Study Committee reference C6

SPECIAL REPORT FOR SC6.
(Distribution Systems and Dispersed Generation)

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Special Reporters

Introduction

The Scope of SC C6 is to assess the technical impacts and requirements which a more widespread adoption of Dispersed Generation (DG) and a larger proportion of undispatchable power generation could impose on the structure and operation of transmission and distribution systems. In parallel the SC also assesses the degree to which solutions are likely to be adopted in the short, medium and long term. Consequently, the practical importance and timing of the technical impacts and requirements mentioned above are discussed. Rural electrification, demand side integration methodologies and application of storage are also within the scope of this SC.

Within this scope for the CIGRE 2016 General Session three preferential subjects were proposed:
- PS1: Integrated planning and operation for upgrading distribution networks
- PS2: Energy infrastructure for urban networks
- PS3: Microgrids and off-grid hybrid systems

A total of 39 papers were selected for discussion at the General Meeting, 19 for PS1, 9 for PS2 and 10 for PS3. The main issues for these papers are summarized below and questions are raised in relation to these papers to ensure a lively and profitable discussion at the General Meeting.

1. Preferential Subject 1 (Integrated planning and operation for up grading distribution networks)

The areas dealt with in the subject ‘Integrated planning and operation for upgrading distribution networks’ are:
- Impact of distributed generation
- Protection issues
- State estimation in the distributed network grid
- Control of the distribution system
- Demand side integration

The papers submitted

PS1 includes 19 papers within the topic. The authors come from 17 different countries, and hence demonstrate a wide international interest in this topic. The papers were regrouped into five subtopics:
- Impact of DG (papers C6-101, C6-102, C6-103, C6-104)

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- Protection and reliability in distribution network grids
  (papers C6-105, C6-106, C6-107, C6-108, C6-109)
- State estimation in distribution grids (papers C6-110, C6-111, C6-112)
- Surveys of distribution grid performance as background for future recommendations
  (papers C6-113, C6-114, C6-115 and C6-116)
- Control issues in the distribution network including demand integration
  (papers C6-117, C6-118, C6-119)

Subtopic 1 - Impact of distribution generation (papers C6-101, C6-102, C6-103, C6-104)
These four papers deal with the impact of DG on the distribution network, especially in relation to voltage issues. Two papers (C6-101 and C6-104) also look into the economic aspects such as payback time and net present value, focus of the papers C6-102 and C6-103 is on functionalities which can be obtained from the installation of DGs.

Paper C6-101 (Brazil, utilities) presents the evolution of DG in Brazil due to a new resolution. It shows the impact of photovoltaic installation on various distribution networks, as well as the main technical and economic (payback time) difficulties faced. Technical issues include bidirectional meters, billing issues, security, planning, standardization, ICT and information systems (Website) etc. As installation of PV systems results in a rise in harmonic injection, their quality has to be improved to achieve higher levels of penetration in low and medium distribution networks.

Paper C6-102 (USA, academia) deals with a distributed resource management system (DERMS), a system which can manage aggregated distributed energy resources (DER) in an effective manner and can be used in a larger DMS system. The functionalities include group creation, status monitoring, group capability discovery, and dispatch of real and reactive power and DER forecast, and describe a guideline as regards how to set up such aggregated systems. The system has been tested, and future work is required in order to map the work into several communication protocols.

Paper C6-103 (Australia, academia) focusses on sharing the preliminary learning experiences from a utility scale PV system in relation to voltage variations in weak grids, voltage regulation, and flicker. Aspects focused in the paper are the effect of fixed tilt and tracking arrays' outputs and the smoothing effect in large PV plants due to geographical dispersion.

Paper C6-104 (Bolivia, Argentina, academia) presents a dynamic model for a distribution network expansion, with the aim to reduce utility costs (net present value). Evolutionary particle swarm optimization and optimal power flow are used to find the best solution, while modelling uncertainty stochastically with Monte Carlo simulations. The economic optimization includes investments in feeder reinforcements, substation expansion and DG investments, operational costs and the penalization for energy not supplied and for energy supplied with voltage issues. The method is verified by a case study on a nine-node test network.

Question 1.1. The creation of new regulations and grid codes for installing DERs may typically be done with different technical and economical perspectives from differing stakeholders including DSOs, TSOs and governments. How do you see the future development of new regulations and grid codes, and how they will influence the installation of DERs in the future?

Question 1.2. In some planning methods the deterministic and worst case methods are still used by utilities. Are such historical approaches preferred, or do stochastic methods need to be used when planning the future distribution grids, taking the probabilities for different scenarios into account when dimensioning the new network structure and its related operation?

