Study Committee C6

SPECIAL REPORT
(Distribution Systems and Dispersed Generation)

Geza Joos (Preferential Subject 1) | **Joao A. Pecas Lopes** (Preferential Subject 2) | **Joseph Maire** (Preferential Subject 3)

Special Reporters

Introduction

The scope of SC C6 is *to assess the technical impacts and requirements which a more widespread adoption of distributed/dispersed generation could impose on the structure and operation of transmission and distribution systems". Rural electrification, demand side management methodologies, including management of the DG and application of storage are within the scope of this SC.*

The SC decided to propose for discussion in the CIGRE 2010 General Session three preferential subjects dealing with:

- PS1. Planning and operation of active distribution networks including Dispersed Generation (DG), Storage and Demand Side Integration (DSI)
- PS2. Integration of Electric Vehicles (EV) in power systems
- PS3. Electricity supply of rural and remote areas including islands

30 papers were selected for discussion in the General Session. The main issues raised in the reports are summarised hereunder, together with some questions to solicit a lively and profitable discussion[1].

1.0 Preferential Subject 1 (Planning and Operation of active distribution networks)

The theme for Preferential Subject 1 is "Planning and operation of active distribution networks including Dispersed Generation, Storage and Demand Side Integration".

The items which will be touched upon are:

- Integration of micro generation and storage
- Experiences with demand elasticity trials and smart meter solutions
- Distribution management systems (advanced applications, real-time simulation, communication infrastructure and data management)
- Business models for active networks

The papers submitted

Preferential Subject 1 includes 17 papers addressing various aspects of the operation of active distribution networks. Authors were drawn from 17 countries reflecting the wide and international interest in the topic. The papers were regrouped under 3 subtopics, from general considerations to specific issues. The following aspects will be addressed:

---

geza.joos@mcgill.ca, jpl@fe.up.pt, joseph.maire@edf.fr

- Active distribution networks – general considerations, implementation, operation – 6 papers
- Active distribution networks – modeling, requirements, data and standards – 4 papers
- Managing a high penetration distributed energy resources, including storage, electric vehicles and demand response – 7 papers

1.1 Subtopic 1 - Active distribution networks – general considerations, implementation, operational issues, smart meter deployment

Paper C6 101 (Canada, utility) describes the Distribution Smart Zone, a distribution smart grid demonstration project deployed in a suburb, close to a large urban centre (Montreal) in Canada. The installation is funded by the public utility, Hydro-Quebec, and Natural Resources Canada. It is also a host site of the EPRI Smart Grid Demonstrations project. The purpose is to demonstrate the features and operation of the more promising smart distribution grid technologies, including fault management, advanced metering infrastructures, Volt/Var compensation, demand response and electric vehicle charging infrastructure management. The objectives are, among others, to experiment distribution automation and protection equipment, with the goal of improving distribution system reliability and efficiency. The overall layout, structure and equipment installed in the Smart Zone are described. They are representative of most of the existing and planned smart grid technologies. The paper also describes the distribution test line installed at the Hydro-Quebec research centre (IREQ), a full size representative distribution feeder for testing different types of distributed energy resources, and control and measurement equipment. It presents test results for a system incorporating distributed energy resources, under normal and islanding operation. The expected benefits are discussed, and quantified in terms of energy savings for the Volt/Var scheme. The experience acquired by the combination of the Smart Zone deployment and the test line operation should provide crucial information for the larger deployment of a smart grid infrastructure.

Paper C6-102 (Italy, academia) describes a methodology to assess the reliability of active distribution systems, incorporating all critical elements of the grid, including renewable energy sources and information and communication technologies (wireless ICT). The paper provides qualitative and quantitative information about the impact of the network communication and control system on the reliability of an active distribution network. Reliability models of ICT infrastructure and power system elements, including renewable generation, and responsive loads are incorporated within a Pseudo Sequential Monte-Carlo (PSMC) simulation tool. The simulation procedure is outlined, the reliability models for power components derived, with a focus on PV generation. Representative reliability data for the active management components are assumed. The impact of weather conditions on the amount of renewable power generation and on the availability of the ICT wireless communication system is included in the simulation. The results of a case study of a representative rural distribution system are presented. The paper concludes that the use of a wireless communication system of the WiMax type does not negatively impact the overall reliability of the power system that incorporates this technology.

Paper C6-110 (Spain, industry) deals with the potential for smart meters that integrate power line carrier technologies to enable synchrophasor functions and related applications in distribution grids. It argues that simultaneous current and voltage measurements can be obtained, which allow a wide range of new applications, such as overloaded neutral wires detection, voltage unbalance detection at different points, network instability due to variable generation and unpredictable loads, such as distributed generation based on renewable energy and electric vehicles. Other uses include detection of calibration errors and of cases of tampering. Synchronization of smart meters in a given area is enabled by means of the power line carrier technology. Simulations are provided to demonstrate the performance of the synchronization scheme in measuring the symmetrical components of a three-phase system and the current in the neutral conductor. The associated synchronization jitter and errors are presented and discussed.

Paper C6-111 (USA, industry) deals with advanced distribution automation management for active distribution systems. It addresses the management of distributed energy resource integration in a holistic way under a dynamic network topology and variable operation conditions. The functional requirements and the coordination capabilities of the proposed system (ADAM) are described. Four different functions are described, including optimization of real and reactive power dispatch, protection coordination, voltage regulation (fast and slow), active network management. The purpose of the first function is to develop active and reactive power management for optimal dispatch of distributed generation to optimize voltage regulation. A case study, based on simulation, is performed to compare different Volt/Var control methods implemented through the generator reactive power control and the impact of the scheme on the distribution system voltage and power profiles and on distribution losses. It demonstrates that losses in the network and the MVA ratings of generators can be minimized. The paper also describes the implementation and benefits of the three other functions. Normal operation, fault isolation and system restoration are also included in the management scheme.

