Special Report - Session 5
PLANNING OF POWER DISTRIBUTION SYSTEMS

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Introduction

The S5 papers will be discussed in three events:
- Main Session (Wednesday, June 17, 9:00-12:30 and 14:00-17:30),
- Poster Session (Thursday, June 18, 9:00-12:30 and 14:00-17:30),
- Research & Innovation Forum (Tuesday, June 16, 16:00-17:30).

Two Round Tables will be organized (Tuesday, June 16, 9:00-12:30):
- RT 3 - Middle earth: Bringing operation in planning, introducing planning into operation (11:00-12:30)
- RT 5 - Efficiency at Component vs. System Level (14:00-15:30).

The aim of this special report is:
1) to present a synthesis of the items treated in the papers,
2) to call for prepared contributions at the plenary session,
3) to stimulate the free discussion at the plenary session.

The 2015 plenary session will be divided into four blocks. Each block will be divided in two main parts:
1) oral presentations based on papers that cover general items or can stimulate the discussion (12 minutes presentation in both the Main Session and RIF), and
2) discussion.

The session received 146 papers divided into 4 blocks that reflect the traditional topics of S5: Risk Management and Asset Management, Network Development, Distribution Planning, and Methods and Tools. The selection process was hard and the acceptance rate was below 60%. The quality of contributions is high and the vitality of the Session is confirmed with many new interesting planning algorithms, new tools and methodologies for planning and for governing in some way the change of the distribution system. Some considerations emerge from the analyses of papers. The first consideration is that the vast majority of the papers smart control of networks, distributed resources, and static and vehicular storage systems with advanced telecommunication facilities have to be included in planning. Modern distribution issues as well as the Smart Grids opportunities have started to be a reality, and do not live only in papers of some visionary academics. The real world needs a change in distribution planning and companies started changing their methods and procedures! For this reason a large number of papers looks at planning in a different way, including operational techniques but also big data analysis, probabilistic models of loads and generation, and time series from smart meters, etc. The second observation is on Low Voltage (LV) planning that often has been not properly considered in many distribution companies' activities. LV system grew up simply following the customers' needs, often without any detailed plan. Nowadays the need of a change is evident. New loads (e.g. electric vehicles) with potentially high coincidence factors, new customers demanding quality and efficiency, and the integration of LV RES are changing the focus from MV to LV systems, due to the poorness of knowledge and the expected possible investments. Finally, long-term planning and development of distribution system was dealt by a relevant number of very good papers. Indeed long-term expansion plans are necessary for the on-going changes in distribution, but the level of risk associated to long-term plans is much higher than in the past. Models and methods to define a distribution master plan are necessary as well as rules to integrate day-by-day operational planning with long-term strategies. Some papers give a good contribution in this field.

In conclusion, it is worth to mention that communication network planning is a new task of power distribution planners as some papers brilliantly showed. The integration of both systems from the planning stage is of the greatest importance for economy and reliability and will be one important research topic for future editions of CIRED.

Block 1: Risk Assessment and Asset Management

Sub block 1: Risk Assessment

Experience has shown that network performance is strongly related to its capability of facing unlikely yet severe contingencies. It is therefore crucial to be able to define which sets of events are more likely to influence grid performance, and in which way, in order to evaluate the most effective actions which can be used to mitigate the reasonably possible risk.

Sub blocks 1 includes papers describing methodologies to collect, rank and assess the main clusters of risks related to the operation of distribution business.

Paper 1000 presents a methodology for assigning risk to a predetermined set of check-points, resulting from field inspections of MV/LV substations. The application of this methodology to this voltage level is a novelty in the distribution business. The risk evaluation is made by means both of monetary parameters, such as Cost of Energy not Supplied (CENS), and of other consequences, such as societal ones.

Paper 1383 describes the application of Monte Carlo simulation (MCS) to support risk-based decision making in MV distribution networks. This procedure uses the concept of prediction of failure probability more than the habitual historical analysis of the failure rates.