Question 1.3. To what extent is the impact of DG and the implementation of new planning tools expected to fundamentally impact on the structure of the distribution grid, and in particular in developing countries where opportunities arise to plan new grids accordingly?

Subtopic 2 - Protection and reliability in distribution network grids
(papers C6-105, C6-106, C6-107, C6-108, C6-109)
Five papers examine protection systems and the reliability of distribution systems with DG connected. Paper C6-105 and C6-107 look at the reliability, and analyse performance indexes. Both paper use Monto Carlo simulations. Paper C6-106 shows a methods for a self-healing protection system, and finally the papers C6-107 and C6-108 are related to adaptive protection methods to ensure reliable protection when connecting new DGs to the network.

Paper C6-105 (Canada, utility) uses a Monte-Carlo simulation technique to assess the reliability of a power network, calculating the typical performance indicators (CAIDI and SAIFI) taking into account events such as network overloading, protection, restoration and network reconfiguration of the distribution network. The model is able to simulate the entire Hydro-Quebec network grid in less than five hours.

Paper C6-106 (Korea, utility) introduces two advanced programs as relate to self-healing for wide area power outages and network reconfiguration. The advanced self-healing consists of four steps: a restoration inside a substation, priority feeder restoration, feeder load uploading, and distribution network reconfiguration. As a result of the implementation of the proposed methods the feeder loading can generally be increased from 10 MVA to 11 MVA.

Paper C6-107 (Greece, academia) describes a probabilistic methodology (Monto Carlo sequential simulation) to assess the reliability and operational performance of low voltage distribution networks with end-users incorporating various types of DER. Aggregators are used to aggregate load demand contributions from several minor customers. Special attention is given to Normally Open Switches (NOS) which can be operated through loop power flow controllers for reducing the components' failure events by connecting adjoining feeders, considering different criteria such as main supply source, surplus of power, minimization of switching action etc. Appropriate indexes such as SAIDI, SAIFI and LOEE are calculated in the model to quantify the reliability performance.

Paper C6-108 (Greece, academia) discusses the impacts of embedded generation on conventional distribution protection, and proposes a hardware-in-the-loop (HIL) infrastructure to be used as a complete testbed for adaptive protection schemes. The system is based on optimisation techniques and adaptive protection, combining the flexibility of automatic relay setting group (SG) adjustment with the determination of optimal relay setting parameters thereby preventing blinding, sympathetic tripping and failed reclosing phenomena.

Paper C6-109 (Egypt, utility/academia) assesses an adaptive protection scheme given that two different settings (in case of loss of coordination) are used dependent on the connection of DG. In relation to bidirectional power flow, a solution using directional protection with one setting for the upstream current and another for the downstream current is recommended. The paper also assesses how DG impacts the fuse saving strategy, and makes recommendations to address the problems that arise if the DG is placed downstream of the recloser. Different case studies verify the recommendations for the proposed new protection methods.

Question 1.4. Concerning the reliability of the network when introducing large amounts of DG, how will such dispersed generation typically affect network performance indexes such as SAIDI, SAIFI, LOEE, and what measures will need to be considered to prevent network performance from degrading?

Question 1.5. Adaptive protection has been proposed as one solution to counteract problems that arise when DGs are connected along the radials in the LV or MV network. How automated should these adaptive protection methods be, is it for instance necessary that we have communication channels between all protection devices, or can they be controlled locally? Are two different settings groups (as mentioned in paper C6-109) enough, or are a lot of different settings required depending on actual infeed?

Subtopic 3 - State estimation in distribution grids (papers C6-110, C6-111, C6-112)
There are three papers related to state estimation. The need for state estimators is addressed in all papers, driven by the high penetration of flexible load and generation. Two of the papers (C6-110 and C6-112) look at state estimation for the MV network, mainly based on measurements at substations, whereas the last paper looks at the LV network using measurements from household smart meters (C6-111). The main consideration in all papers is to improve voltage control using for instance on-load-tap changers, voltage regulators or compensation units.

Paper C6-110 (Spain, academia/utility) analyses an implementation of a state estimator and load allocation algorithm for a MV network, which takes into account specific characteristics of the distribution systems such as any large proportion of injections in the measurement set, long and short lines coming to the same bus, presence of current flow measurements to the detriment of power flows, high R/X ratios and, mainly, reduced number of on-line measurements. Simulations match measurements of daily load curves based on feeder data from the last six months.

