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 2018 General Session three preferential subjects were proposed:

- PS1: Achieve Flexibility through Strategic Distribution Planning
- PS2: Energy Storage in Distribution Systems
- PS3: Intelligent Electrification for All

A total of 34 papers were selected for discussion at the General Meeting, 11 for PS1, 10 for PS2 and 13 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 (Achieve Flexibility through Strategic Distribution Planning)

The papers submitted
PS1 includes 11 papers within the topic. The authors come from 12 different countries, and hence demonstrate a wide international interest in this topic. The areas dealt with in the subject '**Power distribution network planning**' are all related to Distributed Energy Resources (DERs), therefore there may be some crossed sections in below regrouped five subtopics:

1) **Planning and future power distribution aspects:** Distribution Planning with DERs. Impact of DERs on power distribution system planning, and how to consider the uncertainty and availability in both source and load sides (papers C6-101, C6-104, C6-105);
2) **Modelling:** Modelling of Active Distribution Networks. Long-term forecasting model for energy and power flow. Modelling and simulation methods of demand side integration (papers C6-102, C6-103);

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3) **Operation and Control** issues on the distribution network including demand integration, and on low-voltage systems (papers C6-107, C6-108, C6-109);
4) Load management method 'Residential smart thermostats' for potential energy savings. Study on smart meters-based load management method in low-voltage power distribution systems (papers C6-106, C6-111);
5) **Asset management** (papers C6-110).

Subtopic 1 - Planning and future power distribution aspects (C6-101, C6-104, C6-105)

The three papers deal with the impact of DERs on power distribution system planning and how to consider the uncertainty and availability in both source and load sides. The distribution grid structure and the integration of renewable and dispersed generation are concerned, but from different perspectives, e.g. the voltage issues (C6-104 and C6-105), and economic aspects such as payback time and net present value are also discussed (C6-101 and C6-104).

Paper C6-101 (**Serbia**, Utility/Manufacturer) discusses the procedure for expansion planning of distribution networks under uncertainty and variability in both generation and load. A number of extensive expansion plans and appropriate evaluations are required in order to minimize the risk of significant expansion costs. Fuzzy set concept, fuzzy mixed integer linear programming and applicable risk evaluation tools are used in this paper. The numerical results show the necessity of conducting a risk analysis in expansion planning, and demonstrate the potential to improve the planning process in radial distribution networks considering renewable energy and load variability and uncertainty.

Paper C6-104 (**UK**, Academia) discusses the management of DERs at the distribution level and the interaction with transmission networks. As the poorly coordinated decisions by participant and stakeholders, such as generators, energy storage operators, and network owners, will result in increased total cost of the power grid, it is suggested to set-up entities to govern the relationship between them. It is also argued in this paper that the arrangements for energy trading, system operation and network investment should follow a common set of principles that apply across voltage levels and are structured.

Paper C6-105 (Germany, Manufacturers) presents the "Kopernikus initiative" which is supported by the German government since 2016. The project address the structure of distribution networks with renewable/distributed energy integration from different perspectives. The overall objective is to optimally balance investments in grid assets by applying intelligent operating approaches that enable direct use or storage of locally generated energy, or management of the demand side response as well.

Question 1.1. What major factors should be considered when planning power distribution network with an increased penetration of Distributed Energy Resources (DER) including Demand Response (DR)? How should planning approaches be changed to take into account uncertainty and variability in both load and generation? How should this new environment be taken into account when deploying and dimensioning the new network structure and its associated management and operation?

Question 1.2. What form will future developments and new planning strategies and methodologies take? How will these choices influence the design and deployment of future DER installations? Will these choices impact the nature, size and location of new DER installations?

Question 1.3. How can the energy production processes take into account and manage the volatility of the power produced from renewable energy resources? How can flexibility be built into the generation units, thus helping to balance supply and demand in a future distribution grid?
Would such a solution at the individual DER level be more cost effective than a local centralized solution handling a number of DER units operating at their optimal power point with no provision for balancing and energy firming?