Paper C6-112 (Korea, utility) describes a demonstration project, the Smart Power Grid (Jeju Island), which includes an advanced distribution automation system, a digital substation automation system, an advanced transmission system and active telemetering, and many software functionalities which will enhance the operation of the smart grid. The paper details the physical components, the system configuration, and presents algorithms and results for a number of implemented functionalities. These include power flow calculation, on-line fault monitoring, self healing fault processing, feeder reconfiguration for loss minimization and load balancing, and dynamic line rating.

Paper C6-114 (UK, research institute) deals with the control of electricity networks using smart meter data. It provides an overview of smart meter functionalities, uses and outstanding issues. State of the art smart meter hardware and operation features are described and expected benefits summarized. Functionalities and implementation issues are addressed, including security issues (data confidentiality and reliability, supply availability). Planning and deployment issues are discussed. The applications examples are divided into those that can support network planning and those relevant to network operation. Further sections discuss energy usage reduction, frequency support and the impact of more widespread demand response schemes. Communication issues are described. A summary of findings from Irish Smart Metering trials is presented. These address among others different communication techniques and latency issues. Use cases and suggested communication categories are discussed, with the associated requirements and time scales. It is noted that there is no clear consensus on the minimum specifications for a smart meter. It is concluded that ability to support additional functionality will be the limiting factor in the ultimate usefulness over time of the smart metering system from the perspective of network operators.

Question 1.1 – In distributed generation reliability analysis, should equipment availability and reliability be treated in the same manner as unforeseen and stochastic events, such as weather conditions?

Question 1.2 – What are the advantages and disadvantages of power line carrier technologies over wireless technologies in the smart meter information transfer and communication infrastructures?

Question 1.3 – The Volt/Var regulation approach has been shown to reduce the energy consumed and the losses in the distribution network, thus increasing the efficiency of the distribution system. Do these advantages apply for all types of loads? As the nature of the loads evolves, will this remain the case? What changes in load types can enhance or reduce the benefits?

Question 1.4 – What changes are required in distribution system operator procedures and in standards to allow or facilitate distributed generator participation in voltage regulation? What type of coordination, if any, of distributed generators, is required at the distribution level?

Question 1.5 – What are the procedures in utilities for drawing up a specification for smart meter functionalities and features? Is it desirable to standardize smart meter functionalities and features?

Question 1.6 – Can and should smart meter data be used as an input in the management of the power grid at the transmission level?

Question 1.7 – In addition to incorporating existing or known intelligent power system functionalities, what new functionalities can or should smart grids provide in the near future, and on a 15 year horizon? How easy will it be to upgrade the functionalities?

Question 1.8 – Can smart meters be used to facilitate demand side integration? Could operators, other than the distribution system operator, access smart meter information to implement other functions?

1.2 Subtopic 2 - Active distribution networks – modeling requirements, data and standards

Paper C6-104 (Europe, utility, academia) reports on the work of a consortium of 16 partners from the industry and the research community under the Distributed Resources Research Infrastructure project (a DERri work package, started in 2009, part of the FP7). It deals with the portability and exchangeability mechanisms for data for smart grids, with a focus on real time simulation. The result is the development of a Common Reference Model (CRM) for distributed energy resources components. The context is the large scale integration of distributed energy resources, including storage provided, among others, by electric vehicles, to meet, a number of objectives, including greenhouse gas reduction targets. It is argued that, given the stochastic nature of distributed energy resources, one approach to establish behavior and performance is to use real time simulators (the power hardware-in-the loop approach). This requires that standard models be available, and that mechanisms exist to exchange data and models between off-line and real time simulation. The paper describes how Common Reference Models are derived, using an information technology approach, which contains an interface definition, a physical and mathematical representation of the device, a model description and documentation data. It demonstrates the feasibility of the approach by providing an example, a hardware-in-the-loop simulation of a PV inverter, with the associated components, real and simulated, represented in the CRM format.

Paper C6-107 (Germany, industry) discusses generic models for smart distribution grids, taking into account future technical evolutions and energy markets. It is argued that generation control, given the variability of renewable energy resources, cannot alone ensure the security of the energy supply. It is proposed to incorporate active customers, with the potential for active demand side management and supply side management, into future balancing schemes through new energy market schemes. Customers are provided incentives through flexible tariffs and control mechanisms, allowing them to adapt their energy production, if present, and consumption. This allows balancing the renewable energy production. In addition, the scheme helps manage grid loading constraints, while maintaining a non-discriminatory management of loads and local generation. Two mechanisms are described, one based on market price signals, the other on monitoring and intervention at the customer level to maximize the use of the existing infrastructure. These two approaches are building blocks for a smart gird and a smart home. The paper presents the functionalities of smart distribution grids of the future, including the design of an autonomous agent for load monitoring (the subject of a field test, in the context of the INES project). It discusses the involvement of the customer and the need for a broad social consensus.

