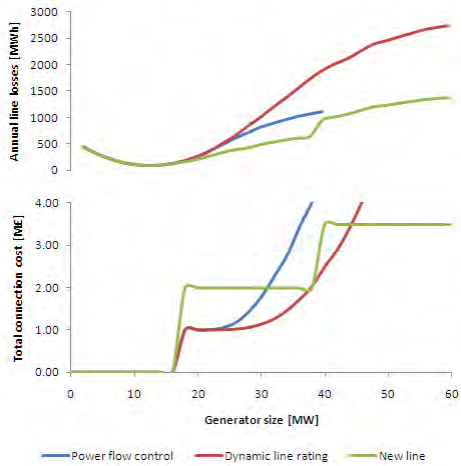
In the topic area of ***stability***, ***protection and power quality*** assessments, there are 7 papers. Paper **0023** deals with wind integration of wind generation within a small, islanded power system and discusses how stability and fault-ride-through requirements may limit the amount of generation that can be connected. The paper shows that the voltage stability margins vary with technology of

distributed generation connected and its reactive power support capabilities. In this context, the authors contrast the impact of synchronous and induction generation on network stability margin. In paper **0370** an exhaustive experimental study has been conducted on the out-of-phase connection for both synchronous and induction generators. Both experimental and simulation results show that in the case of full out-of-phase connection of synchronous or induction generators, the maximum current values are approximately twice those obtained when the terminals are short-circuited. Recommendations are made that the induction generator current limits (160%) would be met for voltage phase between –30º and +40º, while for the synchronous generator the phase angles were –45º and +60º (relative to the voltage at the connection point). The figure below shows the current during the reconnection process.



Papers **0610** and **0432** discuss protection systems and the short circuit behavior of distribution networks with a large share of distributed generation. The first paper discusses rules for quantifying the impact of distributed generation on the functionality of traditional distribution protection systems, while the second paper proposes that the fault clearing process is improved in order to increase the DG availability. This is achieved within an integrated (smart) protection concept that makes use of sensors, standard communication protocols and multifunctional software algorithms. Paper **0583** considers the harmonic emissions of EV chargers and compares active and passive filtering from the point of view of both technical and economic performance. Paper **1226** simulates the operation of unbalanced distribution networks and evaluates the impact of unbalanced loading on power losses and voltage performance. The presented results emphasize the deviations between a multi-phase and a simple single-phase load-flow algorithm.

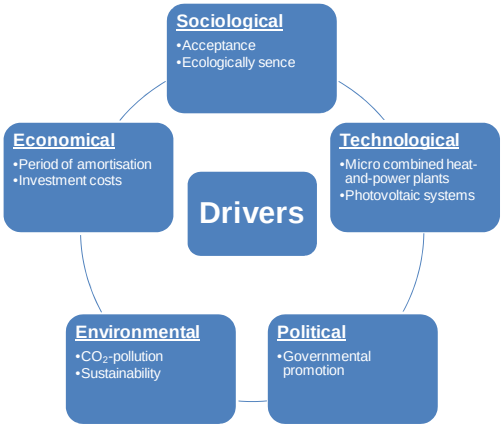
There are 6 papers that deal with the topic of ***benefits of active network management*** including voltage and power flow control in distribution networks with DER. Paper **0285** presents a quantitative and qualitative analysis of the technical and economical impact of different ANM technologies. The technologies considered are power flow management, voltage control, dynamic line rating, demand response and energy storage with the benefits and limits of each technology being assessed individually. The figure below shows losses and total connection cost of DG for different ANM connection solutions.



Paper **0279** proposes the use of the Virtual Power Plant (VPP) concept aggregating micro CHP and PV domestic generation together with flexible demand and storage in order to manage power flows in low voltage networks. Paper **0827** contrasts voltage control concepts based on conventional and improved compounding as well as the concept of controlling the voltage in an optimally chosen node. Paper **0059** discusses Power Factor correction methods and demonstrates the impact on improved voltage profile, release of network capacity and reduction in losses in an electric distribution system in Egypt. Paper **0989** presents the analysis of the impact of a wind farm on the local 30kV distribution network. Results conclude that the impact of the wind farm on the voltage profile mainly depends on the reactive power control strategy and suggests that a variable power factor, rather than fixed power factor, based voltage control strategy would improve the ability of the network to absorb distributed generation. Paper **0840** shows that coordinated control of reactive power can be utilised to control feeder voltages within acceptable limits, reduce power losses and increase the amount of active power generation that can be fed into an existing network.

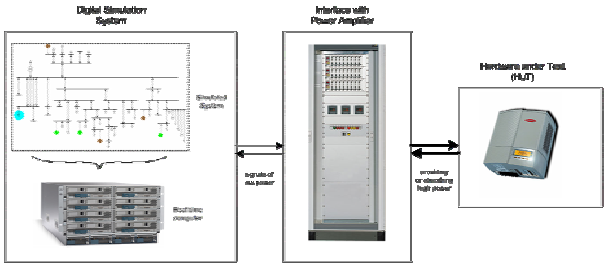
Multi-energy systems are considered in four papers. Paper **0344** optimises operation of a multi-carrier energy system that serves the local area. An integrated optimal power flow for the micro-grid was formulated and simulation results highlight a number of advantages of this approach. Paper **0664** considers the impact of plug-in electric vehicles in planning of hybrid systems. The presented case study deals with optimal sizing of an autonomous wind-fuel cell hybrid power system, for which a particle swarm optimization embedded in the stochastic modelling was

used. Paper **0965** discusses the impact of future energy demand in a German Metropolis on distribution networks considering application of electrical heat pumps and micro CHP plants. The figure below shows the drivers and that should be considered to estimate the impact of technologies. It points out that a strong interconnection between thermal and electrical energy demand will be critical for understanding the impact on the power flows and voltage profile of distribution networks.



Paper **1215** describes an 'energy hubs' modelling method and discusses how they can be manipulated to replicate the flexibility within them for the overall benefit of the hybrid energy system

Advanced ***hardware and software tools*** are discussed in three papers. Paper **0579** highlights the need for new approaches to operational planning in smart distribution networks using near real-time network simulation. The proposed concept is illustrated using a real example distribution system. Paper **0325** presents experience from the construction of a Smart Grid research, development and demonstration platform. The facility is developed within scalable AC/DC network infrastructure and it consists of a small solar, wind and fuel cell-plant with battery, super capacitor and hydrogen energy storage systems and is used to illustrate benefits of alternative technologies. Paper **0437** discusses a wide range of applications for power hardware-in-loop (PHIL) facilities including interface algorithms and options for improvements. An overview of a PHIL configuration is shown in the figure below. The paper develops a probabilistic planning approach for integration of wind turbines into MV distribution networks.

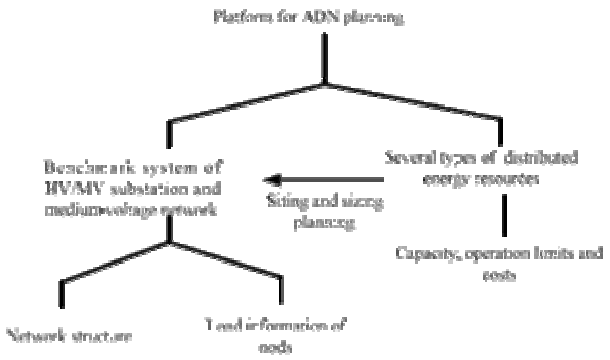


There are 4 papers that discuss ***practices for integration of DER*** adopted by several utilities. Paper **0713** discusses strategies, methods and experiences for the integration of DER into the LV and MV distribution network developed by ENEL (Italy). These include a variety of solutions to connect increased levels of DG within the existing network. Paper **1143**, discusses the approach taken by ESBN from Ireland that focuses on loss-inclusive network investment with CO2 and reliability benefits. Paper **1277**, explains the practical planning limits for DG on distribution circuits as used in the US. It advocates application of sequential-time power flow simulations of multi-phase distribution models, as being particularly important for capturing the response of voltage regulating equipment on North American 4-wire multi-grounded neutral distribution system to DG output variations. Paper **0715** discusses the situation of the Italian electricity system with an emphasis on keeping the technical standards of quality of supply while operating an active network. Paper **0787** describes the Smart Grid Model Region Salzburg (SGMS; see Figure below) as a flagship project in the real environment. This strategy is founded on a portfolio of RD&D projects in the field of Smart Grids, which were accepted for funding recently.