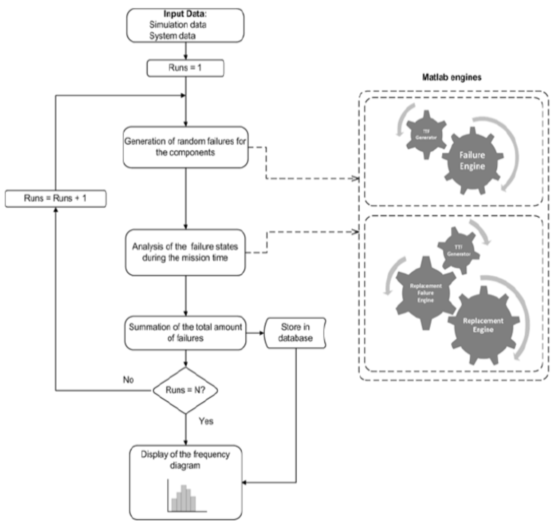

Fig. 1: Flowchart representing the principle of operation of the MCS algorithm adopted in Paper 1383

Paper 0275 proposes the method for reliability evaluation of energy storage system (ESS) combined with renewable energy sources (RES). Power dispatch rule for multiple ESSs is also proposed to extend its duration to produce the required power for charging and discharging periods. With this method, the integration of renewable energy sources in the electric network can be evaluated.

Sub block 2: Reliability assessment

Reliability assessment is related to a specific risk which is of the greatest relevance for the distribution business. As reliability is one of the main drivers in network planning and development, it is important to assess properly the classes of criticalities which significantly affect it and to monitor their evolution, particularly when the dynamics of the system are changing fast.

Sub block 2 deals with the evaluation of electrical systems, in order to find general criteria or specific solutions to enhance or maintain reliability of supply.

Paper 0731 presents a reliability assessment study of a typical realistic backed-up radially operated MV feeder in an urban area of Helsinki using the so-called Three-Layer Reliability Technique. This technique was developed formerly for meshed subtransmission networks analysis purposes and is here adapted to MV networks topology and protection philosophy. The effect in reliability assessment results of considering/neglecting a varying seasonal behavior of MV network availability along the year due to climatic conditions, taking into account different failure rates on each MV network element in each different season along the year, the improvement in global reliability level achieved by replacing manual switches for remote operated switches in the feeder and even the effect of the topological position of each MV-LV substation along the feeder in each individual reliability level are showed.

In Paper 1012 a novel methodology of assessing a reliability index, as is ASIDI, is presented. The index has been developed in such a way that allows taking properly into account the effect of new technology automation devices installed on the grid. The key in the developed methodology is considering the different steps and time intervals involved in the supply restoration process that can be achieved, after a circuit tripping, thanks to each automation technology. The methodology has been applied over a real distribution network with different deployment levels in automation technologies.

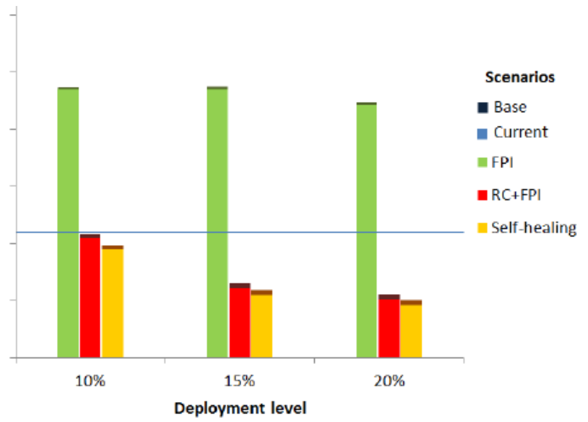

Fig. 2: ASIDI indices resulting from the application of methodology described in Paper 1012 to a real network

Paper 1158 shows the impact on distribution grid reliability indices of HV/MV configuration, MV feeders' topology and MV switches automation deployment level as a whole. The study is applied to a practical case in Gorinchem HV/MV substation and MV network (belonging to Stedin utility, DSO in Rotterdam, The Netherlands). Results show that a single busbar configuration is slightly more reliable than a more complex two busbar one and that the application of remote controlled switches has a positive impact on the overall SAIDI figures. As for automation, the largest reduction in SAIDI can be obtained by automating the normally open points; a further reduction can be acquired by automating a switch in the middle of a feeder, while automating more switches will lead to an increase in costs but the contribution to the SAIDI reduction will decline quickly.