Paper C6-116 (Switzerland, Germany and others, industry) deals with the communication infrastructure and data management for operating smart distribution systems integrating IEC standards. It summarizes a project that proposes a methodology and implementation of an extensive data exchange infrastructure for smart distribution grids (the European lighthouse project WEB2Energy). The three critical functions of the distribution grid, energy management, distribution automation and consumers involvement in the electricity market through smart metering, are integrated using the communication standard IEC 61850 and the Common Information Model (CIM) for data management based on IEC 61968/70. The paper covers in details many aspects of the implementation of the proposed system, including power components (generation, storage, and loads), the communication infrastructure and control software (control centre). It describes the data exchange requirements, and the application and use of the IEC standards, including the data conversion requirements between IEC 61850 and CIM. It explains the operation of the proposed WEB2 Energy system infrastructure, linking generation, distribution system and consumers, and the associated hardware (server) and communication architecture. An application example to a 20 kV distribution network (Darmstadt, Germany) is described. Finally, extensions that are required for application of IEC 61850 to distribution networks are explained, and extensions to the Common Information Model for application to the field of distributed energy resources (including thermal storage), with the creation of new classes of attributes, are described.

Paper C6-117 (Spain, utility) deals with demand management as key resource in smart grids. It summarizes the conclusions of the Smart Grid Communications emulation project, involving a large number of users (GAD project, Active Demand Management, Spain). It presents the new communications architecture, designed for the project, which supports the automatic business procedures from the transmission and distribution systems and market operators. It takes into account new protocols such as IEC 61850. The main objective is to flatten the demand curve in an automatic and efficient manner, while allowing the market signals to operate efficiently. The paper describes, in its introduction, the overall smart grid architecture and agents, and interactive simulation structure, linking the power producers, transmission infrastructure and loads (customers), with the communications and operating system overlays. It describes the emulation tool and its representation of the real interconnections. The tool allows real consumption data inputs, and offers the possibility to develop various scenarios, including large populations (100,000 residential users) with defined consumption patterns over a given period (12 months), taking into account weather patterns. The tool allows new operating procedures to be developed with the aim to automatically flatten the demand response mainly by means of price signals. Various pricing scenarios are presented, with a demonstrated impact on energy savings. This would justify investment in a new communications infrastructure. A number of practical issues are raised, including the impact on power system reliability. The authors mention the need for incentives, policies and investment support.

Question 1.9 – How important is customer acceptance in the implementation of future smart distribution systems? Does the customer have to be actively involved in the operation of the grid, on a continuous basis, or are there other forms of active involvement?

Question 1.10 – How important are financial incentives, for example government subsides, in the implementation of smart grids? Can a business case be demonstrated, in the case where the infrastructure is paid for by a third party, and in the case it is not?

Question 1.11 – In a typical generation dispatch process, the required generation is estimated based on load forecasting, produced from historical data and other considerations (weather, for example). How will a fully active distribution grid affect this process? What are the changes that will be required, what new information is required and how will it be incorporated in the dispatch process?

Question 1.12 – In efforts to fully deploy smart distribution grids, how important is social acceptance? If there is resistance, associated, for example, with implementation costs (and their impact on rates) or with the impact of the communication infrastructure, how can this resistance be managed and what arguments can be used? What are the consequences of a partial deployment of the smart grid and its components?

Question 1.13 – Real time simulators are routinely used for design and commissioning of large installations, particularly involving power electronic converters, at the transmission level. What will be the role, if any, of real time simulators in the integration of a large amount of renewable energy in distribution grids? Will these simulators be required to include and represent the communication infrastructure, in addition to the power conversion and control elements?

1.3 Subtopic 3 - Managing a high penetration distributed energy resources, including storage, electric vehicles and demand response

Paper C6-103 (Australia, academia) discusses the impact on active distribution systems of a high penetration of solar PV systems. It considers four scenarios, the IEEE 1547 requirements (P control), reactive power injection (Q control), and power factor control and voltage regulation. It proposes 4 indices to quantify the impact, the maximum feeder voltage deviation index, the average feeder loading index, the substation reserve capacity index and the feeder loss-to-load ratio. It shows that below a certain penetration level, the presence of solar PV generation may be beneficial. If reactive power is scheduled, it is shown that power factor control is the most effective in reducing reactive power flow and therefore feeder loading and power losses in the networks.

Paper C6-106 (Poland, research institute) deals with the management of high wind penetration on the distribution grid, in the presence of limited transmission capacity. It proposes a Distribution Management System to support distribution system operators, by providing information about potential overloads, and proposing wind reduction schemes to ensure the integrity of distribution power system. The support system includes measured data (SCADA measurements, grid topology), estimated and predicted data (load forecasting, wind generation forecasting, dynamic line rating), operating procedures (reserves, balancing, information about the grid outside the area). Remedial actions and recommendations are provided within the support system, among others, by an expert system module. This module recommends remedial action, including line switching operation, wind generation curtailment, load shedding and reactive power control. Operational approaches to prevent line overloads due to large wind power generation and enhance grid security, include optimizing wind generation using genetic algorithms. A case study is presented, implementing the proposed approach. It gives the permissible maximum wind generation, as a function of location and other operating conditions.

Paper C6-108 (Germany and Austria, industry and academia) deals with demand side integration, including storage, in a virtual power plant context and using customer smart meters. It addresses the issue of a secure and reliable integration of on a large scale of variable renewable energy resources into the power system. The potential of demand side integration (DSI), and its two approaches, demand side management (DSM) and demand response (DSR), considered as the main tools for this integration, are examined in the two studies presented in this paper. The paper concludes that demand side response expectations will be achieved when consumers will be served on the basis of dynamic tariff contracts.