In paper **0930**, the authors apply a systematic approach to evaluate the hosting capacity of the Italian LV distribution networks according to the most significant technical constraints: thermal limits of transformers and lines, steady-state voltage limits and fast voltage variations.

Two papers consider ***reliability*** performance of the network with distributed generation. Paper **0567**, investigates the impact of grid-connected DER on

distribution system reliability. The figure below shows a structure of active distribution network planning platform.



Paper **0153** discuses the extent to which distributed generation can mitigate the risk of interruptions as an alternative to the existing guidelines for assessing the capacity credit, which could be assigned to distributed generators.

Commercial Arrangements to support active network management are discussed in 4 papers. Paper **1186** proposes simplified multi-criteria assessment of Principles of Access options based on engineering judgement with a view to promoting discussion. Recommendations are presented, based on the assessment undertaken and discussions with industry partners, which are relevant to Governments, regulators, network operators and users of the network. Paper **1173** demonstrates that real-time control can optimise revenues from a distributed generation portfolio. DER integration under the new network operation and market paradigm is discussed in Paper **0670**. Paper **0928** presents a multi-criteria approach to the development of strategies for enhancing the integration of distributed generation. This includes consideration of technical, economic, social and environmental aspects.

Potential scope of discussion

A number of papers discuss stability, protection and power quality in distribution networks with DER. To what extent it may be practically desirable to coordinate protection systems through communication infrastructure in order to increase the ability of the network to absorb more DER? Imbalance of load among the phases seems critical for voltage and loss profile of LV networks. What are the emerging technologies that may offer a cost effective solution to this problem?

A significant number of papers discuss the opportunities and benefits of active network management and developments of software and hardware applications to facilitate the new operation paradigm. What are the key barriers for the practical implementation of alternative active management techniques? Are there concerns associated with possible degradation in reliability and service quality? Are the commercial arrangements adequate?

Papers on Multi-energy system point out the need to consider interactions among energy vectors. How significant are the benefits of such a coordinated approach? How could this be practically achieved given the separation in ownership and management of different energy vectors and between energy and network functions?

A number of papers present experiences and approaches from various jurisdictions in relation to network control, operation and design challenges, technology solutions and emerging practices. What are the key drivers that are relevant for setting out the policy and regulation associated with the future development of distribution networks?

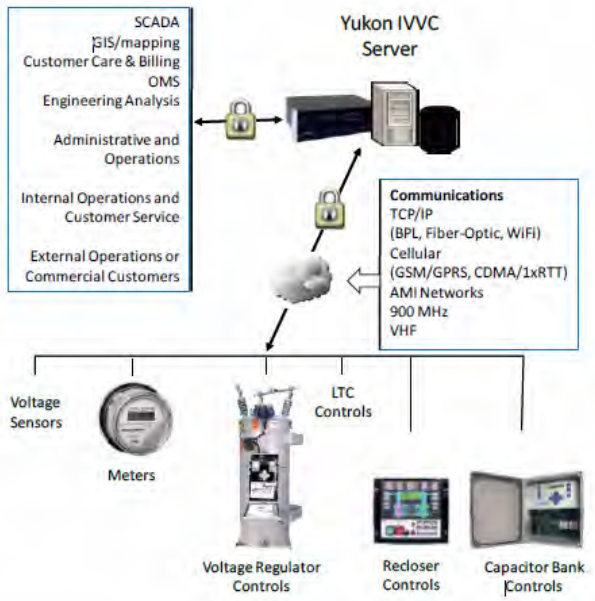
Table 1: Papers of Block 1 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0023: Wind Integration Study for a Small Islanded Power System				
0059: Experimental Simulation to Evaluate the Impact of Reactive Power Control on Distribution Networks Voltage and Energy				
0153: The value of distributed generation for mitigating network risk				
0279: Virtual Power Plants of Micro CHP Units Combined with Active Components Reducing Peak Loads and Load Fluctuations			X	
0285: An assessment of the economic impact of active network management alternatives				
0325: Experience from construction of a Smart Grid Research, Development and Demonstration platform	X			
0344: Integrated Operation of an Energy MicroGrid with Islanded Electricity Network			X	
0370: Study of the Out-of-Phase Connection of Distributed Generators				
0432: Short Circuit Behavior of Distribution Grids With a Large Share of Distributed Generation Units				
0437: Power Hardware in the Loop Simulations for Distributed Generation				
0567: A platform for case study of active distribution network planning				
0579: The Need for Operational Planning in Smart Distribution Grid Using Near Real-Time Network Simulation				
0583: Analysis of the Effect of Shanghai EXPO Electric Vehicle Charging Station on Urban Grid Power Quality				
0610: Towards efficient rules for quantifying the impact of distributed generation on the functionality of traditional distribution protection systems				
0664: Considering impacts of plug-in electric vehicles in planning optimal hybrid systems			X	
0670: DER Integration Under New Grid and Market Paradigms				
0713: Strategies and Methods for the Optimal Integration of Distributed Generation Plants into the LV and MV Distribution Network: Enel Distribuzione Experience			X	
0715: The distribution networks and the large diffusion of renewables power plants: the situation of Italian electric system.	X			
0787: Smart Grids Strategy for Salzburg, Austria				
0827: Improved grid integration of distributed generation in existing network structures				
0840: Smart grid measures to reduce losses in distribution feeders and increase capacity to integrate local small hydro generation	X			
0864: Performance Assessment of Distributed Generation units to Enhance Loadability of Distribution Network under Uncertainties				
0928: A Balanced Scorecard Approach for the Enhancement of Distributed Renewable Penetration Limit in Isolated Networks	X			
0930: Hosting Capacity of Italian LV Distribution Networks				
0965: Analysis of Network Requirements based on an Estimation of the Future Energy Demand for a German Metropolis				
0989: Voltage profile analysis in 30 kV network after connection of wind power plant				
1100: Probabilistic planning for a higher integration of wind turbines to MV distribution networks.			X	
1143: Maximising Benefits to Customers from Utilities Losses Management - an ESBN Perspective				
1173: Optimization of revenues from a distributed generation portfolio: a case study				
1186: Commercial Arrangements to Facilitate Active Network Management	X			
1215: Assessment of the affect of different energy mixes on highly distributed local energy networks			X	
1226: Analysis and Reduction of Effects of Single-Phase Loads and Generators on Low Voltage Distribution Grids				
1277: Determining Practical Planning Limits for DG on Distribution Circuits				

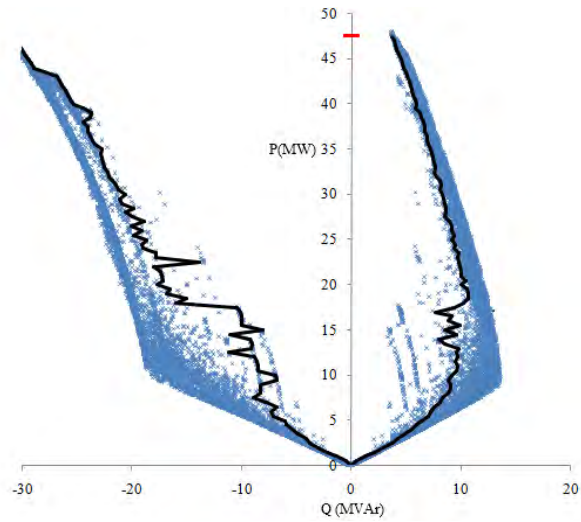
Block 2: *Control of networks with DG/DER*

This block brings together papers with a focus on control of distribution networks with DG/DER. Voltage control features highly along with smart grid projects with DG/DER control emphasis but there is a breadth of papers covering several other aspects of DG/DER operational control.