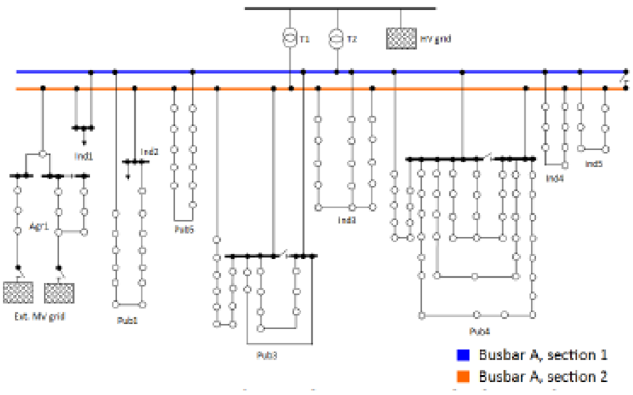

Fig. 3: Optimal HV/MV and MV feeders' arrangement after analysis applied to a real network according to Paper 1158

In **Paper 1368** is also presented a reliability assessment methodology able to take into account on calculation the effects of incorporating new techniques in automation and protection devices on the grid, based in the Logical Structural Matrix (LSM) in this occasion. The method provides the different reliability indices needed by means of LS matrix constituent elements, calculated in turn using properly as input the different times involved in restoring supply after fault clearing process according with automation devices existing on the studied grid scenario. After applying the method over a simplified example, and also a real one Brazilian utility MV network in different scenarios, according to different automation devices presented, improvements in reliability resulting indices are listed, evidencing benefits introduced by each device deployment.

In **Paper 1620** authors focus on the effect that not only single but simultaneous faults have on properly assessing the reliability level of MV networks, mainly in rural overhead feeders exposed to storms. Resulting increase in repairing times due to limited availability of the crews at the same time frame over distant places is focused. By means of Monte Carlo techniques simulations and probabilistic characterization of behavior of either fault rate on each section of the feeder and repairing time a simulation was applied on a selected rural electricity distribution company. The expected reliability indices of the network are so determined and also each feeder section is classified according to its expected fault frequency.

Paper 1240 presents a tool to evaluate the best set of investment measures and the amount of them to undertake for achieving a desired quality service level increase in distribution network for a given time period. The best measures to consider are thoroughly individually analyzed and after that the effect on increasing quality indices provided by each one is correlated by polynomials functions with the amount of investment undertaken /related costs required. How to choose between different possible investment measures - and how much - is determined by solving a cost optimization problem.

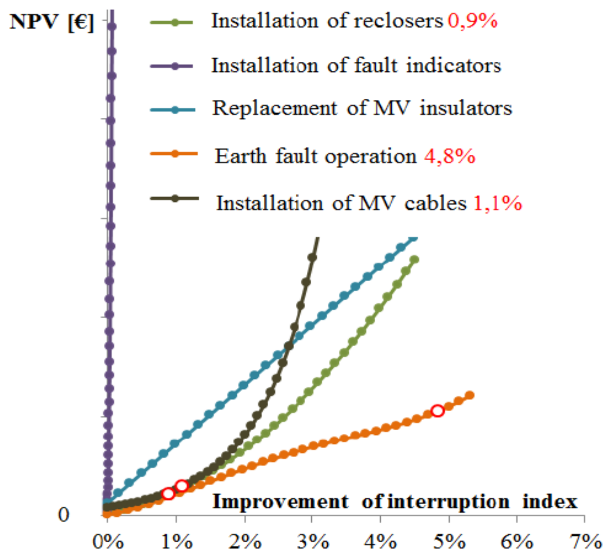

Fig. 4: Polynomials describing, for each investment measure, the quality index increase provided and its correlated costs, as in Paper 1240

Sub block 3: Asset Management and Maintenance Strategies

Sub Block 3 deals with Asset Management in a proper sense, considering it as an analytical problem or dealing with experiences of running such a system. In this section methodologies are proposed to assess the issues of aging equipment and the decisions related to renewal Vs maintenance of existing assets as well as investment optimization process.

Paper 0530 describes a comprehensive package supporting the delivery of sustainable maintenance strategies, taking into account resources, customers' needs, applications and constraints. The authors focus on the benefits that a customizable service plan can provide to avoid downtime due to unexpected failures and enhance people safety while improving sustainability in customer installations and business processes.

Paper 0804 considers distribution transformers and calculates a failure probability value for each of them, taking into account several variables: transformer load, top-oil temperature, ambient temperature, and failure probability. Results show that it is possible to develop a virtual sensing approach to optimize condition-based asset management with reasonable accuracy.