Paper C6-111 (Germany, academia/utility) sets up a state estimator for a LV grid based on smart meter measurements and feed-in forecasts for photovoltaic systems, which are used to reduce voltage rise using distribution transformers with on-load tap changers, voltage regulators or reactive power controllers. Voltage, current as well as active and reactive currents are measured for all three phases, every 10 minutes for loads and every 5 minutes for PV systems. Further data is measured at the local network stations. The measurement redundancy for the LV network is rather low compared to state estimation at transmission level. The state estimation is done for three phases to take unbalances into account. The results from the algorithm are verified using power flow calculations.

Paper C6-112 (Germany, utility) introduces a new tool to control on-load-tap-changing (OLTC) transformers and other compensation equipment in the substations to ensure the stability margin of the MV network. The approach uses the fluctuation of loads connected to the substation, as well as the switching over process of OLTC to estimate both the Thevenin Equivalent of the superordinate grid, and the static aggregated load characteristics in the subordinate grid. The necessary input signals are voltage and current measurements locally in the substation. The method is verified with simulations on the IEEE 14-bus system.

Question 1.6. What are the differences between performing state estimations at the transmission level as compared to the distribution MV and LV levels? Are there different aspects which should be taken into account? Is there a differentiation between what is needed to know and what is nice to know?

Question 1.7. What is the required sampling time for distribution state estimation? Can a criteria be established to determine the number of measuring points as related to the total number of load/generation point or number of radials? What should be measured at the different measuring points, and do the measurement requirements vary with the location of the measurement devices?

Subtopic 4 - Surveys of distribution grid performance as background for future recommendations (papers C6-113, C6-114, C6-115 and C6-116)
These four papers look at future scenarios for the distribution system based on surveys, analyses and benchmark models of existing systems in different countries. Some of the surveys deal with normal operation conditions (paper C6-113, C6-114 and C6-116), whereas the focus of paper C6-115 is related to load shedding. In all papers the integration of a high number of new DG is an important issue, since this may impact the distribution grid both in normal condition as well as in contingency situations.

Paper C6-113 (Croatia, USA, utility) shows the results of South East Europe Distribution System Operators (SEE DSO) benchmarking study, comparing over 100 general, operational performance, operational cost control, financial performance, metering, billing and revenue collection, and customer service key performance indicators over a five year period (2008 – 2012). Parameters from 9 DSOs, also from U.S., are compared, providing recommendations for future network operation.

Paper C6-114 (United Kingdom, academia) summarises the work done by the Smart Grid Forum's Work Stream 7, concerning the technical viability of innovative technologies in Great Britain from the present until 2030. The study is aimed at characterising future network operation, and explores network planning under different low carbon technology energy scenarios, such as photovoltaic and wind generation and electric vehicles and heat pumps as new loads, and with the deployment of a variety of smart network solutions such as energy storage and demand side response. 4 different base networks are studied (urban to city London). The paper concludes with different solutions to overcome, for instance, thermal and voltage issues.

Paper C6-115 (France, utility) assesses the impact of DG on the efficiency of the existing load shedding scheme implemented in France. The analysis is based on the existing Low Frequency Demand Disconnection (LFDD) scheme, which automatically disconnects loads in order to stabilize the frequency above the disconnection threshold for generating units (47.5 Hz). This is presently implemented at the control-command systems of the HV/MV French substations at different levels 49 Hz, 48.5 Hz, 48 Hz and 47.5 Hz, disconnecting 20% of the distribution system demand at each stage. Two scenarios with different high shares of DG distribution are simulated, leading to recommendations that propose different solutions for both scenarios.

Paper C6-116 (Cote d'Ivoire, Belgium, utility) presents the different steps required to develop an expansion plan for the city of Abidjan up to year 2030, with the required quality of service, and taking into account load growth and new investments. The network today exhibits frequent overload conditions of both feeders and transformers, and N-1 redundancy is not satisfied. A Smart Sizing tool has been used to find the optimal long term investment plan that minimizes the total costs, and at the same time takes, for instance, network constraints into account. Sensitivity analysis assesses the impact of some of the most uncertain parameters and thereby explores more what-if situations.

Question 1.8. Based on the analyses of today's distribution grid, what are the main challenges for the future network operation? Are these challenges related to the normal operation or to contingency operations? What investments will be required and are new regulations required to support such investment?

Question 1.9. What new or novel approaches should be implemented in the development and operation of new distribution grids in developing countries that will support DG and provide adequate network reliability?

Subtopic 5 - Control issues in the distribution network including demand integration
(papers C6-117, C6-118, C6-119)
The three papers under this sub-topic consider new advanced control and operation methods for the MV and LV distribution network grid in order to include more dispersed fluctuating generation while ensuring the hosting capacity of the network grid is not compromised and while giving possibilities to have demand management. The methods are either verified in real networks, or by simulations.