On the topic of ***voltage control*** for networks with DG, paper ***0171*** sets out practical considerations for implementation of a coordinated voltage control approach with state estimation. It is concluded that hosting the voltage control algorithms on a Distribution Management System (DMS) platform provides advantages for DNOs. Paper ***0208*** also picks up the theme of a centralised DMS based approach to voltage control and presents the results of analyses to ascertain the most effective solution using state estimation. The study concludes that voltage control for circuits with DG is best achieved through control of on-load tap changers only and this approach is now to be field trialled. Paper ***0510*** presents the results of analysis of a centralised automatic voltage control approach based on state estimation in a case study network in Portugal. Paper 0518 presents an integrated volt/VAR control (IVVC) system with results from a field deployment in the US. The system diagram shown below illustrates the scope of the controlled devices and other system features.



The issue of voltage control is further addressed in paper ***0707*** where the aggregation of reactive power capability from DG and their aggregate impact on the higher voltage level systems is examined. Measurements from four operational DGs are used to characterise the PQ characteristics of DG in the study and an example of this characterisation is shown in the figure below.



Paper ***0762*** proposes a localised optimal control of voltage in distribution networks with DER by controlling feeder sending end voltage and DER reactive power. The results show the effect on DG interconnection capacity within voltage limits and the effect on system losses for a case study system in Korea. Paper ***0934*** presents an approach for voltage control based on local control of DG reactive power. The paper concludes that a variable reactive power method for DG enhances the hosting capacity for DG in the presence of voltage constraints.

Paper ***0969*** provides a comparative assessment of voltage control methods through simulation in a typical German low voltage case study network. The paper concludes that MV/LV substation tap change control and reactive power control at LV connected DG units provide some headroom for DG connection but have limitations and drawbacks and that other voltage control methods need to be considered alongside these methods.

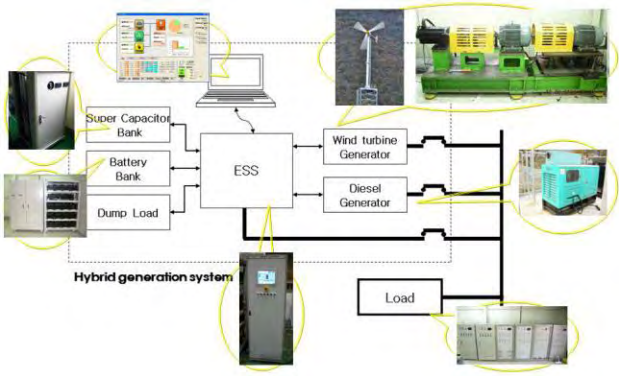
On the topic of ***scheduling and dispatching DG***, paper ***0174*** sets out a method and case study results for a cost minimisation DG dispatch incorporating losses, OPEX, CAPEX and distribution use of system tariffs. The results show that actively scheduling DG operation can lead to reduced economic costs. A price based DER scheduling approach is proposed in paper ***0788*** which relies on forecast demand and price. While the results are for heat storage DER units the technique seems more broadly applicable to other DER unit types. Practical issues with the approach are discussed.

On the issue of ***losses minimisation*** in active networks with DG, paper ***0247*** sets out a case based reasoning approach which has been demonstrated in research labs. The paper sets out early results from simulations and lab tests and describes further developments necessary. Paper ***0324*** combines the voltage management and losses minimisation

objectives into a Sequential Linear Programming method which is applied to the IEEE 37 node test feeder system and found to be both fast to compute and accurate in terms of result obtained.

On the topic of ***active network management*** more generally, paper ***0497*** proposes the use of synchrophasor measurements to support DMS in managing angle constrained DG and also as an alternative means of estimating real time ratings for overhead lines.

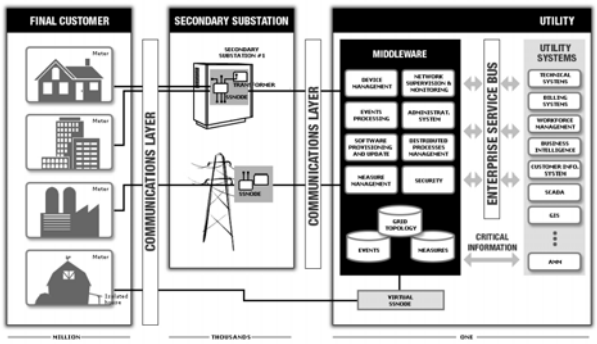
On the topic of ***microgrids***, paper ***0207*** presents the results of simulations of different DG portfolios in a microgrid and the effect of demand management and energy storage on the energy autonomy of the microgrid. Paper ***0381*** presents results from tests in the Korean microgrid test facility (shown below in island configuration) where voltage and frequency are tested in island configuration. The paper shows clearly how battery energy storage provides positive impacts for the microgrid voltage and frequency performance. Paper ***0655*** describes the modeling and simulation of voltage dynamics in microgrids using the reactive power control capabilities of Doubly Fed Induction Generators (DFIG) with optimally tuned control parameters.



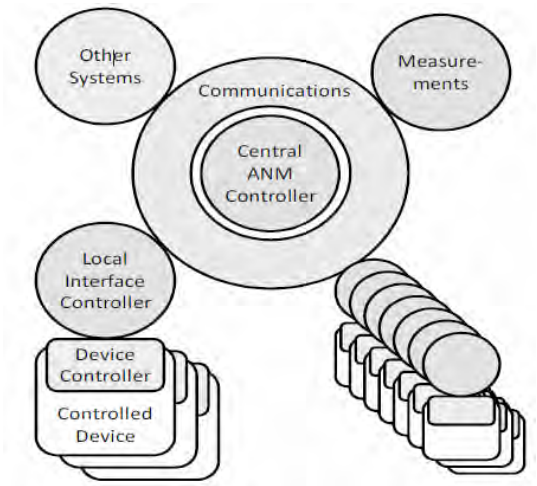
Related to the microgrid is the concept of the ***Virtual Synchronous Machine (VSM)*** which is assessed in paper ***0359*** where simulation results show the effect of power/frequency and reactive power/voltage droop controls on distribution system performance in both grid connected and island configuration. The paper concludes that the VSM is an effective method of control of inverter connected DG/DER. Paper ***0535*** presents results of VSM studies and draws conclusions on the costs, benefits and performance of a VSM approach to converter control in microgrids.

The management of ***power quality*** in distribution systems with DG and load connections through the use of voltage source converter interfaced energy storage systems is assessed in paper ***0331*** where results showing the improvement potential are presented.

The ***smart grid*** concept is taken up in paper ***0246*** where the drivers of the low carbon smart grid in the UK are reviewed and a method for the development of demonstration projects is set out. Paper ***0465*** describes an ongoing smart grid demonstration project in Italy and sets out in detail the required functionality, the hardware and software changes at each level of the distribution system and the expected benefits for the network. Paper **0530** presents a collaborative international smart grid demonstration programme and sets out the criteria for projects to become part of the programme. The future focus areas are presented: Conservation Voltage Reduction and Volt/VAR Optimization; Distribution Management System (DMS) Integration and Visualization; Energy Storage Monetization; and Consumer Behavior and Engagement. Paper ***0770*** proposes an open approach for secondary substations communications and control architecture (shown below) and describes the OPENNODE concept which is currently under development.

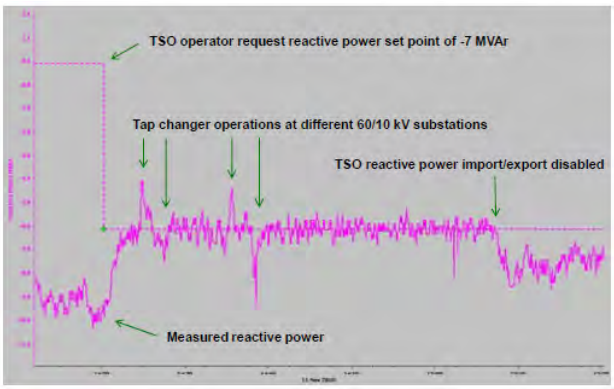


Paper ***1124*** provides details of project components and active network control functions in a major smart grid demonstration project in the UK in an area with high renewable energy development resource and activity. The network management approach proposed is illustrated below.