Paper C6-109 (France, utility) deals with the practical implementation issues of a centralized voltage control scheme in a medium voltage network incorporating distributed generation. It is argued that, with local generation, there may be situations in which the voltage rises along the feeders. Two solutions are proposed: a local voltage control function (primary voltage control) and centralized voltage controller at the primary level (substation) implemented in the distribution management system. The paper describes the implementation of the centralized controller and its impact on the medium voltage network (the impact on the low voltage network is not considered). The implementation requires that the medium voltage lines be instrumented to read voltages in real or near real time. Accuracy (1 % for voltage, 3 % for power) and synchronization of the measurements are critical in the implementation. Measurements, including voltage, power and reactive at the sending end of the feeder (beginning), are fed into a state estimation function in the control centre, and the feeder voltage, at the substation sending end, is adjusted, if the transmission constraints allow this. In a future deployment, the reactive power capability of distributed generators will be exploited. The paper describes the site for the planned deployment and the tests that will be performed.

Paper C6-113 (Japan, academia and industry) deals with the experimental verification of advanced voltage control approaches for a high penetration of PV generation in a distribution system with automatic, remotely operable sectionalizing switches, incorporating sensors. The proposed approach uses data from switches and implements a centralized and coordinated voltage control method using voltage control devices such as load ratio control transformers (LRT), step voltage regulators (SVR) and static synchronous compensators (STATCOM).

The proposed centralized and coordinated voltage control system monitors the voltages along the feeder using information provided by the sectionalizing switches. It conducts four procedures: (1) data acquisition, (2) state estimation, (3) voltage gap evaluation, and (4) tap change instruction, in 1-5 minute cycles. Reduction of total number of tap changes of LRT and SVR are obtained by compensating voltage fluctuations by means of the STATCOM. This increases their mechanical life. The approach is verified by computer simulations and on an analog type distribution system simulator, a 200V experimental system that represents three-phase, three-wire, and non-grounded systems, and 6.6kV distribution system (Japan). Distribution systems, implemented on the analog simulator, include one feeder with residential loads (with an SVR towards the centre and a STATCOM at the end), and system with two feeders, one feeder with residential loads (SVR towards the middle) and one with industrial loads (STATCOM at the end). PV systems are installed along the residential feeders. Tests are carried out for various levels of sun exposure (sunny and cloudy), and the voltage along the feeder monitored when the LRT and SVR are operated, with or without the STATCOM. Results show that the centralized and coordinated voltage control allows higher penetration of PV on the residential feeders, while significantly reducing voltage fluctuations and respecting the voltage constraints: for the two feeder system, up to 100 %, with LRT, SVR and STATCOM (10 % feeder capacity), up to 90 % with LRT and SVR, while penetration is limited to 50 % with conventional LRT and SVR control. In addition, the tests show that the operation of the STATCOM significantly reduces the number of tap changing operations of the LRT and SVR (from 34 to 20 on a cloudy day).

Paper C6-105 (Denmark, university research centre**)** deals with the impact of electric vehicle integration on low voltage electric grids, specifically through charging schedule management and charging scenarios, in a typical low voltage grid. The purpose is to identify bottlenecks and solutions. Five charging scenarios have been considered for the EV charging management: dumb charging all day (up to the maximum stat of charge), dumb charging at home, timed charging, fleet charging all day (using an optimization algorithm, including a day ahead electricity price), fleet charging at night. The methodology is to use a time series approach to determine power flows to assess loading of the electric grid power components and the voltage profile. The modeling of the low voltage grid includes topological and demand data. Demand is estimated from yearly consumption data. The case study deals with typical single phase and three phase feeders. Penetration levels considered vary from 10 to 20 %, and two charging levels are considered (single and three-phase). Results for transformer loading are given on an hourly basis for a 24 hour cycle. They show that the transformers are the main bottleneck. Studies also indicate that dumb charging at home does not lead to the worst case transformer loading. The paper concludes that, in order to alleviate congestion, the distribution system operator should be involved in the management of charging demand in some form or another (direct control or demand shifting for example).

Paper C6-115 (Switzerland, research laboratory) deals with the combination of energy storage and demand response in the residential sector, in a single-family house dwelling. It develops a model for the house in terms of heat flow and energy hub, including energy conversion and storage, and demand response. The purpose of the optimization study is to minimize energy costs, taking into account variations in energy prices, storage and demand response parameters, and available renewable energy sources. Issues such as the interaction of storage devices and demand response with renewable energy sources are studied. Consumer behavior is considered. The paper details the energy requirements of a single family house, resulting from a constant internal temperature, the available energy sources, including grid supplied electricity, renewable energy sources and natural gas, and storage. The power supply strategy consists in minimizing the cost of energy over time, based on constraints that include available power and energy, temperature and other parameters. Summer and winter cycles are considered. The impact of electricity storage capacity on energy costs are considered, with and without demand response. Preliminary results indicate that the impact of the storage capacity on energy costs decreases as capacity increases, particularly when demand response competes for excess electricity and as the price of electricity decreases.

Question 1.14 – Will it be necessary and/or desirable for the distribution system operator to monitor the availability and the generation level of distributed generators, particularly of the PV type? Will this allow the distribution system operator to enhance the reliability and energy supply security of the distribution grid? How can this function be implemented? Is real time data required?

Question 1.15 – What are the benefits of local storage for the end user? Can the benefits be monetized and shared with the distribution system operator, and if yes, how can the sharing be implemented?

Question 1.16 – How significant is the impact of local storage on the capacity to integrate distributed generation based on renewable energy, from the perspective of the distribution system operator?

Question 1.17 – To what extend can the distribution system operator rely on customers to manage their loads in a responsible way? What are the main barriers to customer involvement? Should consumer demand response be fully automated?

Question 1.18 – What are the ancillary services that residential and commercial customers can provide that have the greatest value to the distribution system operator? Will these services evolve as the level of penetration of distributed resources increase? What is required to access these resources? How are the benefits shared?

Question 1.19 – If most residential and commercial buildings become net-zero loads over a given period of time (a year for example), what is the business case for the distribution system operator to continue supplying energy to the load when required? Should new mechanisms be put in place to compensate the distribution system operator?