Subtopic 2 - Modelling (C6-102, C6-103)

Both papers deal with models of distribution networks integrating distributed generation. Paper C6-102 examines the long-term forecasting model for energy and power flow. Paper C6-103 presents a modelling approach for active distribution networks applicable to distributed generation planning.

Paper C6-102 (Italy, Academia) argues that a large integration of renewable energy resources has a significant impact on the overall production significant and can no longer be neglected. An algorithm is developed to forecast both the Renewable Energy Resources (RES) generation and the load consumption, and thus can forecast the "net energy transfer" at MV busbar of the HV/MV transformer in the primary substation in the planning process. Possible saturation issues and critical operating conditions which have to be considered during the planning process are also discussed in the paper.

Paper C6-103 (Egypt, Academia/Utility) introduces a new power flow algorithm for modelling balanced and unbalanced distribution networks with any number of laterals or sub-laterals with an unlimited number of nodes. The algorithm is based on BFS method. The commonly used MV components are used in the preliminary steps. The validity of the proposed method is verified by means of two test feeders and practical 22kV distribution networks. The final results show the effectiveness and robustness of the proposed method.

Question 1.4. Are there benefits in planning process of using the "net energy transfer"?
Are there drawbacks in establishing for example the load flows and determining the line loadings? What are the saturation and congestion issues and critical operating conditions which should be considered in planning processes? How these operating modes and conditions be modelled?

Question 1.5. To what extent can or will Advanced Distribution Systems (ADS) and the implementation of new planning tools, those described in the papers and others, impact the structure of existing and new distribution systems? What will the impact be in developing countries where opportunities exist to plan new grids using these tools and others?

***Subtopic 3* - Operation and Control** issues in the distribution network including demand integration (C6-107, C6-108, C6-109)

The three papers relate to renewable energy resources integrated into LV or MV systems. The issues of voltage constraints and the solutions are discussed, i.e. namely methods to improve the ability to control the feeder voltage profiles with embedded generation and storage. Paper C6-108 focuses on the applications of flexible grid operation to increase the penetration of renewable energy in low voltage distribution networks.

Paper C6-107 (Australia, Consultant) describes a new approach to the analysis of feeder voltage profiles, and discusses the utilisation of Embedded Generation (EG) and Embedded Storage (ES) control capabilities in order to realize the effective management of the voltage profile when the feeder hosts many small and variable loads and EG sources. An analytical framework is presented for studying the load flow relations between voltage, power demand and reactive power dispatch. A statistical formula for active power flow and losses at all points along a feeder with a specified load and generation profile, and an exponential-power-law asymptotic formulae for voltage profiles on low-loss feeders are introduced in this paper. The generalization to practical feeders with higher resistance is suggested.

Paper C6-108 (Poland, Institute) points out that LV generation modules without any requirements on reactive power control combined with ability to remotely curtail generation of active power will cause additional problems. Some flexible control strategies for LV and MV power grid are introduced to reduce curtailment. The effectiveness of selected methods is verified by simulation and illustrated using practical case studies. Moreover, a reference to the Requirements for the Generator imposed by ENTSO-E, applicable to all future generating units, called power generating modules (PGM), connected to the grid, is presented.

Paper C6-109 (Germany, Institute) shows a concept illustrating how different flexibility options can be integrated into a single framework. This allows the selection of the most cost-effective option to mitigate local grid voltage violations and congestion problems (overloading)

Question 1.6. How can a coordinated control between MV and LV grid be achieved?
What is the most urgent problem that needs to be addressed?
Are there any additional requirements for high-voltage power grids?

Subtopic 4 - Load management method (C6-106, C6-111)

Both papers deal with the energy usage and load management of end user or consumers. Paper C6-106 introduce an idea of energy saving by using smart thermostats in the household area. Paper C6-111 studies a hybrid load management based on forecasting data and measurement data from smart meters.

Paper C6-106 (Turkey, Academia) introduces an idea to realize energy saving by using thermostats in households. In the study, for manual, programmable, smart thermostats, three different tests were carried out to assess the efficient use of thermostats. Some field tests were carried to verify the potential energy saving by using thermostats in the residential area.