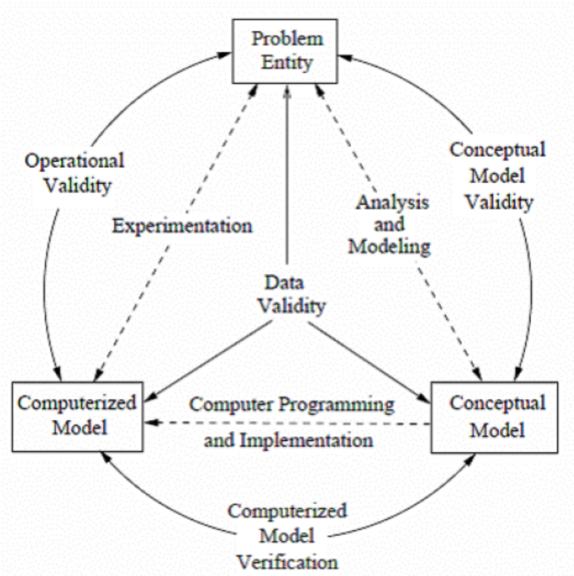

Fig. 5: Overview of validation methodology for the model exposed in Paper 0804

Paper 0980 evaluates the possibility of applying life extension strategy on a significant number of cables that have outlived their design life. Statistical analysis is made to determine the failure rate as a function of cable age, and a prediction of the future values. The conclusion is that they have several decades of remaining lives, because the failure frequency will not exceed 100 per year at 2050.

Paper 1061 proposes a method to make future failure predictions from input data on population age distribution and failure rate, using a Monte Carlo approach; to implement this method, a software tool has been developed in MATLAB. The methods and the tool are validated through a case study with data for cables and joints in the 10 kV urban distribution network of Gothenburg.

Potential scope of discussion
Network performance is more and more driven by high impact, low probability (HILP) events, which are far from representing ordinary conditions in an "historical" sense, but are becoming relevant both because everyday performance of the network has constantly evolved in last decades and such extreme episodes are not so uncommon anymore. However, most risk and reliability assessments are based on the response of a given system (e.g. a distribution network) to phenomena that can be represented by a Gauss probability function. How can we take into account rigorously the occurrence of HILP events while assessing the inherent risk of a distribution infrastructure ?

Table 1: Papers of Block 1 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0275: Reliability Evaluation for Energy Storage System Combined with Renewable Energy Sources				X
0530: Sustainable Asset Management Strategy Achievable Today with Adaptable Services Plans				X
0731: Layered reliability assessment of a typical Finnish medium voltage network under multiple weather and load scenarios				X
0804: Validation of the Effectiveness of Virtual Instrumentation for Distribution Transformers				X
0980: Knowledge preparations for extending lives of 10 kV PILC cables	3			X
1000: Calculation of risk levels for substation failures in a full scale implementation				X
1012: Novel Power System Reliability Indices Calculation Method				X
1061: Failure Rate Trends in an Aging Population – Monte Carlo Approach				X
1158: Reliability improvement by optimizing MV substation configuration in combination with remote controlled switches				X
1240: Smart Improvement of Distribution Grid Reliability				X
1368: The Application of the Logical Structural Matrix for Reliability Analysis in a Distribution System Planning Environment				X
1383: Application of Monte Carlo Simulation to Support Risk-based Decision Making in MV Distribution Networks	1			X
1620: Modeling of simultaneous fault to Reliability enhancement in distribution system	2			X

Block 2: Network Development

Sub block 1: Innovative Power Distribution

The distribution network is the place where innovation in electric systems is presently happening: lower costs and reduced size make previously unavailable functionalities at hand to be deployed in everyday operation. New materials, components and systems are constantly tested and introduced, expanding DSOs' possibilities in network management.

Most of the innovation in distribution is centered on the contribution of new equipment, either owned by the network operator or run by individual network users, to the management of the distribution system. In terms of planning, it implies new reflections on how to take these capabilities into account while designing future grids.

Sub block 1 deals with innovation not linked to specifically "structured" issues, either delivering systemic overviews or describing advanced system functionalities related - among others - to reactive management, voltage regulation and fault current limitation.

Paper 0991 summarizes the activity of IEC Advisory Committee on Electricity Transmission And Distribution (ACTAD) Task Force regarding future T&D systems up to 2030. The TF vision is developed starting from the foreseen evolution of the generation and load portfolio on one side and the expected deployment of emerging technologies in power systems on the other. Major future trends are exposed both in terms of innovative features of the transmission/distribution network and of increasing users' contribution to the system as a whole.