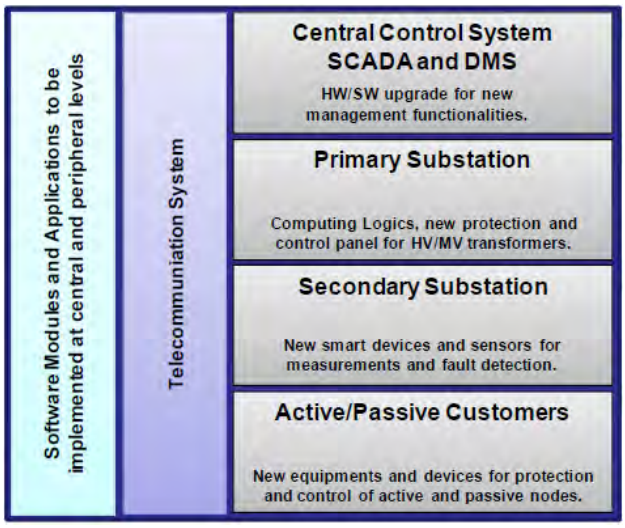


Continuing on the smart grid theme and with a focus on more larger more mature projects, paper ***1187*** provides an update on recent developments and performance of the

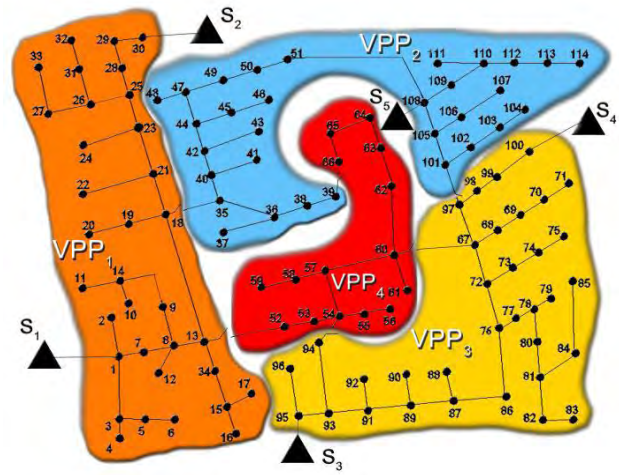
Orkney (UK) smart grid. Several aspects of the development and operation of the active network management system are discussed. The real operational experience of this innovative approach to system development and management is worthy of note. The development and assessment of a dynamic line ratings function for integration into the Orkney smart grid is presented in paper ***1245***. The generation constraint reduction provided by real time line ratings is calculated and the results are promising. The plans for the major, recently started low carbon smart grid demonstration project in London (UK) are presented in paper ***1192.*** The objectives of the project are set out and the planned system deployments are described. Paper ***1221*** provides an update on the Cell Controller smart grid demonstration project in Denmark. The functions of the Cell Controller are set out and the results from field testing in 2010 are presented. These show performance in line with expectation. One illustrative result for VPP reactive power control is shown below.



Paper ***0521*** presents a discussion of the use of ***energy storage*** to manage distribution system peaks, firm renewable generation, regulate frequency and avoid/defer network reinforcement. Pointers on matching battery technology to application are provided. Paper ***1051*** presents an analysis of the effect of energy storage on roof mounted Photovoltaic (PV) DER and concludes that as well as providing additional capacity for PV connection in distribution systems there are other benefits such as backup power and power quality. One interesting conclusion is the need for good forecast data to best schedule the operation of the storage devices to achieve the best outcomes.



Paper ***0397*** deals with the topic of ***virtual power plants*** and presents the case for decentralized energy management with considerations of the functional modules required. Paper ***0810*** goes further and provides a detailed analysis of a Locational Marginal Price based approach to scheduling DER units in a 114 node case study network with four VPPs as illustrated below. The results demonstrate some relatively complex interactions of the four VPPs at different stages of the simulated period..



The VPP concept is further demonstrated through a trial deployment project presented in paper ***0874***. The VPP components are tested in the Slovenian distribution system with controllers installed at five sites with monitored data from one site illustrated below. The next steps in the project include development of more advanced functionality.

On the topic of ***electric vehicle (EV) charging***, paper ***0974*** discusses the objectives and possible methods for coordinating EV charging. A multi-agent systems approach is proposed and considerations for implementing such a system are presented.

Potential scope of discussion

Several papers deal with the issue of voltage control in active networks with DG/DER but conclusive outcomes or convergence of thinking on the most worthwhile methods is not evident. From the current set of papers and the many paper already in the archive on this topic, what conclusions can be drawn on the best methods for voltage control in different voltage level networks?

Some papers deal with the microgrid concept and present worthwhile results for methods of control within a microgrid. How wide is the applicability of these methods? Is there evidence that the microgrid concept and the related technology is finding its way into the smart grid mainstream?

Several papers present results from existing smart grid demonstration projects and several new smart grid demonstration projects are highlighted in other papers. What are the performance measures to be applied to smart grid trial deployments? How can the results from quite different projects be brought together in a rigorous way to develop consensus in a very broad topic area? What are the most valuable specific smart grid functions?

The Virtual Power Plant concept is explicit and implicit in many papers in this block. What is the evidence that the general concept has achieved acceptability? Given the many different techniques to deliver VPP functionality what is the consensus on the most appropriate approaches?

Table 2: Papers of Block 2 assigned to the Session

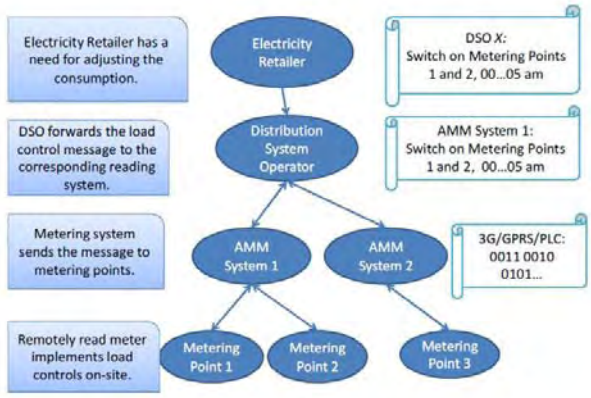
Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0171 Coordinated voltage control as a part of distribution management system				
0174 Planning of Distributed Generation Dispatch in Distribution Networks				
0207 Micro Grids in Austria? Results of ADRES Concept				
0208 Technical and Economic assessment of possible centralised voltage control functions in presence of DG in the French MV network				
0246 Developing a Smart Grid Trial Site in the UK				
0247 A Case for Losses Minimisation in Active Network Management Systems				
0324 A control method of Distributed Generators in Smart Distribution System considering system loss and voltage			X	
0331 Research on the Control of Energy Storage System parallel connected to the grid				
0359 Parallel operation of virtual synchronous machines				
0381 Voltage And Frequency Stability Enhancement Of The Islanded Microgrid Using Battery Energy Storage	X			
0397 A Decentralized Energy Management System for Efficiency Improvements of Distributed Energy Resources				
0465 Advanced management of Distributed Generation on MV network				
0497 Connection and Management of Distributed Generation using Synchrophasor Measurements and Advanced Distribution Management Systems (DMS)			X	
0510 The Application of Distribution State Estimation to Support a Real-time Voltage Control Algorithm: A path to increase the integration of distributed generation				
0518 Volt/Var Control for Smart Grid Solutions				
0521 Smart Power Applications and peak load management in distribution networks with Energy Storage Solutions			X	
0530 International Collaboration of Smart Grid Demonstration Projects Integrating Distributed Energy Resources	X			
0535 A Converter Controller of Virtual Synchronous Machine for Stable Operation of Microgrid				
0655 Modeling and Optimal Control of Reactive Power in a Microgrid Using Doubly Fed Induction Generator				
0707 Effect of Energy Harvesting Network Reactive Support on Transmission System Voltage Performance			X	
0762 Interconnection Guidelines and Control Coordination of Reactive Power Support Functions of Distributed Energy Resources				
0770 OpenNode. Open Architecture for Secondary Nodes of the Electricity SmartGrid				
0788 Indirect regulation of many DER units through broadcasted dynamic price signal			X	
0810 Energy Resources Scheduling in Competitive Environment	X			
0874 Intelligent power system platform for supervision and control of distributed generation and customer demands - SUPERMEN				
0934 MV networks with Dispersed Generation: voltage regulation based on local controllers			X	
0969 Analysis of Various Voltage Control Methods for Low Voltage Networks with Distributed Generators				
0974 Classification and comparison of multi agent based control strategies for electric vehicles in distribution networks				
1051 Optimised operation strategies for energy storages in low-voltage grids with a high degree of decentralized generation				
1124 The Shetland Islands Smart Grid				
1187 Operating the Orkney Smart Grid: Practical Experience	X			
1192 London Carbon London - A Learning Journey				
1221 The Cell Controller Pilot Project: From Surviving System Black-out to Market Support	X			
1245 Preliminary findings from deployment of a dynamic line rating system on Orkney Islands				