Paper C6-111 (Japan, Utility) studies a hybrid load management method with forecasting for LV systems and actual measurement using smart meters. It presents the efforts deployed to validate accuracy. It has also been confirmed that the use of the method proposed by this paper allows appropriate identification of the presence and operation of PV systems and loads in LV systems. It was also confirmed that utilizing data from smart meter in forecasting allows more accurate forecasts.

Question 1.7. To achieve higher energy saving and utilization efficiency, what strategies and scenarios should be considered in future residential smart thermostats and home automation systems? What are the expected energy savings? What limits the potential for savings? What is the impact of missing and distorted data on the forecasting and operating of the smart thermostats?

***Subtopic 5* - Asset managemen**t (C6-110)

Paper C6-110 (China, Academia) proposes a systematic power distribution network health index and the underlying theory to achieve the accurate evaluation and prediction of health of assets and networks. A unified, comprehensive and sharable prototype platform is developed to integrate data-driven analytics, model based reasoning and expert knowledge of the assets. A novel machine learning framework and method, guiding learning, is proposed to tackle the nonlinear multi-classification problem under open, dynamic and stochastic environment. The pilot application in a utility environment demonstrates that the platform has the potential to systematically improve asset management from a qualitative to a quantitative approach, from a partial to a holistic representation, from a local to a global perspective.

Question 1.8. Compared to power transmission system, what are the most important difference in asset management issues and approaches in power distribution system? What factors need to be considered to develop a holistic distribution network health index? Is there a difference between the different asset index classification methods? Are there benefits to using machine learning techniques, and if yes, what is the information needed and the data bases required to implement these techniques?

2. Preferential Subject 2 (Energy Storage in Distribution Systems)

The theme for Preferential Subject 2 (PS2) is 'Energy Storage in Distribution Systems'.
The areas dealt with in this subject are:

- Deploying and managing energy storage;
- Electrical and thermal applications, including advances in transportation electrification;
- Multi-energy systems and load interaction for energy efficiency.

The papers submitted

PS2 includes 10 papers within the topic. The authors come from 12 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 grouped into three subtopics:

1) Planning for the deployment of energy storage systems (papers C6-201, C6-202, C6-203);
2) Electrical, thermal and transportation applications (papers C6-204, C6-206, C6-208, C6-209);
3) Multi-energy systems including load interactions (papers C6-207, C6-210, C6-211).

Subtopic 1 – Planning for the deployment of energy storage systems (C6-201, C6-202, C6-203)

These three papers broadly deal with issues regarding the planning steps needed for the deployment of energy storage systems (ESS). C6-201 and C6-203 deal with the cost-benefit analysis of energy storage systems. C6-202 focuses on the impact of widespread prosumers (with PV-ESS combinations) on active distribution networks.

Paper C6-201 (**USA**, Utility) provides a cost-benefit analysis methodology for battery energy storage systems to defer distribution capacity upgrades on utility distribution systems. Sample results, established through a feeder-level study, are used to demonstrate the methodology application and these are extrapolated via a system-level analysis to estimate the total beneficial amount of storage. The methodology has been operationalized by a distribution utility and used to construct a practical deployment roadmap based on detailed engineering analysis and financial analysis.

Paper C6-202 (**Italy**, Academia/Utility) assesses the impact of prosumer energy storage systems on active distribution network planning. A real active distribution network is used to analyse different combinations, scenarios and operating conditions of photovoltaic and energy storage systems (PV-ESS). The aggregated profiles for each MV/LV substation were evaluated and benefits were demonstrated including the exploitation of distributed renewable energy sources, the mitigation of load ramps and the reduction of reverse power flow in the MV/HV substation.

Paper C6-203 (**Italy**, Academia) uses a cost-benefit analysis within the Italian regulatory framework to illustrate the implementation of energy storage in MV distribution networks. The potential services offered by energy storage systems are selected and ad-hoc metrics have been formulated to quantify benefits. A procedure is proposed to help determine cases where the benefits of ESS outweigh the costs. The results are used to identify ESS applications with a positive cost-benefit allocation projects without the need for additional assessments and proofs.