2030 is also the reference year for the large-scale study presented in **Paper 1280**, based on the activity of GB Smart Grid Forum Work Stream 7. SGF WS7 is presently investigating the technical viability of some of the most promising innovative technologies within the GB distribution network as a response to the challenges that can be envisaged up to 2030 (see also **Fig. 6**).

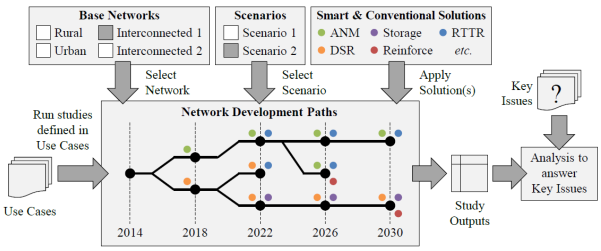

Fig. 6: Overview of the study methodology in Paper 1280

To do so, models of HV/MV distribution network have been defined and use cases have been detailed; both of them are described in the paper. The activity of the WS7 is expected to be completed by the end of 2015, where results and recommendation will be publicly available.

Management of reactive power flows and voltage regulation services ranks among the most relevant issues in the near-future DSOs' agenda. **Paper 0633** deals with the possible use of Storage for network purposes and with the requirements it must fulfill in order to be connected to the distribution grid in a safe and effective way. A complete catalogue of applications, including services potentially to be delivered through market mechanisms, is provided and the related capabilities and requirements are described accordingly. Recommendations are also given in order to avoid possible risks arising from the stabilizing capabilities that storage system may eventually introduce as inherent "side effects".

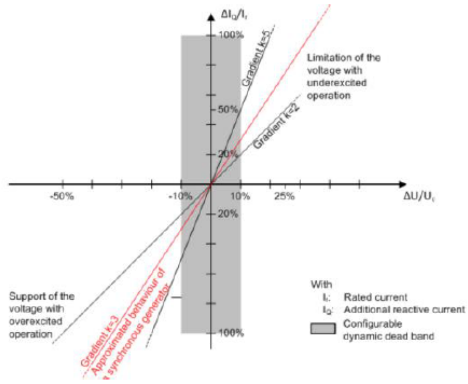

Fig. 7: Reactive power response of a storage system in case of voltage dips according to Paper 0633

Storage systems' flexibility features can also be used to optimize the performance of a non-dispatchable power plant in order both to maximize the usage of the primary source and to increase predictability with regards to the interface with the grid. **Paper 0431** presents a control and operation strategy based on a battery storage system for wind farm; results show that the proposed strategy, in which power generation scheduling and real-time operation are defined taking into account the battery safe margin, allows an efficient use of both the wind resource and the battery storage system.

The change in reactive behavior of network users, related both to the contribution of non-conventional, static loads and to the modification in the mix of generation facilities' portfolio as well as to the voltage level to which they are connected, deeply affects transmission and distribution system operators individually as well as while interfacing to each other. **Paper 0760** starts from a concise problem setting about reactive exchange at TSO-DSO interface and explores several possible strategies to overcome existing and incoming criticalities by making an appropriate use of existing capabilities, including those already embedded into distribution grids. Results show that separate optimizations do not necessarily lead to maximum overall efficiency.

Paper 0414 similarly deals with the phenomena that are presently contributing to a significant modification in reactive behavior of T&D systems, with specific reference to HV/MV substations and HV/MV transformers' OLTC. Undesired consequences of increased reactive power flows (more specifically, saturation in OLTC) are then examined and possible countermeasures analyzed.

The effect of PV generation fluctuations on the frequency of the operation of Step Voltage Regulators and its impact on their forecasted life in analyzed in **Paper 0880**. The authors describe a methodology to assess voltage variations within a given distribution system, based on the estimation of PV generation contribution as well as on the description of network configuration, in order to predict the frequency of SVR tap changing (see also **Fig. 8**); through simulation case studies using real PV generation data, impacts of PV capacity and PV generation smoothing effect are determined. The proposed approach can lead to an optimal definition of time constant of SVR tap changer aiming at keeping voltage in regulated range while ensuring proper SVR lifetime.