Question 1.20 – How can direct control of electric vehicle charging be implemented at the residential level? Can battery charging be curtailed or controlled without impacting on the driver ability to make use of his vehicle?

Question 1.21 – What are the on-going implementations or experiments in using electricity pricing signals to implement demand response, and how successful are they?

Question 1.22 – One of the proposed solutions to handle an excess of generation produced by renewable energy sources is curtailment of the power produced. What are the most effective mechanisms to compensate independent power producers, owners of the equipment, for lost revenue? Can curtailment be an impediment to a wide penetration of renewable energy?

Question 1.23 – Given the large number of parameters to be optimized at the customer level when integrating demand response and local storage, namely in the choice and design of the equipment, and taking into account operating conditions, including summer and winter periods and electricity prices, how can an effective energy cost minimization plan be implemented?

2. Preferential Subject 2: Integration of electric vehicles (EV) in power systems

PS2. Integration of Electric Vehicles (EV) in power systems
The theme for Preferential Subject 2 is attracting high attention throughout the world.

Important topics that will be discussed in this session include:

- Impact on the power system
- Emerging standards
- Business models

2.1 The papers submitted

A total of 7 papers will be discussed under Preferential Subject 2:

Paper C6-201 - Impact of electric and plug-in hybrid vehicles on grid infrastructure - Results from the MERGE project
This paper highlights findings of the EU FP7 funded project called MERGE (Mobile Energy Resources in Grids of Electricity). The MERGE project dealt with the development and adaptation of existing software tools to incorporate electric vehicle (EV) models and provide evaluations of the impacts that EV will have on the European Union (EU) electric power systems with regards to planning, operation (steady state and dynamic behaviour) and market functioning. The focus is placed on EV and SmartGrid/MicroGrid simultaneous deployment, together with renewable energy increase, leading to CO_2 emission reduction through the identification of enabling technologies and advanced control approaches.
In this paper indicative results from the impact of the additional EV load will have in the daily and yearly system load diagrams and in the operation of the transmission and distribution networks of five European countries (Greece, UK, Spain, Portugal, and Germany) in 2020 are presented.
The main conclusions are that the steady state analysis of the transmission systems has shown they will not confront significant impacts due to the additional EV load even in the case of highest EV deployment. The distribution system analysis indicated that the operation of these networks may become affected and the magnitude of the EV impacts is influenced by several factors namely the EV integration level, the EV owners' behaviour, mobility patterns, the networks' load profiles and technical characteristics, the number and location of fast charging stations in the grid and the EV charging modes. However distribution systems can easily handle up to a certain number of EVs without the need of premature reinforcements provided that smart charging strategies are adopted.

Paper C6-202 - Electric vehicle business models & interoperability platforms
This paper deals with two separate areas which are crucial to the uptake and rollout of electric vehicles (EV) - high-level market & business models and standardisation requirements on EV charging infrastructure. A market model describing market transactions is developed and described with the objective of achieving rapid and widespread availability of charging infrastructures. Key issues such as investment costs, integration with existing electricity market, ease of market entry for energy suppliers, grid system support capabilities and the need for government subventions are considered to derive the proposed market model. The model is based on a Distribution System Operator (DSO) driven model which is considered to

be best placed to deliver a rapid, cohesive and widespread development of charging network during the early phases of EV development. The ecar project being implemented in Ireland is an example of this model. This model recognises the critical function of governments and regulators in devising regulations and incentives for DSOs. It requires subvention in providing clear mechanisms on how the investment costs of charging network can be earned in the future. The model provides the options of integrating EV charging network as part of DSO regulated asset pool or the separate pooling of EV charging network. The basic design of the proposed model would enable value-adding business models to be developed in the areas of energy retailing and the provision of EV grid services. Many grid services will require high level of standardisation in terms of market structure, charging equipment and communication technologies. Standardisation of charging systems is critical in achieving the interoperability objective. Various established and emerging standards are presented. It is shown that many of the plug-in EV grid services can be achieved using standards that are currently available and being rolled out across Europe.

Paper C6-203 - Challenges and barriers of integrating e-cars into a grid with high amount of renewable generation

This paper describes some international experiences concerning the integration of electric vehicles (EV) into the electrical grid in particular when there is a high penetration of renewable energies. The development of the electric mobility shift will be based on existing infrastructures (electricity system, road infrastructure, etc.) but it can also partially be considered as a “green field” approach. In the paper new strategies and global trends in the development of an e-mobility system will be presented, including strategies to combine the power system with the information and communication systems. Practical experiences and data based on few projects e.g. Harz.EE-Mobility in Germany. European research as well as industry projects with these aims will be introduced and results are presented in the paper.

Simulations show that single-phase charging (3.7 kW) in the low and medium voltage grid does not lead to grid situations that require any significant adjustments in the power network regarding the loading of the assets. However, uncoordinated single-phase charging could create significant voltage deviations due to unbalanced loading of the three-phase low voltage grid. The different phases influence each other in unbalanced situations, through the common neutral conductor. These effects can already occur at low market penetration levels, due to the presence of local penetration levels being significantly higher than the average market level. For a significant amount of EV and high power charging (up to 22 kW in Germany) after 2020 the main concerns of investigation will be the forecasting of the requested charging power, the location of this demand and the impact on power grid operation security without active grid control (e.g. voltage, asset overloading).

Full integration of renewable generation is also important as the amount of thermal power plants decrease, because they currently balance the intermittent, renewable generation. Specific control strategies installed at the EV grid connection points are required to deal effectively with such operation scenario.