Question 2.1. What steps are needed to plan, effectively, for the deployment of energy storage systems into distribution networks? What elements of the cost-benefit analysis, if one is executed, are used as inputs to the plan? How would different cost-benefit analyses impact the plan?

Question 2.2. When deploying energy storage systems into distribution networks, who benefits and how? How are the benefits allocated to the different stakeholders or beneficiaries and how are the benefits quantified? Can a single benefit accrue to more than one stakeholder?

Subtopic 2 – Electrical, thermal and transportation applications (C6-204, C6-206, C6-208, C6-209)

These four papers focus on electrical, thermal and transportation applications of energy storage. C6-204 considers the novel application of using energy storage in combination with wind and photovoltaics to form a hybrid power station. C6-206 presents a stratified thermal model for heat pumps and electric boilers to improve voltage quality and mage congestion in electricity distribution networks. C6-208 demonstrates the advantages of shifting peak load from electricity and heat consumption. C6-209 shows that energy storage can be combined with wind power to maximise energy delivered from renewable sources.

Paper C6-204 (**Greece, Germany, France, Italy, Spain**, Utility/Academia/Manufacturer) presents an overview of the innovative research program TILOS (Technology Innovation for the Local Scale Optimum Integration of Battery Energy Storage), demonstrating the optimal integration of local-scale energy storage in a microgrid on the island of Tilos. The main objective of TILOS is the demonstration of a prototype battery system, based on NaNiCl2 batteries, which form the basis of a Hybrid Power Station comprising a wind turbine and a photovoltaic (PV) unit. The battery system supports multiple applications which range from microgrid energy management, maximized penetration of renewable energy sources and grid stability, to export of guaranteed energy levels to the main grid. The paper also describes the basic infrastructure, hardware and software components.

Paper C6-206 (**Denmark**, Academia, Investor) describes how flexibility can be unleashed from electric boilers and heat pumps in a Danish residential distribution network. The paper examines the possibility and need for interaction between the heating systems and the electric distribution network. Helping to overcome under-voltage and grid congestion, the use of heating systems for electrical demand response applications are explored. A strategy based on temperature and voltage control associated with flexible control of the thermal unit is discussed to mitigate the problems with low voltage in weak feeders, satisfying the end-user need simultaneously. Application of a stratified model, compared to the average model of thermal storage, improves information about the voltage quality and overcomes practical constraints associated with electric boilers.

Paper C6-208 (**China**, Utility/Academia) presents a coordinated planning methodology between electric distribution networks and regional electric thermal storage boilers, based on peak load shifting of heat and electricity consumption. The results show that, through peak-shifting and using the surplus capacity of the electric distribution network, the corresponding electric network investment cost for new electric storage heat boiler can be significantly reduced (along with the emissions associated with burning fossil fuels).

Paper C6-209 (**Korea**, Utility) demonstrates the application of an energy storage system to facilitate a wind power connection at Youngheung thermal power station in order to meet mandatory renewable energy certificate targets. Whilst 1 MWh of renewable energy generation corresponds to 1 REC, the combination of wind generation and energy storage can result in 4.5 – 5.5 REC for the discharge of 1MWh. This provides a good incentive for wind power generators to couple their systems with energy storage devices. In this application, for the first time, a lithium-ion battery (2MW peak, 8MWh capacity) has been installed in Korea to maximise REC acquisition. The operation functions of the energy storage system comprise REC-maximizing operation and ramp rate operation.

Question 2.3. What are the state-of-art applications for energy storage in electrical, thermal and transportation systems? What are the available ratings at the present time? What is the relative size of the energy storage system required to obtain a significant impact on improving the efficiency of these systems?

Question 2.4. What are the quantifiable benefits of applying energy storage systems to interactive electrical and thermal networks? Is the energy storage solution cost effective in the present context? If not what would be required for this to happen?