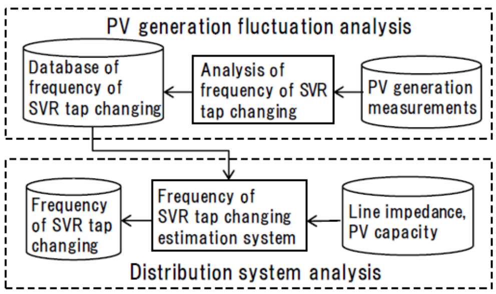

Fig. 8: Estimation method for frequency of SVR tap changing exposed in Paper 0880

Fault Current Limiters (FCL) have already become reliable components and are gradually appearing as a standard option in the network planner's portfolio. **Paper 1129** analyzes the introduction of a FCL as a solution alternative to more conventional ones (splitting the network, installing high impedance transformers, upgrading circuit breakers) while facing a short circuit level increase beyond equipment performances, comparing technical features and cost data of different options. Result show that a future reduction in costs of FCL technology may lead to possible niches for the adoption of this kind of equipment.

Paper 1035 describes the results coming from two years of operation of a 10 MVA saturated core FCL with immediate recovery capability. The component is a standard power transformer technology, superconducting-free, and was installed in a 33/11 kV substation, allowing the parallel operation of three transformers instead of two and ensuring higher short circuit power level in ordinary conditions while limiting short circuit current during single-phase and three-phase faults (the 11 kV neutral is solidly grounded), also in the case of multiple consecutive events. Field tests' results show the component proved reliable and effective.

Paper 1232 describes the use of a Quadrature-booster in a 33 kV distribution network in order to increase the hosting capacity of the grid to accept a 70 MW CHP installed in a sugar beet factory in Wissington, UK. The abovementioned solution was tested, among other innovative ones, within the framework of the Flexible Plug and Play (FPP) project. Results show the Quadrature-booster succeeded - as foreseen in the planning phase - in balancing power flows among different circuit, thus releasing existing yet previously unavailable capacity headroom.

Massive underground cabling in rural areas in Finland is investigated in **Paper 1116**. Starting from the experience of Sweden, where the supply security reform has established large scale underground cabling wave after the destructive storms in 2005 and 2007, the authors analyze the main factors supporting the reduction of overhead lines deployment in favor of underground ones: the tightening of supply security requirements, the urge for increased levels of network resiliency, the reduction in operational maintenance costs. Then a comparison between the costs of MV network renovation in rural areas using underground cables and overhead lines, taking into account operational and customer interruption costs peculiar to considered network types, is performed. Results show that underground cabling in rural areas can be competitive in the medium to long term as its technology is not yet mature and leaves room for operational improvement and cost reduction.

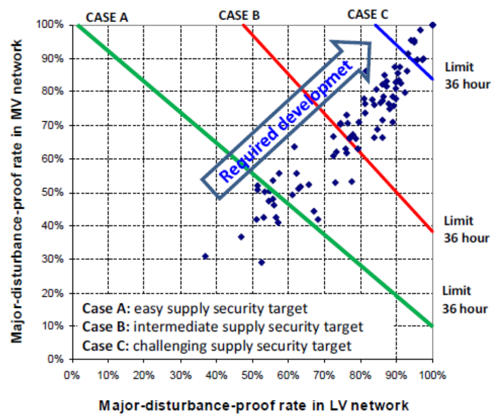

Fig. 9: Rates of major-disturbance-proof networks of Finnish DSOs as in Paper 1116

Meshed operation in LV grid is analyzed in **Paper 1530**. The authors list several possible solutions for coupling LV feeders and evaluate their feasibility in most common existing contexts. Positive effects on continuity of supply, voltage profile and network losses, inherently linked with meshed operation, are then described and quantified for a given network; technical challenges related to operation and protection in meshed LV networks are also mentioned, but not explicitly addressed.

Sub block 2: Smart Grid Systems and Applications

Sub block 2 hosts papers in which explicit mention to Smart Grid concepts is made. They essentially deal with the description of systems in which non-conventional features, including advanced operation and control, are introduced to support innovative network functionalities including, but not limited to, adaptive network behavior and demand response services.

Paper 0701 delivers a framework for collecting, classifying and clustering Smart Grid concepts. Possible taxonomy architecture is described, comprising most common definitions and features as well as new ones which were developed in order to assess the issue in general terms. Specific Smart Grid-related entities (namely: Enablers, Concepts, Goals and Stakeholders) are introduced and mapped; the result is a - hopefully - exhaustive classification of existing and possible initiatives.