Block 3: Customer side developments

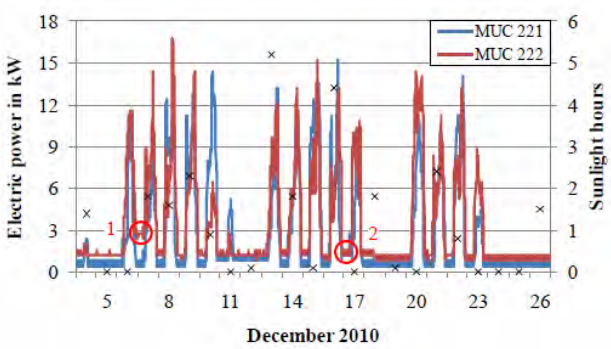
This block brings together papers around the general theme of customer side developments including those in the areas of smart metering, demand response, energy efficiency and electric vehicles. There is a mix of concepts and computational analyses and modelling exercises with implementation architectures and designs and field trial results.

On the topic of ***smart metering***, paper **0018** describes three uses of smart metering infrastructure in distribution: demand response; distribution system asset management, and; power quality monitoring and outage management. The value of the smart meter as a remote distributed sensor for the network company is highlighted. Paper **0832** describes the design and role of a smart meter designed to act as the hub for home energy control and as the interface to smart grid control in the context of a new project in Italy. The paper provides detailed functionality and architecture information. Paper **0833** describes the use of demand meter data in a scenario based load prediction tool for network planning based on a clustering and mapping technique. Paper **1083** describes the power snapshot technique for analysing high resolution metering data in LV networks and concludes that this is a valuable approach to undertake analysis of load and performance of LV grids and provides a useful way to build and validate accurate models of LV networks.

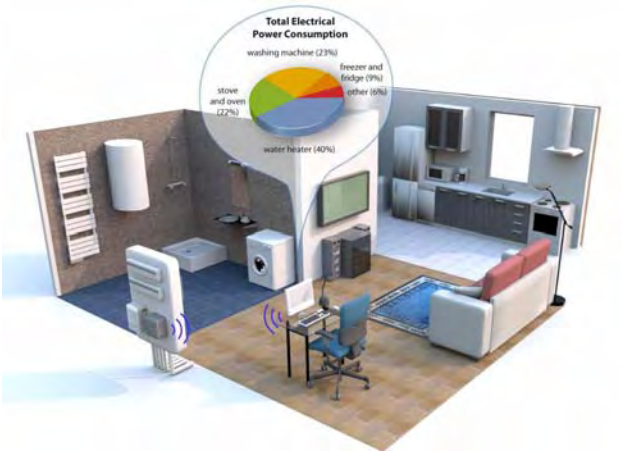
On the topic of ***domestic heat pumps***, paper **0125** presents an approach and the results of characterisation, prediction and management of domestic heat pump demand. The paper shows that there is potential for management of heat pump demand with greater potential for water heating applications over space heating applications with the aid of a buffer water storage tank. An assessment of residential heat pumps with heat storage is presented in paper **0442** with particular emphasis on the additional grid flexibility provided. The relationship of flexibility (measured in hours) with storage tank volume and temperature is presented. Paper **0796** describes a market price based approach to control of electric heating loads (illustrated below) and describes how this is facilitated through smart meters with control functionality. The concept has been field tested and initial positive results will be verified through a further winter heating season in 2011/12.



On the topic of ***energy efficiency***, paper **0131** describes measures introduced at a German university data centre to reduce electrical demand for air conditioning and the role of smart metering in enabling this. The insights into data centre demand and efficiency measures are a valuable contribution. The illustration below shows the demand pattern in two data centre rooms with variation due to usage and sunlight.



Paper **0287** presents a statistical analysis of residential energy efficiency based on hourly data from automated meter reading data sets and additional survey data. The paper points out that while there is high value in the analysis of available data there are challenges such as capturing the effects of location of plug-point electronic devices and the impact of cheap overnight electricity rates on customer behaviour. Paper **0408** describes a consumer focused analysis of energy consumption based on smart meters data analysis on a mini-PC. The authors conclude that the analysis could be moved onto the smart meter in future and that this type of analysis of individual energy usage by specific devices underpins effective decision making on energy efficiency. A schematic of the system is illustrated below.

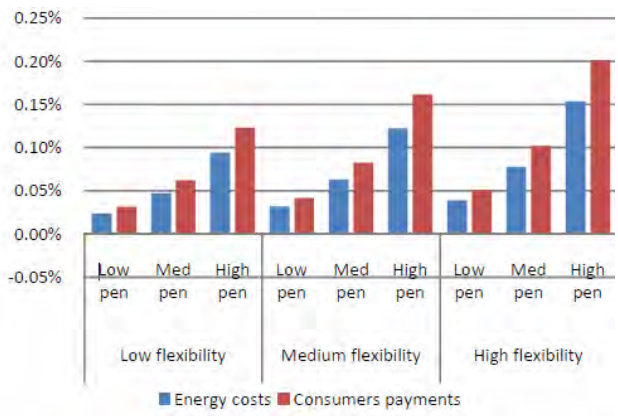


Paper **1046** addresses energy efficiency in supermarkets and assesses two development options (*smart-grid* and *off-grid* both with self-generation and demand management features) including the criteria of cost and carbon emissions.

On the topic of ***demand response*** (or demand side management), paper **0241** presents the results of studies to assess the potential for demand response in non-residential buildings. The assessment which focused on climate control and cooling concludes that there is potential for demand response utilising existing building automation systems and that the main factors in the potential are building and customer type. Paper **0743** describes an network expansion model based economic assessment of demand response. The paper emphasises the network investment reduction benefit from a load reduction programme and examines the tariff and elasticity effects on the outcome.

Paper **0865** describes the trial deployment of a commercial building focused demand response programme in Spain which has shown that management of heating, ventilation and air conditioning (HVAC) loads provides good demand management potential. The paper offers several practical outcomes of the project including the in-service experience of trial load management events. Paper **0904** presents results of simulations to quantify the impact of consumer appliance flexibility and shows that while tariff design is an important factor in the flexibility, the amount of appliance flexibility does not necessarily result in customer benefit.

Paper **0958** examines the potential for demand response in Germany through analysis of a relatively large case study area and detailed assessment of the different customer groups. The paper concludes with a clear technical potential for a large amount of demand response across the customer groups but that financial incentives and an ICT infrastructure are prerequisites for successful implementation. Paper **1049** addresses the participation of responsive domestic wet appliances in electricity markets and takes uses optimisation to settle the problem with appliances represented by agents in the simulation. The paper presents the analysis of a case study where flexibility and penetration are among the variables. The results are illustrated below showing the modest customer cost and payments reduction achieved.

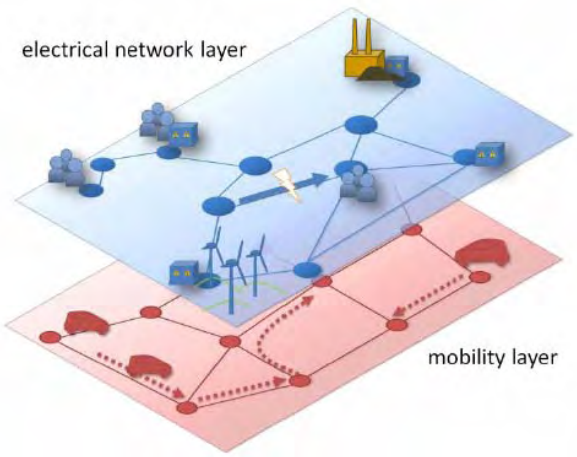


Paper **1166** presents results of a modelling approach to assessing demand response from HVAC systems. The approach draws on detailed building thermal modelling tools and shows that building comfort levels can be maintained while effecting valuable electrical demand peak reduction. Paper **1291** brings together demand response with other smart grid functions and reports results of a field trial of the PowerMatcher concept. The results presented are significant and future issues are identified with such integrated and intelligent smart home to smart grid approaches.