Subtopic 3 – Multi-energy systems including load interactions (C6-207, C6-210, C6-211)

These three papers broadly deal with multi-energy systems and load interactions including the interoperability requirements for energy networks for remote or island networks (C6-207), the remote control of PV integrated to power conditioning and home energy management systems (C6-210) and a study of energy storage systems for the multi-level integration of generators and consumers.

Paper C6-207 (**UK**, Consultancy) describes the opportunities for interoperability between different energy networks for remote or island networks. Island and remote electricity networks present particular technical and commercial challenges for integration of low carbon generation and demand. Taking a broader "whole system" approach that considers interoperable electricity, heating/cooling and gas networks can help to resolve some of these challenges cost-effectively. Using real-world case study examples, this paper presents the quantifiable benefits that can be achieved through interoperability (such as diesel fuel reductions of 16-18% on Ramea Island).

Paper C6-210 (**Japan**, Academia/Utility) formulates a demonstration system for the remote control of PV and local load. Bi-directional communications using standard interfaces facilitated PV curtailment for large-, middle- and small-scale systems. Although delays existed with the operation of PV and Power Conditioning Systems (PCS), comprehensive testing showed that the system was applicable for all the practical purposes. The mitigation of PV curtailment for residential systems was also tested by the shifting load operation to cancel the reverse power flow. Two connection configurations between PV-PCS and home energy management systems (HEMS) can be applied to make maximum use of residential PV generation.

Paper C6-211 (**Russia**, Academia/Utility) presents experimental studies of energy storage systems for multi-level integration of generating stations and consumers. The models of multilevel integration were developed, dividing generation and consumption by temporal and integral characteristics (from the point of view of converted electric energy), and also using the hierarchy of data transmission and information between control systems.

Question 2.5. What monitoring and control systems are needed to facilitate the operation of multi-vector energy systems (including load interactions)?
Is there an advantage in using the decentralized approach rather than the centralized approach?
Can the elements of multi-energy systems be optimized and operated independently?
If not, what is the compromise solution or priority based control approach based on?

3. Preferential subject 3 (Intelligent electrification for all)

Electrification is a process of adopting electric end-use technologies. There are two main aspects of electrification:

- In developing countries - making electric power available to customers for the first time;
- In advanced economies – displacing other energy forms in final use.

Electrification provides opportunities to lower cost, lower energy use, reduced air pollution, etc.

The areas dealt within this preferential subject are:

1) Electric energy systems for smart cities and regions
   (papers C6-307, C6-313, C6-314, C6-315);
2) Grid-connected microgrids (papers C6-301, C6-304, C6-305, C6-312);
3) Off-grid electrical systems for remote and rural deployment
   (papers C6-306, C6-308, C6-309, C6-310, C6-311).

The papers submitted

PS3 includes 13 papers within the topic. The authors come from 14 different countries which clearly shows a widespread interest in this topic. The papers were regrouped in three subtopics.

Subtopic 1 - Electric energy systems for smart cities and regions (C6-307, C6-313, C6-314, C6-315)

Paper C6-307 (**EU**, EC/H2020 consortium) presents the progress in the integrated Pan-European research infrastructure project ERIGrid where integrated, cyber-physical systems based, multi-domain approach for a holistic testing of smart grid systems and solutions is currently being developed. It includes various simulation-based methods, hardware-in-the-loop approaches, and lab-based testing, which is combined in a flexible manner. The challenges of and solutions for integration and online connection of the partners' labs across different EU member states is discussed.

Paper C6-313 (**India**, academia) describes a smart city pilot project in the campus of Indian Institute of Technology Kanpur (IITK). This pilot project aims to identify the key challenges in implementing smart grid functionalities in India, and innovative solutions. Major R&D thrusts are: implementation of SCADA system, integration of renewable energy source (solar PV) with the distribution grid, smart home automation system and AMI. Several communication technologies, such as RF, ZigBee, Z-wave, and Wi-Fi have been tested and evaluated for monitoring and control of household loads for demand response and emergency load curtailment. The projects has demonstrated improvement in the overall power quality, a reduction in outage durations, and savings on electricity bills for households.