Paper C6-117 (Italy, utility) deals with the integration of Battery Energy Storage Systems (BESS) at the power generation plants, and how they can provide benefit via deferring or avoiding MV and LV grid reinforcements, providing ancillary services such as frequency control, loss reduction, voltage profile enhancement, and RES dispatching both at local (distribution) and at global (transmission) levels. However, the BESS integration also resulted in some challenges for the DSOs since a lack of any utility control of the BESS gives rise to unpredictable forecasts of loads and production. Therefore, the diffusion of embedded storage has to be carefully managed through rules and technical standards to assess the different requirements of the stakeholders involved (DSO, TSO, producers).

Paper C6-118 (Italy, utility) presents results from the European GRID4EU project as seen from the Italian perspective, showing results from advanced MV network control. Special focus is on voltage regulation - open and closed loop results, statistical data analysis regarding the daily usage of the

HV/MV transformer's On Load Tap Changer (OLTC), real field results and lessons learnt from the usage of an Electric Energy Storage System (EESS) and finally "Black-start" experience using the EESS. The state of the network is analyzed using state estimation using real measurements, forecasts of PV production and historical data, followed by an optimal power flow calculation every 15 min to find best solutions for the voltage regulation. Three different scenarios are discussed for the voltage regulation method: normal operation, planned operation 24 hours ahead (open loop) and on-line operation (closed loop). The method can be used both for real-time application, and as a planning tool.

Paper C6-119 (China, academia) describes a linear optimization model for active and reactive power dispatch in Active Distribution Systems (ADS). It uses a new DC-power flow that takes reactive power into consideration and which can linearize the power balance equations, the loss of grid, and apparent power of lines as well as guarantee the precision of calculation. The optimization is done at two stages. First, the schedule of DGs and DR is optimized under the assumption that DR resources are independent of voltage. Then, the model of load is revised according to the optimal DR at the first stage, and then the scheduling of DGs is optimized again with DR unchanged. The method is verified for the IEEE 33-node system.

Question 1.10. When is it envisaged that there will be utility scale implementation of demand side integration with an associated market, which can actually handle it? What are the main obstacles to achieve this?

Question 1.11. The control and specifically the automation of the distribution network requires a significant number of measurements. What are the most important parameters to be measured, with which purpose and with what resolution? Is there a risk that we are or will measure too many parameters, resulting in unnecessary complexity and increased errors?

2. Preferential Subject 2 (Energy infrastructure for urban networks)

The areas dealt within the subject 'Energy infrastructure for urban networks' are:

- Smart Cities
- Multi-energy systems including heat, cooling, gas, water, transport
- Impact of developments in energy technology, IT, big data, and further trends on the distribution system

The papers submitted

There are nine papers submitted for Preferential Subject 2. In view of the wide variety of topics, the papers were grouped into three subtopics:

- Smart Cities (papers C6-202, C6-203, and C6-204)
- Multi-energy systems including heat, cooling, gas, water, transport (papers C6-201, C6-208, and C6-210)
- Impact of developments in energy technology, IT, big data, and further trends on the distribution system (papers C6-205, C6-206, and C6-209)

Sub-Topic 1 – Smart Cities

The submitted papers describe the architecture pursued in power systems and smart cities. These consist of an integrated approach to develop the relationship between stakeholders and the public service, etc., while utilizing all renewable energy sources maximally and promoting the introduction of electric vehicles. In addition, multiple approaches to analyzing and evaluating these complex smart grid systems are proposed using virtual-based and real-world based approaches and a combination of both approaches.

Paper C6-202 (Austrian, academia) describes system validation approaches for smart grids. Previous and ongoing research activities have focused mainly on validating certain aspects of smart grids, but until now, no integrated approach for analyzing and evaluating complex configurations in a cyber-physical systems manner has been available. This paper analyses different validation approaches taking virtual-based (simulation, software-in-the-loop, and co-simulation) and real-world-based (laboratory- and field-based) approaches and a combination of both approaches (e.g., controller-hardware-in-the-loop and power-hardware-in-the-loop) into account.

Paper C6-203 (Austria, academia) describes an optimized and enhanced grid architecture for EVs in Europe aimed at installing a large number of EVs in the grid while maximizing the potential of DER integration. Grid architecture has been developed by including relevant clusters through following a smart grid architecture model framework and an IEC smart grid standards map to study various scenarios and approaches from different DSOs. However, network types must be limited in order to increase readability, focusing only on the most important networks. EV charging infrastructure is placed between DERs and consumers, as EVs may act as generators as well as consumers. Various use cases of flexibility services, including users and providers of services, are mapped in the architecture model and how they affect all domains of the grid is evaluated.