The use of ***heat storage*** as a means of providing flexibility and control of electrical generation and demand is dealt with in paper **0336**. The results of a trialled control approach for a combined heat and power with heat storage system are presented. Paper **0671** compares four different control modes for a combined, small scale cooling and power generation system through a series of simulation experiments.

This idea of electrical thermal demand and thermal storage management is tackled in paper **0481**. The provision of tertiary frequency response by managed heat demand and the role of this in the ancillary services market is presented. The smart grid infrastructure required as well as the control algorithms to fit with the Swiss ancillary services market are described in detail and the authors conclude that there is good potential for this solution.

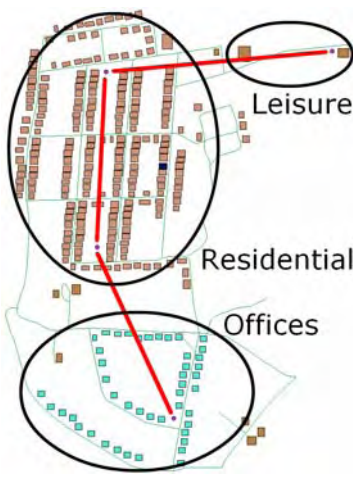
On the topic of ***electric vehicles*** (EV), paper **0686** describes the development of an integrated mobility and grid model (illustrated below) to examine the vehicle charging strategies. The paper makes the case for very detailed spatial and temporal data to provide an accurate view of the impact of EVs and the different charging strategies.



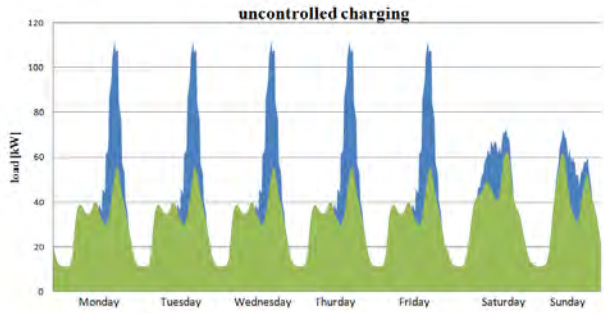
Paper **0701** also examines the impact of EV charging on the distribution system by using a Monte Carlo model of vehicle movements (in this case plug-in EVs) and battery deficit at the location and time of charging. The conclusion drawn is that with uncontrolled charging the reinforcement requirement for power networks will be significant.

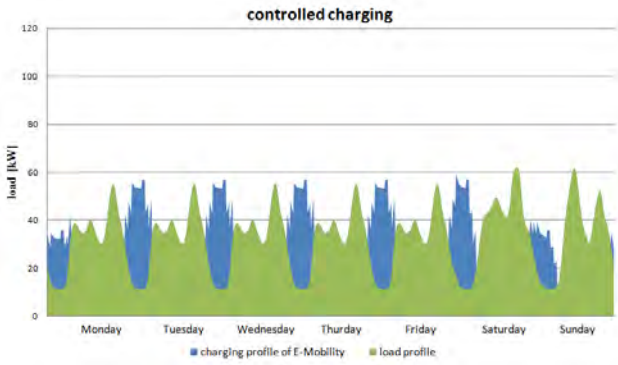
Paper **0865** presents results of simulations of different pricing approaches to shape the charging schedules of EVs. The simulation results show that there are benefits of response to dynamic pricing through reduced demand in high prices periods but that there are significant 'inrush' effects of charging during low price periods with the conclusions that this effect needs smarter management.

Paper **1042** describes a combined agent based modelling and optimal power flow approach for studying the potential for demand response in electric vehicle charging. The agent based modelling model provides a rich input of vehicle movements and charging needs. The combined modelling concept is demonstrated on a case study as illustrated below.



Paper **0806** examines the impact on distribution networks of ***photovoltaic*** (PV) and ***electric vehicle*** development and establishes the limits of PV penetration with reactive power control and the impact of controlled charging of the EV (illustrated below).

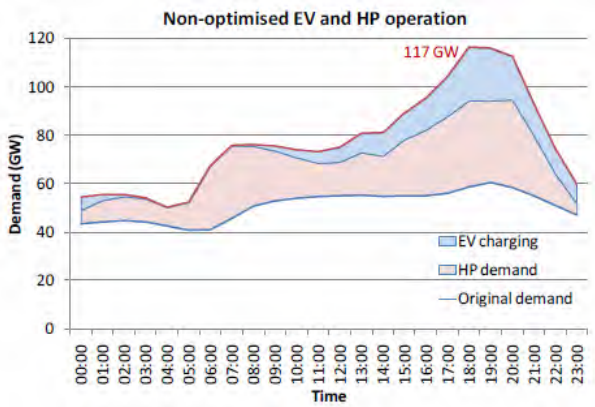


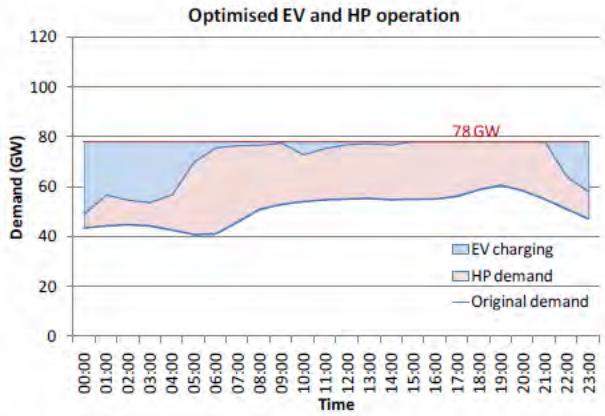


Paper **1104** also looks at charging strategies for EVs with the purpose of optimising distribution system planning and operation. An OPF technique is used to meet vehicle utilisation constraints and minimise distribution losses and meet network constraints. The optimal charging approach is shown to increase the permitted penetration of EVs and reduce system losses.

Continuing on the topic of ***electric transportation***, paper **0651** describes the concept of diesel-electric rail locomotives with flywheel or super-capacitor energy storage to increase the energy efficiency through regenerative braking and managed utilisation of the diesel engine. Combined with fully electric trains, the energy efficiency is shown to be significantly enhanced in analysis of a case study with a particular itinerary of train movements.

Paper **0710** combines the analysis of the impacts of electrical heating and electric vehicles on the power system and studies the costs and benefits of uncontrolled and demand managed approaches showing that there are substantial net benefits to the active control approach. The following figures illustrate the difference between the uncontrolled and optimised approaches at the national system in the UK.

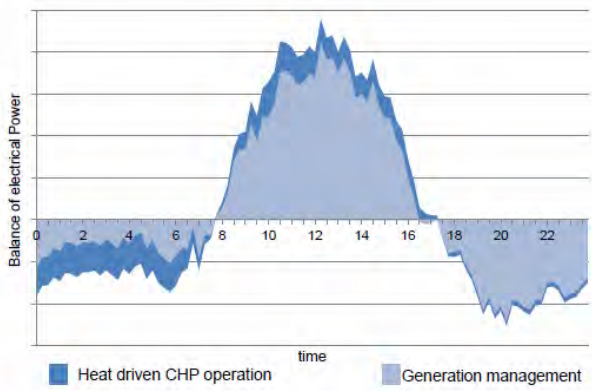




On the topic of ***commercial arrangements*** for DER/DG connection, paper **0662** proposes new commercial arrangements for Croatia including producer and consumer metering, utility metering, calculations and interconnection standards.