Paper C6-314 (**Spain**, industry, utility) discusses digitalization (AMI deployment) of LV distribution grids and shows how data analytics can enhance their real-time visibility, controllability and operation. As shown through the results obtained, data correlation analysis allows a step forwards to predictive O&M where preventive actions can be taken. For example, having more detailed information and capability of remote control allows DSOs to be less conservative regarding the amount of DG connected into the network. This work is part of the UPGRID project "Real proven solutions to enable active demand and DG flexible integration, through a fully controllable LV and MV distribution grid".

Paper C6-315 (**WG C6.31**, industry, utility) summarizes key findings of an MVDC feasibility study carried out by 35 experts from 14 countries. It targets MVDC distribution systems and applications with voltage range between 1.5kV (±750V) up to ±100kV. From the 16 survey reports received worldwide, it is found that the main driving force for the development of MVDC grids are the growth of DER and DC loads. The survey depicted the key technical requirements and features of MVDC grids include the structure/grid configuration, power convers and protective devices as well as system control and protection strategies. The study results show that the power supply capacity of MVDC is ~1.6x of corresponding MVAC circuit having similar installation and conductor cross section.

Question 3.1. What is a minimum level of ICT infrastructure (metering/sensing, communication, computation and data analytics/mining, etc.) required for smart city/region and what are minimum technical requirements (sampling, commutation speed, inter-operability, etc.) for different applications (operation, maintenance/service and planning)?
What kind of simulation/testing environment should be in place for a holistic analysis of new complex scenarios (planning) and validation of new solutions (operations), e.g. such as multi-energy systems, cyber-physical, etc..?

Question 3.2. What role can MVDC technology play in urban environment, what flexibility and benefits can it provide compared to MVAC distribution?
What are key technical challenges of using DC in distribution grids?

Question 3.3. How important is end-consumer participation in energy balancing and what kind of best regional practices can be shared (customer awareness, incentives, regulations, etc.)?

Subtopic 2 - Grid connected microgrid control architecture and functions
(C6-301, C6-304, C6-305, C6-312))

Paper C6-301 (Brazil, research foundation) presents an architecture, control and regulatory challenges for grid connected microgrids in Brazil. It gives an overview of a residential microgrid project in Fortaleza. A distributed control system manages the microgrid components such as IEDs and 3rd-party systems in a coordinated way. Another important element of the microgrid is the SCADA system, which enables a complete overview of the microgrid and performs control operations in a manual or automated modes. It is indicated that the main regulatory challenge for the development of microgrids in Brazil is the definition and management of the connection of the microgrid to the T&D systems.

Paper C6-304 (**Hungary**, industry) presents a simulation model of LV microgrid "The Liveable Future Park" in Fót connected to the MV utility network. As part of the project, a Full-scope Microgrid Simulator (FMS) was created to study various control schemes in different weather conditions and network configurations, without disturbing the everyday running of the park. The paper provides insights into main features and operational experiences of FMS.

Paper C6-305 (**Spain**, industrial research/utility) introduces MGridStorage project which aims to build and manage (by DSO) a 1 MW medium voltage advanced microgrid in a rural area of Alava. The project will address the following aspects: (1) operation of several distributed energy storage systems covering different technologies beyond lithium-ion, and the hybridization of some of them; (2) use of IEC61850 communication standard to achieve high performance and ensure interoperability; (3) develop an intelligent energy management system to operate the microgrid in both connected and isolated configurations by taking into account on-line generation and loads measurements, previsions as well as storage systems capacity and response time.

Paper C6-312 (**Australia**, academia) presents thorough investigations of a 3.275 MW_P solar PV and 600kW/760kWh battery storage system operation, located at the University of Queensland Gatton campus and connected to an 11 kV distribution feeder. Performance of PV tracking technologies (fixed-tilt, single- and double-axis tracking) and battery system as well as voltage variations are discussed in details. Results indicate that seasonal production gains from solar tracking point to summer and spring being the best seasons. In terms of battery, the overall operation and performance has been found to be satisfactory. Excessive operations of step voltage regulator are identified in cloudy days because of sporadic changes in PV generation due to cloud movement.