Paper C6-204 (India, academia) describes a national project for developing smart cities by introducing the smart grid as their fundamental infrastructure. First, a geometric information system for all infrastructures will be developed by one designated agency. Next, grids that can supply stable electricity 24×7 to all citizens will be developed, followed by the integration of DERs and EVs into the grid. Finally, other social services such as water and gas distribution, transportation, and social security will be optimized in an integrated manner. It will be more difficult to apply this development process to existing cities, although the IT and automation systems of state-owned electricity distribution companies are expected to be leveraged while other services are integrated in the same way. A new standard framework for benchmarking smart cities called the smart city maturity model (SCMM) is developed to evaluate the existing state of a city followed by decision making as to the target state for the city in each of the infrastructure domains and services.

Question 2.1. There are many stakeholders, inspection methods, and approaches in the realization of smart cities, including consideration of the effective uses of renewable energy resources and electric vehicles. Currently, are there any examples of smart cities that have been attained?

Question 2.2. Renewable energy resources and electric vehicles are the key factors of a smart grid. On the other hand, these energy resources have uncertainty in terms of output and uncontrollability compared with conventional ones, as they depend on weather or on the lifestyles of vehicle owners. Based on these characteristics, are there any points to keep in mind for urbanization and electricity use? In addition, what are the advantages or disadvantages of EVs compared with ordinary battery-based energy storage systems?

Sub-Topic 2 - Multi-energy systems including heat, cooling, gas, water, and transport

There is a wide global interest in applying new generation and power consumption technology that could change load curves significantly for distribution networks such as renewable energy sources (RES) and electric vehicles (EV), demand response, etc., and various demonstrations have been conducted. Spreading these new technologies into distribution networks may affect power quality, including voltage fluctuation and voltage deviation caused by rapid load changes, and some challenges must be met. In these papers, control technologies to maintain appropriate voltages are proposed.

Paper C6-201 (Denmark, academia) describes an adaptive control technique using an electric water heater (EWH) and photovoltaics (PV) to cope with the grid under-voltage (UV) and over-voltage (OV) in low-voltage distribution networks. These challenges occur with increasing integration of renewable energy resources and electrification of heating, gas, and transport under favorable Danish government policies. The proposed control technique performs active control and reactive power injection/consumption for EWHs and PVs according to the magnitude of voltage violation indicated by voltage information at a connection point in real time. The effectiveness of the proposed technique was demonstrated in a typical 0.4-kV distribution network by time-sweep simulations.

Paper C6-208 (Italy, utility) describes the simulation results of a wide planning study performed on a real active distribution grid, including EV charging stations connected to MV/LV grids in different EV propagation scenarios in Italy. In the near future, a large spread of electric vehicles (EVs) is anticipated in accordance with European policies and regulations dealing with environmental sustainability. This will make the number of charging station connections important. This paper considers a smart management approach for this situation, taking into account coordinated control of RES energy production and EV charging stations and the operation limits of grids in actual assets to defer or avoid network reinforcement and development.

Paper C6-210 (Japan, academia) describes a coherent demand response demonstration project the examined various use cases (including the aggregator business, four area demonstration projects, and incentive-type DR demonstrations) toward standardization of automatic demand response (DR) in Japan to prove business viability of official industry-university cooperation. The project has been recognized as verification for the ADR construction technique in Japan, including a connection summary report based on rearranging technical problems and their demonstration results. Moreover, considering that the voltage fluctuation problem in distribution systems under DR will arise when DR becomes widespread, cooperated voltage control techniques are proposed for linking battery energy storage systems (BESS) with conventional voltage control devices such as load ratio transformers (LRT) and step voltage regulators (SVR), and their evaluation results are described.

Question 2.3. It is a practice of smart inverters to control the load apparatus and PV on the consumer side for the purpose of contributing to distribution networks. Are there any other functions or ideas for using distribution networks with load apparatus and batteries to contribute, such as at generation facilities? If so, what kind of contribution is expected for networks?

Question 2.4. Demand response (DR) has attracted attention as a new technique that can change the load curve dramatically, and various demonstration projects have been performed. Are there any examples of methods for which DR has been applied?

Sub-Topic 3 – Impact of developments in energy technology, IT, big data, and further trends in distribution systems

The standardization of system interconnection requirements such as the common information model (CIM) is very important for realizing active distribution networks that cooperate with smart meters and market systems, etc. Examples of utilizing measured data from smart meters include load estimation in MV networks and detection of various events on LV network such as over/under-voltage, neutral loss, etc.