A conceptualization of Smart Grids functionalities and of the forms of integration and relationships between stakeholders, including network operators, grid users and market players, is provided in **Paper 1356**. The paper presents a methodology, developed within the framework of a R&D project approved by the Brazilian Energy Agency and the Brazilian Association of Distribution Companies, to assess present-state situation with reference to distribution networks and to enable the proposition to Smart Grid roadmaps.

A methodology for comparing Smart Grid initiatives and projects is proposed in **Paper 0120**. Starting from universally acknowledged Smart Grid characteristic and relying on most common demonstration projects' outputs publicly available, the authors build a composite score (Smart Grid Scope Indicator, SGSI hereinafter) quantifying the level and the extent of innovation of a specific initiative integrating Smart Grid functionalities. The exposed methodology has been applied to a database containing references of 165 Smart grid demonstration projects that have been initiated worldwide since 2006.

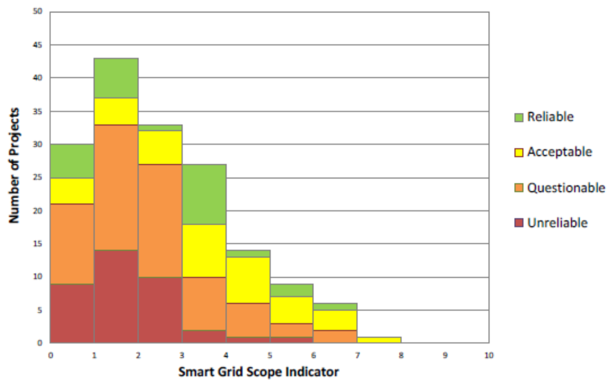

Fig. 10: Analysis of 165 Smart Grid demonstration projects' innovation content according to Paper 0120

Paper 1281 also approaches the topic of evaluating different Smart Grid initiatives or architectures in terms of their respective "smart" performances, according to a methodology adopted in IGREENGrid FP7-funded project. Specific individual KPIs are proposed to assess universally acknowledged Smart Grid features (increase of hosting capacity, enhancement of quality of supply, improvement in energy efficiency), comparing expected or experienced Smart Grid performances to Business As Usual conditions, and a weighting methodology to combine them is defined.

Evaluating and certifying Smart Grid features requires a "smart" test site, such as Concept Grid, a new laboratory set-up by EDF R&D and dedicated to the test and validation of smart grid equipment, systems and functions. **Paper 0737** briefly introduces the installation itself and then describes various experiments, centered in the evaluation of typical Smart Grid functionalities such as Demand Response, that have been run both in laboratories and under real conditions on the grid.

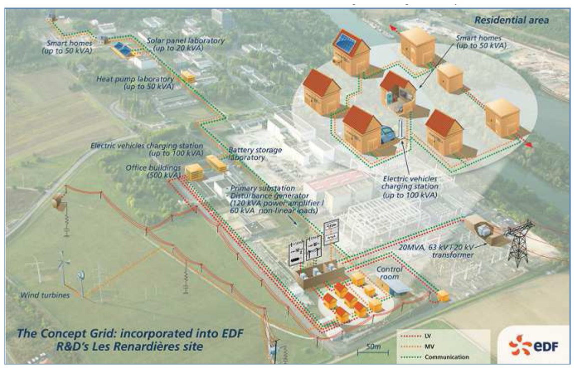

Fig. 11: Overview of Concept Grid (Paper 0737)

Paper 0605 reports the main outcomes of a series of projects, run in Austria within the last decade, centered about voltage monitoring and control in MV and LV networks. A description of different technical solutions that have been implemented, as well as of the operational practices adopted, is provided. Lessons learned range from integration of voltage control system with SCADA to PV generators' reactive control margins, from tolerances in voltage margins to possible increase of hosting capacity.

Paper 0682 delivers the results of field tests on MV/LV transformers, equipped with an OLTC that is operated according to a voltage observation method based on local measurements of power infeed into LV lines and voltage level at LV substation busbar. Voltage observers are firstly calibrated for each feeder with reference to the boundary conditions resulting from load flow calculations run on a modeled grid; in everyday operation, then, each observer acts on the OLTC according to a simplified rule based on actual (P_{feeder}, V_{busbar}) measured conditions.