Paper **0683** describes a hybrid, small scale wind and solar system for ***public lighting*** in remote areas. The system is under test at present and a monitoring programme is underway to establish the performance of the system. Initial results

Paper **0835** brings together the modelling of CHP, renewable energy, energy storage and heat pumps and makes the case for optimised active management of the components. The illustration below shows the net electrical power requirement based on two operational modes for the CHP unit with the obvious reduced impact (both positive and negative) when electrical generation is managed.



Paper **1080** looks at the operation of grid oriented CHP units for domestic energy supply and presents the initial results of a field trial. The results show that a reduction in net demand at the site is possible through smart control of the CHP unit.

Potential scope of discussion

Several papers deal with the topic of smart meter data capture and analysis for customer and distribution system focused analysis. There are issues of data volume, ownership and privacy as well as analysis techniques and deployment of results for planning and operation of the distribution system as well as for customer efficiency and response. Discussion in this topic would be valuable in the areas of standardization of smart metering architectures, device functionality and processes for data capture and use for customers and distribution companies. Large scale trial design and integration of results from trials when smart meter roll-out gathers pace across many countries are topics where discussion at this stage might prove valuable.

Demand response is dealt with in many papers in this block and there seems to be some consensus that demand response from heating, cooling and wet appliance loads offers most potential benefit with heat storage providing additional benefits. The role of ICT technology and pricing and incentive mechanisms are touched upon several times and consensus in these areas is a worthwhile topic for discussion.

Electric vehicle charging scheduling is a topic in many papers in this block and there are positive results for the prospect and overall effect of intelligent approaches to scheduling charging. The modeling approaches appear to be relatively sophisticated already but questions remain about the reality of the modeled benefits when there is relatively little field experience of vehicle charging methods and far less where intelligent approaches to charge scheduling have been deployed.

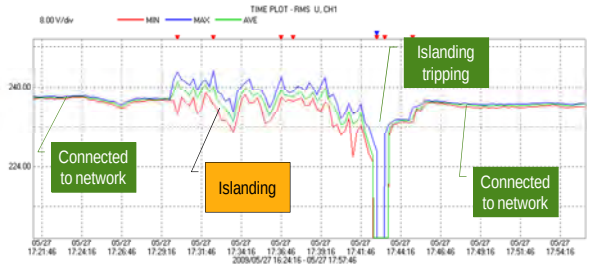
Table 3: Papers of Block 3 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0018 Strategic use of smart meters data and AMI capability to develop advanced smart grid applications				
0125 Electrical load characteristics of domestic heat pumps and scope for demand side management		X		
0131 Efficient utilisation of electrical energy in the data centre of the HS Augsburg by using smart metering				
0241 Potential of Demand Side Management in nonresidentual Buildings			X	
0287 Energy Efficiency Analysis of Residential Electric End-Uses: Based on Statistical Survey and Hourly Metered Data				
0336 Innovative Heat Storage Management by Object Oriented Control				
0408 Automated electrical energy analysis for domestic consumers based on smart meters			X	
0442 Exploring the flexibility potential of residential heat pumps combined with thermal energy storage for smart grids.				
0481 Flexible Thermal Load Management for Ancillary Services Market: Experience of Swiss Smart Grid Pilot Project		X		
0651 Energy Efficiency, Storage and Generation in a Railway Electrical Distribution System Through Hybrid Diesel-Electric Locomotives				
0662 Initiative to improve approach to eligible electric energy producers				
0671 Energy Optimization Management of Combined Cooling and Power Distributed Energy Supply System with Micro Turbine				
0683 Monitoring of Hybrid Power Supply System for Public Lighting				
0686 Integrated analysis of traffic and power flows				
0701 Demand Side Management for Domestic Plug-in Electric Vehicles in Power Distribution System Operation				
0710 Investigation of the impact of electrifying transport and heat sectors on the UK distribution networks		X		
0743 Demand Response and Network Reconfiguration on Distribution System Investment Deferment				
0796 Market price based control of electrical heating loads				
0806 Impact of an increasing penetration of urban photovoltaic systems and electric cars on the low voltage networks			X	
0832 Smart info and energy@home: the solution tool to address and assess customer participation to the energy market				
0833 Scenario based electricity load prediction tool for distribution planning and management				
0835 Modelling approach to assess the impact of heat and electricity storage on distribution systems				
0865 Demand Response in practice: OPTIGES project final results and lessons learned			X	
0898 Distributed generation and electric vehicle integration (VERDE project)				
0904 An assessment of demand-response flexibility on household level				
0958 Demand Side Management Potential A case study for Germany		X		
1042 Integrated Modelling of Agent-Based Electric Vehicles into Optimal Power Flow Studies				
1046 Innovative Strategies to Increase Energy Efficiency and Economic Performance in Supermarkets				
1049 Decentralized, Agent-Based Participation of Load Appliances in Electricity Pool Markets				
1080 Field test of grid oriented CHP micro units for the domestic energy supply		X		
1083 Power SnapShot Analysis: A new method for analyzing low voltage grids using a smart metering system				
1104 Scheduling Charging of Electric Vehicles for Optimal Distribution Systems Planning and Operation			X	
1166 Thermo-electrical load modelling of buildings for assessment of demand response based on Heating Ventilation and Air Conditioning (HVAC) devices			X	
1291 Field-testing Smart Houses for a Smart Grid				

Block 4: DG/DER Technology

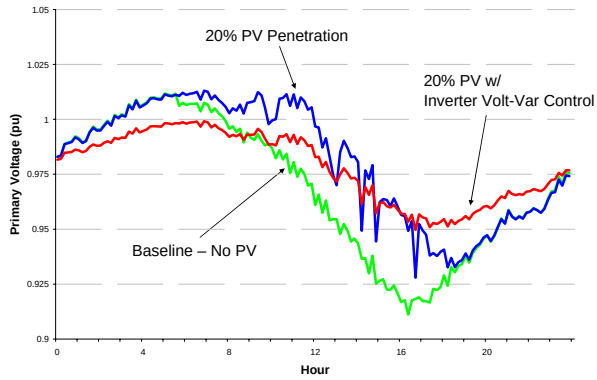
The scope of this block covers technologies and solutions that would enhance the capabilities of the system to integrate increased amounts of distributed generation and load growth as well as the DG/DER technologies themselves.

Three papers deal with the experiences with connecting ***PV generation***. Paper **0184** presents the experience and proposes improvement of islanding operation of distribution networks connecting large PV plants. The recommendations include improvements in protection systems, involving either relays or control algorithms of the inverters, development of new procedures and the use of communication systems. The figure below shows an example of voltage fluctuation.



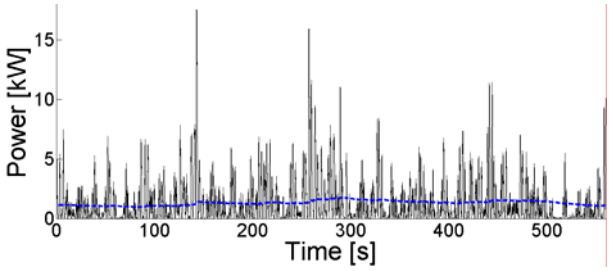
Paper **0933** presents the case of connecting 2×24 MW of PV into a 110 kV distribution system and discusses issues associated with reactive power and voltage control. Paper **0879** discusses measures that could be taken to manage large penetrations of PV generation including voltage control and network reinforcements.

Four papers deal with voltage and frequency control of ***inverter-connected generation***. Paper **0615** presents a robust control strategy of power electronics connected DG during voltage sag conditions. The analysis includes active power control and voltage sag ride-through capability showing both simulation and experimental results. Paper **0795** presents a solution of a combined power electronic and battery storage systems aimed at improving grid performance by reducing power fluctuations, changes of power flow directions and steady state voltage fluctuations. Paper **1203** demonstrates the volt-var control of PV inverters in order to reduce the voltage variations caused by the PV ramping. The figure below shows the simulated distribution feeder voltage response with high penetration of PV.



Paper **1190** presents an approach to modeling of three phase PV inverters for RMS-based grid integration studies under balanced and unbalanced conditions. Paper **1243** describes the approach to increase PV generation in the low voltage network by controlling reactive power and the potential of controllable medium to low voltage transformers. Paper **0807** analyses the benefits of employing a synthetic inertia concept associated with inverter-connected wind turbines in order to the contribute to network frequency control and stability.