Paper C6-205 (Japan, utility) describes a method of estimating the actual load in MV distribution lines by utilizing smart meter data. The Japanese utility measured distribution line current at substations for proper distribution system operation; however, it has become difficult to determine the actual load because measured line currents recently have included dispersed energy resource generation. In this paper, averaged load curves for consumers with similar load patterns are composed using smart meter data. Results indicate that the actual load of distribution lines can be estimated and that they need not handle all consumers' data in order to estimate the distribution line load accurately. In addition, PV generation can be also estimated by utilizing this method.

Paper C6-206 (Spain, utility) describes the development of a system to operate and manage LV networks by utilizing data from smart meters and related systems. This system can visualize changes on an LV network such as switching operations through cooperation with AMI, GIS, CIS, etc., using the CIM standard. As an advanced LV network management function, the system can detect various events on an LV network such as over/under-voltage, neutral loss, etc., based on event information from smart meters transmitted only in the case of spontaneous event recording. This data utilization could impact communication systems and require new devices to be adopted, thus a demonstration project is ongoing in the Bilbao area.

Paper C6-209 (China, industry) suggests an integrated model for marketing and distribution information standards that can provide fundamental information for next-generation data integration and application. This includes a constructed topology extension model and an application management extension model. In the former suggestion, a simplified model of a distribution system was built to improve the program operation speed of the distribution system. Subsequently, a feeder automation expansion unified model was built based on the IEC6186868/CIM standard for detailed description of power outages in order to propagate feeder automation among many systems.

Question 2.5. As residential-level PVs such as the roof-top type are being installed, the needs of state monitoring of distribution are enhanced. As this depends on the balance between required measurement accuracy and cost, which use cases, ideas, or techniques are considered for estimation of the state of distribution networks using data from smart meters and managing them?

Question 2.6. Extensibility of distribution system management and increased quantity of provided data are of concern in terms of their influence on communication infrastructure. Expanding these viewpoints to whole distribution systems, what practical communication systems, or infrastructure should be adopted?

3. Preferential Subject 3 (Microgrids and off-grid hybrid systems)

The theme for Preferential Subject 3 (PS3) is 'Microgrids and off-grid hybrid systems'.
The areas dealt with in this subject are:

- Flexible options for operating isolated and grid-connected microgrids
- Advanced automation and voltage control schemes for DG
- Storage systems for microgrids and network management applications
- Planning of active networks with distributed energy resources and microgrids
- Business cases for microgrids and community energy systems

The papers submitted

PS3 includes 10 papers within the topic. The authors come from 10 different countries and four continents, which clearly demonstrates international breadth of the discussion, diversity of applications and widespread interest in the topic.
The papers were regrouped in three subtopics:

- Voltage control and automation of active networks (papers C6-305, C6-306, C6-308)
- Flexibility and enabling technologies for microgrids and active distribution networks (papers C6-302, C6-303, C6-307, C6-310)
- Planning of and business cases for future networks (papers C6-301, C6-304, C6-309)

Subtopic 1 – Voltage control and automation of active networks (papers C6-305, C6-306, C6-308)
These three papers broadly deal with issues regarding advanced automation and voltage control schemes that can be applied in active networks and microgrids alike, as well as with the opportunity to operate parts of the distribution grid as microgrids to improve reliability. C6-305 deals more specifically with MV level centralised and decentralised solution for voltage control for new DG connections. On the other hand, C6-306 and C6-308 discuss projects with advanced automation schemes also allowing islanded operation of certain network areas, with the former paper considering in particular a CHP-based microgrid, and the latter applications of storage and electric vehicles.

Paper C6-305 (Korea, utility) presents and discusses technical guidelines used by Korea to assess new connections of DER to the MV distribution network. Potential issues, primarily in terms of steady state voltage control, are solved by active network management schemes (otherwise further DER integration is not allowed). Two active voltage management (AVM) schemes are proposed here by the Korea Electric Power Corporation (KEPCO), namely, DER-AVM for regulating voltage at the point of common coupling of DER by means of reactive power control of the inverter (self-regulating, *distributed* solution), and step voltage regulator-AVM (SVR-AVM) for regulating voltage profiles under the installed point of SVR (*operator side, centralised* solution). The schemes are discussed in detail and a case study for a field trial shows the effectiveness of the concept.

Paper C6-306 (Czech Republic, utility) aims to assess how automation and smart control facilitated by ICT can optimize network operation on MV and LV levels as well as enable islanded operation to improve reliability provision in certain areas of the network, especially those more exposed to failures (e.g., in mountain areas). Islanding, in particular, was tested on an MV urban network (1.2 MW peak) with supply from a CHP plant (1.6 MW peak), and it is discussed in detail and shown how such a microgrid can improve reliability to about 2,000 customers.