Question 3.4. What kind of control architecture is most suitable for microgrids and how does it depend on particular microgrid configuration?
What is a role of and requirements (bandwidth, interoperability, etc.) for communication system?
With a continuously growing performance and reduced cost of ICT, can we envision microgrids running in full "auto-pilot" mode satisfying both – stability and economic optimization?

Question 3.5. What is a role of numerical analysis and digital twins (components and control systems) in efficient microgrid design and testing? How can operational data received from SCADA and other services (e.g. weather) be used to fine tune digital models?

Subtopic 3 - Off-grid systems for effective rural electrification (C6-306, C6-308, C6-309, C6-310, C6-311)

Paper C6-306 (**Belgium**, utility/academia) presents an optimization tool to select the best fitting technology (on or off grid) for rural electrification based on a techno-economic analysis which uses extensive GIS data. These allow to model a real lengths of possible grid connection paths and specific geographical conditions (landscape, impenetrable zones) as well as existing infrastructures (roads and railways). It takes into account voltage and line loading constraints and is scalable to entire region or country. Several examples provide a comprehensive illustration of required input data and simulation results.

Paper C6-308 (**Italy**, utility) deals with the replacement of diesel generation in Giannutri and Giglio islands in the Tyrrhenian Sea, with a hybrid power plant, including solar PV power plants and energy storage systems. Steady state and dynamic simulations have been carried out, for selecting type and size of key system components in order to maintain reliable and stable network operation while reducing cost and environmental impact of diesel generation. Simulation results show that if the installed PV power is less than about 20% of peak load there is limited need for energy storage.

Paper C6-309 (**Canada**, academia) addresses the integration challenges of a high penetration of intermittent resources, such as solar PV or wind generation, into a diesel-based remote power systems. Specifically it presents a software tool which automates and performs the grid impact studies that are of most concern to diesel-based remote power systems. The results of the studies performed in Old Crow provide several significant results. Based on the stability study, it is found that the system can host a 260kW solar plant under normal operation with minimal impact on voltage, frequency and the existing protection system. However, the solar plant capacity is limited by the economic implications associated with curtailing an upwards of 16% of the energy produced by the plant.

Paper C6-310 (**Singapore**, industry, utility, academia) introduces the Renewable Energy Integration Demonstration-Singapore (REIDS) initiative, the world largest microgrid demonstrator in Semakau Island. Industrial and academic partners set up a state-of-the-art multi-fluid microgrid solution to integrate decentralized systems with increased renewable penetration supported by energy digitization enabling control features. The solution targets a scalable and open platform for a multi-fluid optimization across renewables, flexible demand, batteries and hydrogen storage. A power control module allows up to 100% intermittent RES penetration thanks to a virtual synchronous generator mode.

Paper C6-311 (**Australia**, academia) discusses operational aspects of a hybrid diesel-variable renewables off-grid application. Recent advances in diesel generator technology are redefining low load diesel (LLD) thresholds with opportunity for hybrid power systems to increased system flexibility. This paper identifies opportunity in adoption of LLD as a forerunner to ESS integration. Conversion of an existing generator to LLD is presented as an affordable and accessible transitional technology. A case study of the King Island power system is offered in defining the commercial and environmental benefits of LLD integration. In extending system capability to medium renewable penetrations, LLD is able to return fuel savings of 8-16%, in comparison to conventional operation.

Question 3.6. What kind of new tools and models are needed for optimal investment planning and technology selection for rural electrification? What kind of studies must be performed and what are the most important/relevant objective functions and constraints?

Question 3.7. What is a maximum level of variable renewables for microgrid seamless transition and isolated operation? What kind of enabling technologies (energy storage, low load diesel, virtual sync generation mode, etc.) can increase that level? What is an optimum size and response time of those solutions?

The C6 contributor´s meeting will take place on Monday, August 25, 12.00-14.30 h in Room 361, 3rd floor. Prepared contributions should be sent to the corresponding special reporters by August 10, 2018.