Paper C6-204 - Polyphase recharge point - Optimized integration of high power EV recharge into the distribution grid

This paper provides an overview of Electric Vehicle charging solutions and factors related with the availability of one to three phase low voltage power grids and their voltage ratings for this purpose. This overview sets a framework to present a cost-benefit analysis for different charging alternatives ranging from low power AC charging to high power AC or DC charging, comparing pros and cons for each of the possible modes. This analysis considers factors such as the supported powers for different types of IEC62196 plugs, the usability of different cables, installation of each type of charging station, cost, impact on the electric grid etc.

The paper concludes that interoperability for high power charging scenarios is necessary to facilitate the introduction of EVs even if low power charging is expected to be the default option for EV charging. With the existing connectors, below 50 kW mode 3 is the most cost effective option from the infrastructure point of view. This mode not only supports high power charging but also allows the use of the same infrastructure for low power charges.

Paper C6-205 - Electric vehicles: The barriers to power system integration

This paper presents a critical review of literature regarding the negative impact of electric vehicle charging on the network and the lack of standardisation in the charging process, along with recommendations on ways to reduce these barriers.

Uncontrolled PEV charging can cause a range of power network problems including voltage limit violations, component overloads, increase in power system losses, phase imbalance and issues with power quality and stability. Smart charging is considered as the best long-term solution to deal with this problem, due to its ability to integrate the highest number of PEVs, whilst ensuring that no new component overloads or voltage limit violations occur, and whilst reducing power system losses. Smart charging offers a cost benefit compared to network reinforcement, despite additional infrastructure requirements. In the short-term dual tariff offers the best overall mitigation for the discussed network impacts.

Lack of standardisation in the PEV charging process increases the likelihood that charging infrastructure across EU nation states will become non-interoperable. This paper presents also a critical review of the status of standardisation of the physical (IEC 61851, IEC 62961) and communications IEC/ISO 15118) aspects of PEV charging interfaces in Europe, finding that the communications standards are the least developed. European PEV manufacturers, standardisation bodies and governance all support the adoption of the international standards being developed, but decisions on the implementation of IEC 61851 charging modes for public and domestic settings still needs addressing. This paper recommends that public charging infrastructure is equipped to supply charge in multiple modes until EU standard harmonisation.

Paper C6-206 - Impact of fully electric vehicle battery charging loads on the load demand of distribution systems

This paper states that in the UK, the effect of widespread adoption of Electric Vehicles (EV) grid integration would be manageable on the electricity grid at the 132kV level, but the same is not true for the local distribution network. The increased loading, particularly in residential areas where EVs are more likely to be connected to, could require replacement of cables or establishment of local ‘smart grids’ to manage loading on a street-by-street basis to optimise load and generation scheduling. This paper focuses on quantifying the impact of EV battery charging loads on the load demand in distribution systems. The paper aims to develop a methodology to determine the load profile at distribution level when the FEV battery charging load is given consideration. This includes the time of the peak load, the size of the peak load and the shape of the load curve. The methodology takes into account the stochastic nature of the start time of individual battery charging and the initial battery state-of-charge. Results show that a 10% market penetration of FEVs in the studied system would result in an increase in daily peak demand by up to 20.2%, while a 20% level of EV penetration would lead to a 38.4% increase in peak load, for the scenario of uncontrolled domestic charging – the ‘worst case’ scenario.

Paper C6-207 - Towards ultrafast charging solutions of electric vehicles
This paper is devoted to the problems arising from the ultrafast (≤ 10 min) charging of an electric vehicle (EV). An ultrafast charging station (UFCS) must provide high power output with minimal influence on the electricity transmission system, which can only be achieved by the application of energy storage acting as an additional buffer between the vehicle and the grid. Besides storage, interfaces between a fast charging station and the outside environment (vehicle, utility grid) must be designed to fulfil a set of requirements.
The main challenge is to be found within the specification of parameters for the design of future energy supply systems, providing for fast charging of the vehicle batteries while avoiding solicitations of the local distribution system which exceed its instantaneous power capabilities. The possible impact of an UFCS on the power distribution system is analysed with the stochastic approach, based on the utilisation of such a station. The general aspects of highly variable load profile clearly include the use of energy storage means that must be specified regarding both the energy storage and the instant power capabilities. Different technologies are analysed in terms of performances and costs.

Question 2.1: Paper C6-201 describes the foreseen impacts of electric and plug-in hybrid vehicles on grid infrastructure. In a large EV scale deployment scenario, how can EV charging be handled from the electricity markets point of view, together with the need to cope with operational restrictions of the electrical distribution grid.

Question 2.2: Paper C6-202 describes Market and Business models to accommodate EV deployment. Regarding the metering solutions, what should be the solution (on board metering or fixed meters installed at the connection point) to be adopted in order to reduce investments, increase interoperability and allow EVs to participate in ancillary service provision? What should be the main characteristics of these meters? Can home charging meters be adopted for this purpose?

Question 2.3: Paper C6-203 describes, besides other approaches, a real time price signal solution to manage EV charging / discharging in a project being developed in Denmark. What are the communication requirements needed to allow for this approach to become effective?

Question 2.4: Paper C6-204 addresses technical issues related with the deployment of polyphase charging stations. What should be the main capabilities / characteristics (in terms of power and communications) of a future charging station in order to be able to fulfill with the foreseen needs of the EV drivers, taking into account the limitations of the grid in accommodating the presence of this new consumer? How will the charging procedure be managed, considering that the charging station areas will be often located in commercial areas?

Question 2.5: Paper C6-205 addresses some of the main barriers related with EV grid integration. Regarding standardization what should be the main issues to be subjected to revision regarding the existing standards? Are the existing standards capable to handle advanced EV grid interactions regarding Smart Grid developments?