Paper C6-308 (Germany, Spain, utility/academia) discusses two key areas of smart grid development, namely, rural networks and management of electric vehicles. The work describes two lighthouse European projects ("Well2Wheel" and "Smart Rural Grid") dealing with these topics. The link is the implementation of the same virtual power plant technology and the approach of "grid cells". More specifically, the first project attempts 15 minutes average energy balance in several individual grid cells, while the second one pushes the cells to achieve islanded operation. It is shown how existing infrastructure can enable renewable integration (without network reinforcement) in rural areas by optimised asset control and using "intelligent distribution power routers" (IDPR). These are active power electronic devices operating at LV to reduce losses from unbalanced loads and enable active voltage and reactive power control. If also batteries (besides EVs) are included, the IDPR can also allow temporary islanded mode of grid cells at times. As cells can in principle run local markets too, the DSO could avoid centralised control by sending local price signals according to the grid situation and forecasted congestions.

Question 3.1. Considering a microgrid and the development of DER technologies (including inverters and reactive power capabilities), what type of voltage control concepts should be adopted within the microgrid? To what extent reactive control of inverters can support voltage control, as opposed to use of active power and On-Load Tap Changers (OLTC)? Should a difference be made between LV and MV applications, and which schemes should be preferred at different voltage levels?
What voltage control options are available at different voltage levels and in different countries?

Question 3.2. While the benefits of microgrid for network reliability are quite clear, what are the benefits in terms of support of the upstream network? How can the microgrid contribute to upstream voltage regulation and other services, through which services and to whom? Is there any clear evidence of provision of different upstream services in microgrid trials or real schemes? When operating the microgrid as a VPP for both technical and economic purposes, who would 'control' it and how would one solve the commercial/regulatory aspects of it? Is there any experience?

Subtopic 2 – Flexibility and enabling technologies for active networks and microgrids
(papers C6-302, C6-303, C6-307, C6-310)
These four papers discuss various flexibility options for microgrids and active networks, particularly demand response (Paper C6-302) and low load diesel generators (C6-303), especially for off-grid system, and battery storage (C6-307 and C6-310). Further, C6-307 analyzes more in detail the issue of aging when considering different services from the battery storage, while C6-310 considers a hybrid storage system to improve islanded and grid-connected operations.

Paper C6-302 (Australia, utilities/research centre/ academia) addresses the context of consumers living in remote areas or on islands serviced by a local electricity generation (usually a diesel generator) and distribution system 'isolated power system' (IPS). The cost of diesel supply to remote areas brings about very high electricity costs. While this is an incentive for RES, their intermittency characteristics still hamper full development. Enabling technologies such as battery or hydrogen storage may be complex and expensive and not solve potential inertia issues. In this paper an automatic fast (i.e., sub-second) DR scheme is discussed along with provision of spinning reserve, with demand effectively working as a virtual power plant. It is shown in detail, with the relevant control architectures and communication infrastructure, how fast DR could effectively support RES integration in IPSs by using well-proven and relatively inexpensive components.

Paper C6-303 (Australia, utilities/academia) is a sort of companion paper of C6-302 described above, where the problem of integration of RES and stability in islands and remote areas is addressed via combining diesel and RES in a hybrid power system (HPS), able to reduce both operational cost and environmental emissions. However, RES penetration is limited by the minimum load limit of diesel generators, which at time creates excess energy that needs to be "dumped" into storage (increasing complexity and cost) or curtailed (increasing waste and cost). In the paper, a new flexibility solution is tested that adopts "*low load*" diesel generators to integrate additional RES, reducing cost (of diesel fuel, mainly) and complexity and increasing efficiency.

Paper C6-307 (Switzerland, industry), in the context of decreasing cost of lithium-ion battery energy storage systems (BESS) and the consequent rise of interest towards it, investigates the effects of continuous (stochastic) or periodic (deterministic) operation of BESS on *aging* of batteries, consisting of BESS capacity and performance decreasing with time due to chemical processes. To address this, the paper discusses a semi-empirical aging model that considers both cyclic and calendar aging. In particular, due to the BESS energy constraints and internal losses, the restoration of the State of Charge (SoC) to a reference range is key. Hence, several SoC control schemes are assessed under predictable and stochastic power system applications, with the results showing that lifetime extension depends on the specific application, namely, on the degree of flexibility allowed by a given service. One of the suggestions made is also to use forecasts in microgrid applications to increase benefits.