Several papers analyze ***demand side management and storage applications*** in distribution networks. Paper **0180** presents a software tool for optimization of the number, type and location of storage systems in distribution network. The authors discuss a tool developed that is based on evolutionary algorithm techniques that generate storage alternatives that are then evaluated in a multi-objective framework Paper **0674** specifies the verification process for battery energy storage system grid compliance testing. This also includes performance testing to ascertain the unit power rating, energy capacity and efficiency characteristics. Paper **0702** presents a method for optimization of energy storage systems using an equivalent generator approach. The model developed allows storage systems to be readily incorporated into an optimal power flow algorithm, removing the need to prepare an algorithm especially for solving storage problems. Paper **0761** presents simulation analysis of control of consumer equipment such as electric water heaters to maximize PV generation and minimize the reverse power flow. Paper **0940** presents the application of flywheel energy storage for power quality enhancement by smoothing the power output from renewable energy converters. The figure below shows power from a wave energy converter sent into a flywheel (solid line) and the power out from the flywheel (dashed line).



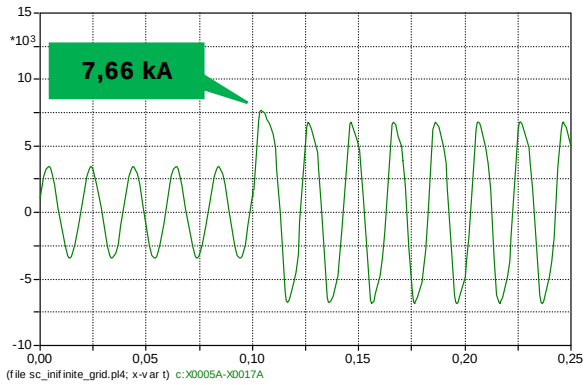
Paper **1133** presents the use of energy storage for enhancing the capability of small power systems to control frequency fluctuations. Paper **1090** demonstrates the cost effectiveness and dispatch-ability of wind power plants by using dynamic reactive power and battery energy storage system.

Advanced laboratory facilities for hardware simulation and testing relevant for active distribution networks are described in two papers. Paper **0030** outlines the laboratory testing method to determine whether the generator under test satisfies the ride through requirements with the ability to control fault / voltage dip conditions. Paper **0342** describes the laboratory implementation of the microgrid with emulated power systems managed through a dedicated communications system, which enables analysis of the impact of random changes in generation and load conditions.

Demonstration of energy storage applications for distribution networks is described in two papers. Paper **0413** describes practical demonstration of energy storage in a UK distribution network and discusses the perceived role of electrical energy storage and modeling and simulation results and preparation for the commissioning of the storage installation. Similarly, paper **0747** presents experience with battery storage systems in Shanghai Power Grid.

Several papers present techniques for maximizing the ***yield of distributed generation***. Paper **0042** presents design and implementation outputs of wind cube - a wind generation device utilizing tunnel effect in order to increase electricity generation. Paper **0129** describes the method for control of the modulation index of inverters to maximize wind output without measurement of wind or rotor speed. Paper **0528** proposes the probabilistic assessment of wind farm energy yield considering wake turbulence and variable turbine availabilities.

Two papers discuss application of ***superconductivity*** that may enhance the capability of distribution networks to absorb increased levels of distributed generation. Paper **1152** presents the role of high-temperature superconducting cables (HTC) with integrated fault current limitation (FCL) in efficient connection of large-scale DG. The figure below shows the response to a three-phase fault with a FCL HTC cable. Paper **0955** presents an inductive shielded high temperature superconducting fault current limiter.



Two papers discuss ***reduction of losses***. Paper **0248** presents s method for reduction in network losses through optimizing location, rating and control of electrolysers with respect to the location and rating of the wind farms. Paper **0269** study the impacts of a single-phase capacitor installation on reducing energy losses. This involved 431 residential consumers and resulted in the increase in the power factor from 0.83 to 0.92 and voltage level improvement from 205 to 228 volts.

There are four papers that deal with ***protection and grid compliance***. Paper **0182** simulates the operational stability of shunt circuit-breaker systems with DG. Paper **0964** describes measurement of the grid impedances and in particular the neutral line impedance in four-wire systems. Paper **0667** describes the reactive power capability and fault ride through performance of ENERCON wind energy converters. Paper **1132** describes the certification process in Germany with a focus on the extended electrical properties of PV-inverters connected to the medium voltage network.

Potential scope of discussion

A number of papers discuss alternative measures for voltage control in LV distribution networks with PV generation, including reactive power control. To what extent could reactive power control provide an effective solution to voltage rise in different LV distribution networks? What are the experiences in field trials?

A number of papers discuss the role of energy storage in future distribution networks. Under what conditions is the application of energy storage in distribution networks expected to be commercially viable? Are the commercial arrangements adequate?

What is the experience of the application of DER technologies providing system management services at distribution and transmission levels? Are the commercial arrangements adequate?

What are the key barriers for establishing grid code compliance for connection of DG of different technologies and how can new laboratory activities facilitate this?

Table 4: Papers of Block 4 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0030: Electrical Network Testing and Simulation : An effective method of testing the fault ride through capabilities of Proto-Type Embedded Generation				
0042: Design and Implementation of The 10 kw Wind Cube				
0129: Implementation of Sensor-Less Maximum Power Extraction Scheme for PMSG Small Wind Turbine Systems				
0180: Storage optimization in distribution systems			X	
0182: Operational stability of shunt circuit-breaker systems in ungrounded MV networks with distributed generation (DG)			X	
0184: Operational experience and field tests on islanding events caused by large photovoltaic plants		X		
0248: Demand Side Management Using Alkaline Electrolysers within the UKGDS simulation network			X	
0269: Impacts of single phase capacitor installation on reducing energy loss				
0342: Implementation of a Test Microgrid in Barcelona			X	
0413: Early findings of an Energy Storage practical demonstration		X		
0528: Probabilistic assessment of wind farm energy yield considering wake turbulence and variable turbine availabilities			X	
0615: Control of Photovoltaic Power Generation System During Unbalanced Grid Voltage Sag Conditions				
0667: Actual developments in the FACTS Capabilities of wind energy converters according to latest fault ride though requirements for distribution systems in Germany				
0674: Battery Energy Storage system testing for grid standard compliance and application performance				
0702: Modelling and Optimisation of Energy Storage Systems in Power Distribution Networks				
0747: Research on the Application of Multiple Energy Storage System in Shanghai Power Grid				
0761: Cooperative Control of Distribution System with Customer Equipment to utilize Surplus Electric Power of Photovoltaic Systems				
0795: SVC Light with energy storage for smart grids				
0807: Facilitating the integration of wind turbines into power networks while maintaining frequency stability				
0879: PV development in France : impact on Distribution Network and potential of innovative solutions				
0933: Integration of Large Photovoltaic Power Plants to Distribution Networks				
0940: Dynamic stability of an electricity generation system based on renewable energy				
0955: Inductive Shielded Superconducting Fault Current Limiter - An Enabler of Smarter Grids		X		
0964: Grid Impedance Determination - Identification of Neutral Line Impedance				
1058: Distribution Network Impacts of High Penetration of Distributed Photovoltaic Systems				
1064: High-Speed Bus Transfer for distribution networks with DG connected				
1067: Increasing Grid Transmission Capacity and Power Quality by a new Solar Inverter Concept in Low Voltage Grids with a high Proportion of Distributed Power Plants		X		
1090: Integrating Intermittent Wind Power on Distribution Networks Using Dynamic Reactive Power and Energy Storage				
1132: Confirmation of extended electrical properties of PV-inverters according to German MV Grid Code - Experiences in the certification process				
1133: Divergence Operator for a novel Power Systems Regulation				
1152: Efficient connection of large-scale DER with intelligent superconducting cables		X		
1190: Grid integration of photovoltaic plants - a generic description of PV plants for grid studies				
1203: Simulation of Solar Generation with Advanced Volt-Var Control			X	
1243: Increasing the Photovoltaic-System Hosting Capacity of Low Voltage Distribution Networks				