Question 2.6: Paper C6-206 describes a methodology to determine the load profile at distribution level when EV battery charging is taking place. In this study how was the traffic pattern taken into account regarding the geographical availability of the charging points? Is the identification of the charging profile taking into account the preferences of the EV drivers regarding the place where to charge (home, public parking areas, charging stations)?

Question 2.7: Paper C6-207 – describes an ultrafast charging solution based on additional storage installed at charging stations to alleviate the network from peak consumptions that could result from the operation of the EV charging station. How can the overall management of the charging station be performed taking into account market prices and grid restrictions?

3.0 Preferential Subject 3 (Electricity supply of rural and remote areas including islands)

The theme for Preferential Subject 3 is "Electricity supply of rural and remote areas including islands".

The aspects which will be discussed are:

- Planning and operation of systems with high penetration of renewables
- Effects of storage, hybrid systems, solar home systems
- Emerging grid based technologies to support rural and remote area electrification

3.1 The papers submitted

A total of 6 papers will be discussed under Preferential Subject 3.

Paper C6-301 describes the approach used in King Islands (situated between Tasmania and Australia) to reduce expensive diesel fuel consumption by increasing drastically the share of energy produced by Wind Turbine Generators. The island's load varies between 1,2 MW and 3,5 MW with an annual consumption of 16GWh. The 2,45 MW of WTG produce about 10 GWh per year but due to inflexibility of Diesel Generator they only represent 33% of the total production, about 4,5 GWh being spilled. To increase this share up to 40%, a Resistive Frequency Control has been designed to cope with the changes of 600/800kW/second that may be observed with the WTG that does not match with DG regulation capability. This RFC consists of a large resistive load (1,5 MW) fed by a thyristor Phase Angle Controller. The different modes of operation are described in the paper and field results are shown. Instantaneously, with this device on, the wind production may exceed 50 % of the demand level.
But the system has reached the limit of renewable energy penetration mainly because one DG is permanently required. The renewable energy waste may be high especially when the demand is low even if the DG is operated at its minimum production level. To go further, several solutions are considered and studied in the paper. Diesel Uninterruptible Power Supply appears to be the best solution as shown by dynamic PSCAD simulation presented and might enable the increase the WTG's share of energy up to 50 %.

Paper C6-302 presents the field experience of the hybrid energy system of the island of Eigg 16km away from the Scottish west coast. Initially, the people were dependent on their own diesel generator production. Since 2008, a hybrid system has been put in place with a medium

voltage grid connecting several productions units: 10 kWp PV, 3 hydro plants (100 kW, 2 x 6 kW), 4 wind turbines (4 x 6 kW) and 2 diesel generators (2 x 64 kVA).
This system is feeding nearly 100 inhabitants owning around 40 residential and 5 commercial properties. With approval of the residents; domestic and small business supplies have been limited to 5 kW, and larger business supplies to 10 kW representing a total consumption of 316 MWh/year. The control of the total system is assured by inverters feeding a 48 V-4400 Ah (C10) battery without any communication lines. The control is exclusively done through the grid frequency monitoring. The battery can provide to approximately 12 hours of power for the whole island. The paper describes how the master battery inverter starts and stops the generators depending on the available production, the State Of Charge of the battery and naturally the demand. Thanks to this system, 80 % of the demand is covered by the hydro generator about 10% from the wind turbines and only 2% from the PV arrays (mainly in June and July when hydrogenerators produce less and when Diesel generators are largely producing). The systems costs is presented (2M€) and is much cheaper than a submarine cable. A 85% spare on the diesel fuel consumption of the island has reduced the overall cost of energy for the inhabitants while quality of service was improved compared to the previous situation.

Paper C6-303 presents the basic challenges of the operation of the Greek Islands in the following years. Greece has 36 non interconnected islands (NII) with a peak load demand ranging from 100kW to 700MW! The primary power supply is based on various types of heavy and light fuel oil. The cost of production is varying from 350 €/MWh in very small island to less than 100 €/MWh in the largest islands. They are summer peaking systems with a very high ratio between minimum and maximum load (typically 2.5). The penetration of Renewable Energy Sources is very high in several islands. Being generally characterized by the intermittency of their production, the penetration of RES in the generation mix is limited due to technical constraints introduced by the conventional units. With limited control capabilities, operators are obliged to follow conservative procedures, rejecting part of the available resources. To overcome this limitation, advanced management systems with effective control capabilities need to be implemented. Another driving force for these changes is the new legal framework that requires the operation of an energy market. That is why the Greek island system operator plans to install an advanced Energy Management System (EMS) in the non interconnected islands with a semi-distributed architecture and new functions (including market dedicated ones) described in the paper.
During operation, the main constraint is the instantaneous intermittent RES penetration level that should be kept below 30% of the total load. Without any care, the spill of renewable energy will increased as shown by the study conducted for the island of Crete. In the absence of modern control centers, RES penetration would not exceed approximately 19%. This will not allow the rapid increase of renewable generation needed to reach 2025 goals (>40%). This will fit with the significant interest from private investors to install large RES stations, using not only conventional technologies, such as Wind Farms and Photovoltaic Plants, but also new technologies in large scale: Hybrid Stations (Combination of Wind Farms and Pumped or Battery Energy Storage) and Concentrating Solar Thermal Power Plants (STPP).