Paper C6-310 (Russia, utilities/research centres) deals with development of a hybrid energy storage (HES) system based on a battery and a set of supercapacitors, for both autonomous and grid-connected applications in the presence of RES. A HES (200 kW power, 200 kWh energy) was developed and tested. The results indicate that the battery's charge and discharge profile is much smoother relative to its operation without supercapacitors, which also positively impacts the physics of battery cells. Further, the HES could be operated for short time in "forced mode", with output double than rated power. The HES operation can also contribute to MV and HV grid regulation to cover peak loads for up to 1 hour, while flexibly compensating strong fluctuations of frequency, active and reactive power. These benefits apply to both grid connected and microgrid operation.

Question 3.3. What are the main constraints in terms of frequency response in microgrids and what are the opportunities for innovation? Do we need to develop new means to provide inertia to off-grid systems or can we replace this with advanced control schemes? Do we have examples of different approaches depending on size of the system, RES penetration/type, conventional portfolio, etc.?

Question 3.4. What flexibility options can be envisaged for microgrids? What flexibility could microgrids deliver to the upstream grid? Is there any evidence from real applications of high flexibility options inside the microgrid and for provision of upstream services? To what extent can we use forecast to minimize the use of dispatchable resources as a flexibility option (particularly offgrid)?

Question 3.5. What should we use storage for (frequency response? intradaily/daily arbitrage? etc.) and what technologies are most suitable today? How can we plan an optimal portfolio of hybrid storage? To what extent could DR be a substitute for storage technologies, and for what services? Can we have microgrids without (electric) storage?

Question 3.6. How do we deal with the tradeoff between providing multiple services to optimise the business case for storage and additional loss of life due to increased cycling? What studies or real evidence are available on this?

Subtopic 3 – Planning of and business cases for future networks (papers C6-301, C6-304, C6-309)

These three papers deal with planning of microgrids, including a discussion on design criteria and specifications as from a competition in New York (C6-301), a methodology to outline and quantify the business case opportunities for off-grid and grid-connected applications (C6-304), and the inclusion of microgrid in distribution system planning to reduce overall investment and operational costs (C6-309).

Paper C6-301 (USA, industry/governmental authorities) describes one of the processes by which the New York State is reforming its energy industry and regulatory practices to foster energy efficiency, RES integration and adoption of new technologies (including microgrids, primarily for resilience purposes). More specifically, the paper presents the $40,000,000 NY Prize Community Grid Competition project announced in December 2014 to support the development of community microgrids. The tree stages of the competition are presented, consisting of Stage 1: Feasibility Assessment, Stage 2: Audit-Grade Detailed Engineering Design and Financial/Business Plan, and Stage 3: Microgrid Build-out and Operation. The paper deals with the key technical, commercial and financial guidelines to the participants for each stage, detailing in particular the technical aspects of electrical, controls and communication infrastructure of the community microgrid. Summarizing in great detail such guidelines aims to be beneficial to other such schemes that might be developed to promote microgrids worldwide.

Paper C6-304 (Canada, utility/academia) discusses a general methodology to set up a business case for Microgrids, which can also steer the Microgrid design (e.g., storage and DR requirements). The methodology provides a systematic approach to formulate and quantify a business case, and is based on an adaptation of the “use case approach” whereby stakeholders, benefits, and beneficiaries and relevant allocated benefits are defined and assessed/optimised. Applications to practical cases such as remote mining sites and communities and Microgrids that are grid-connected to critical distribution grids illustrate the approach. Results show that already today there may be clear benefits in the case of remote communities and mining sites.

Paper C6-309 (Italy, academia) discusses a new planning methodology that can maximize the benefits from microgrids to the whole system. In particular, the methodology defines new expansion approaches for MV distribution systems with multiple LV microgrids as integral part. These multi-microgrids are assessed based on both CAPEX and OPEX, with the underlying rationale that the realization of microgrids will be driven by customers for economic and environmental reasons and will at the same time represent an important opportunity for the DSO (provided that a suitable regulatory framework is in place) to save in network investment, besides increasing the reliability and quality of supply under emergency. When internalised in the system plan, these benefits could also justify the storage that would be required to enable microgrid (and multi-microgrid) development.

Question 3.7. Why should we and how can we incorporate microgrids in distribution system planning? What are the barriers? Are these barriers more of technical or commercial and regulatory nature?

Question 3.8. How can we foster the business case for grid-connected microgrids? Is it relying on the business case for storage? Is it related to internalization of energy externality? Or to identification of suitable services that the microgrid could provide to its customers as well as the upstream network?

Question 3.9. Should microgrids be incentivised as enabling technology (e.g., for RES integration or for resilience)? Do you know of any other schemes such as the NY Competition?

The C6 Contributor´s meeting will take place on Thursday, August 25, 14-18h in Room 361, 3rd floor. Prepared contributions should be sent to the corresponding special reporters by August 10, 2016.