Paper C6-305 describes the Stand Alone Power System that has been developed and tested as an alternative to the renewing of remote rural distribution lines in New Zealand. In this country, most of these lines have been built during the post second world war period thanks to subsidies and are nearing end of life. They serve communities whose population density has decreased over the years and where the costs of on-going vegetation maintenance have increased. In accordance with recent changes to legislation, distributors are allowed to provide alternatives to grid supply if acceptable quality and service criteria are met. The aim of this SAPS is to continue to supply existing customer at a lower overall (or whole life) cost than grid supply renewal. This modular “plug and play” concept includes energy storage modules, load management (inverter) modules, scalable photovoltaic cells, scalable micro-hydro generation, fossil fuel generators, and the use of bottled LPG for stoves and water heating and energy efficient products for lighting and motive power. Satellite or mobile communications are used to monitor performance and indicate system failures. The first system was put in place in 2008 and was representing one third of the cost of the line replacement. Detailed description and results are given in the paper. The feedback both from the customer and the distribution operator are good. New operations are now envisaged with a study of this refurbishment alternative taking place as soon as typically two kilometers of line are needed for one customer with a transformer capacity of less than 15 kVA.

The main object of **Paper C6-306** is the development an optimal unit sizing methodology for remote autonomous microgrid with multiple energy sources. The methodology takes into account the economical and environmental values of RES. Generally, the microgrid load is supplied by a diesel generator (which serves as a balancing plant) and Renewable Energy Sources (typically wind turbine and solar PV). An Energy Storage System (ESS) is used in the microgrid to smooth the output fluctuation of RES and to provide peak load shaving. A dump load is used to absorb the redundant power of the microgrid system when ESS is fully charged or at its maximum charging power. The goal of energy dispatching strategy is to maximize the total RES energy contribution to the system and improve the overall efficiency of diesel generation (or maximize the fuel saving). DG production has to adapt to the RES production available, to the demand and, of course, to the State Of Charge of the Energy Storage System. The different situations are fully described in the paper. Particle Swarm Organisation is used to solve the optimal unit sizing problem of the islanded microgrid with matlab and a one year simulation approach is made on an hourly basis. The paper gives results with an example (75kW Diesel Generator, 80kW Wind Turbine Generator, 30kWp PV and 8kW/15kWh ESS) comparing two scenarios : the first one ignores the environmental benefits of wind turbine and PV and the second one takes them into account. Results show that considering the environmental benefit of RES DGs increases the capacity of wind turbine by 16 % and PV by 10% and decreases Diesel unit production by 10% in the optimization result. A sensitivity analysis is presented showing either the effect of diesel fuel price or average wind speed variation on optimal sizing: the increase of diesel fuel price and average wind speed leads to a decrease of proportion of diesel generator in microgrid and an increase of contribution of wind and PV generation.

The economical interest of providing primary reserve services with energy storage system in isolated system is discussed in **Paper C6-307**. The size and the lack of external support in such systems make them more vulnerable than interconnected one, especially in case of disturbances due to frequency stability issues. For this reasons, provision of primary reserve service in an isolated power system may have a significant impact since it may require not only generators operating below their optimal operating points but also the connection of units that otherwise would not be needed.
Provision of primary reserve with Energy Storage Systems (EESs) could be an economic alternative to scheduling spare generation capacity in the on-line units. Although pumped storage power plants have been the only practical solutions for massive storage, current developments of battery energy storage systems may enable them to be used for primary reserve services in isolated systems.

The state of the art of battery energy storage systems is presently being tested in two power systems of the Canary Islands :

- Gran Canaria (total demand : 3560 GWh per year ; peak demand : 577 MW; installed capacity : 1045 MW) with 1MW /7,2 MWh of NaS battery,
- La Gomera (total demand : 72 GWh per year ; peak demand : 12,5 MW ; installed capacity : 20 MW) with 500kW/2,8 MWh of Zn Br battery ,

The paper presents the technical and economical framework applied for the Spanish isolated power system and the mathematical model applied to dispatch economically the production between the units and the EES. This model is applied in the cases of Gran Canaria and La Gomera. The savings of providing primary reserve with EESs are approximately linear functions of the EES rating. In addition, when the rating of the EES is approximately 20% of the peak demand, the savings become approximately 4% and 6% of the total generation costs respectively in the La Gomera and Gran Canaria system.

Question 3.1: Generally, in isolated systems as described above, Diesel Generators are used very often as the basic mean of production. What are the main limits of such generators to cope with the future situation (cost of fossil fuel, growing of public environmental concern, …)? Is there any breakthrough in such devices (such as the DUPS mentioned in paper C6 301 or new conceptions) that may enhance the flexibility of this type of generators in the future? What role should they play in future islanded systems?

Question 3.2: To compensate the inflexibility of diesel generators and the intermittency of wind and solar production while keeping the system stability, several devices or exploitation rules are used such as maximum limit of intermittent power penetration, resistive frequency controller, chemical storage, load control, pumping station, …
What is the field return of experience on these measures or devices?
Taking into account this return of experience, what kind of evolutions or development will be needed to reduce economically the use of fossil fuel in isolated systems and enable to go beyond actual RES penetration limits fixed to operate safely?

Question 3.3: By nature, the cost of energy in isolated systems is higher than elsewhere. Nevertheless, most of the solutions proposed to stabilize these systems when introducing intermittent renewable energy are spilling more or less energy: resistive frequency controller, storage, high permanent needs of primary reserve, …. As done in paper C6-306, what kind of efforts may be done to optimize the sizing of components and operations rules to reduce the energy spilled? Is it always leading to the less costly solution? Are these rules dependent on the size of the systems and why is it so?

Question 3.4: The paper C6 305 described how Stand Alone Power System may be considered as an alternative to renewing remote rural distribution lines. Is there any another example of such approach? What is the feed-back and the economic issues for the grid operator in that case? What is the position of local authority and regulation on such an alternative?