Flexible Urban Network - Low Voltage (FUN-LV) can be defined as a specific application of Smart Grid features to technical management of LV networks. More in detail, it involves telecommunication systems and power electronic components and aims at ensuring monitoring, (remote) control and protection capabilities resembling MV automated grids. **Paper 0981** describes FUN-LV project, its innovative contents, its main components and technical solutions and the process of selecting the most suitable sites for implementing.

A systematic comparison between expected network conditions and real measurements can be operated through an Automatic Meter Management (AMM) infrastructure. **Paper 1205** describes the experimental interactions, based on data coming from ERDF AMM system (Linky) data, that have been run within the framework of GreenLys Smart Grid funded project in the city of Lyon and outlines the benefits that can be expected from the integration of Smart Metering data in technical information systems (GIS cartography, load flow calculation and state estimation, customers' voltage monitoring, etc.).

Paper 1006 describes a small-scale pilot test started in the city of Stavanger, Norway. A scalable architecture of Smart Substation, including MV and LV monitoring, MV fault location, remote operated switching and accurate measurements and distributed protections is deployed in a portion of the local distribution network including 1 complete MV feeder, 25 MV/LV substations and supplying 1400 final customers. The project started in 2015 and will last 5 years, providing evidence of cost effectiveness of Smart Grid solutions compared to conventional ones.

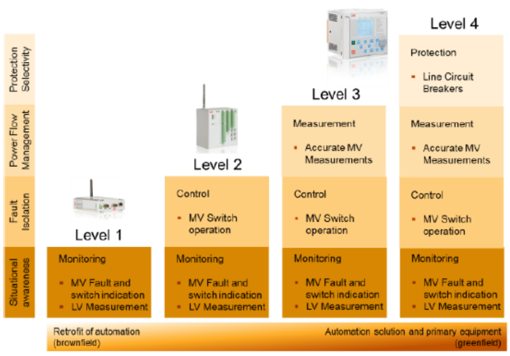

Fig. 12: Scalable architecture of Smart Substation as in Paper 1006

Demand Response functionalities are strictly linked to the Smart Grid concept, not only because they somehow assume a Smart Grid infrastructure as a prerequisite, but also because they can be used as a tool for avoiding conventional network investments (thus entering the smart planner's toolkit). **Paper 0219** introduces CITYOPT, a collaborative FP7-funded project, whose scope is the set-up of a series of applications and guidelines that support efficient planning, detailed design and operation of energy systems in urban districts. A case study in Nice Côte d'Azur, focusing on optimization scenarios related to demand response services to improve the continuity of service in the area, is described. Planned project features include an Internet application called "Community Network for Energy" that will be tested on 200 citizens living in Nice: participants will be rewarded for their efforts in response to the utility's requests with CITYOPT points, a virtual currency which they can convert to support the realization of local community projects for their city.

A comprehensive cost-benefit analysis of the overall economical impact of the increased penetration of Distributed Energy Resources (DER), including final customers' costs, is provided by **Paper 1238**. The authors analyze the main components of investments and operational costs for system stakeholders (customers, market operators, DSOs) within different scenarios all allowing the required level of penetration of DER. Results, obtained through a methodological approach based on dependency matrix representing the relationships between functionalities, technologies and benefits, show that for the Austrian market structure in the 2014-2030 period the adoption of smart, flexible solutions brings more value than conventional network development.

Paper 1117 introduces a techno-economic modeling tool (see **Fig. 13**) that has been developed to assess the network impact of ongoing changes in electricity usage driven by the low carbon agenda and to model the impact of a range of intervention strategies, both traditional and smart, to address this changing demand. Analyses are performed according to a scenario-based approach, implying e.g. different levels of penetrations of DG or EV. Optimized investment programs, indicating the type and timing of various intervention options both conventional and innovative such as DSR, electrical energy storage, etc., can be developed accordingly. Authors report the tool has been extensively used in Great Britain by DSOs and National Regulator both to deliver and to evaluate large-scale investment plans.

Fig. 13: Overview of the Transform Method as exposed in Paper 1117

Paper 1033 deals with grid connection of industrial and commercial complex sites by means of a micro-grid, loosely tightened to the main system. In conventional planning, static scenarios are adopted and potentially available flexibility is not taken into account, eventually leading to a network infrastructure either oversized for the majority of time or underdeveloped for the few cases of real need. A pragmatic approach to planning is therefore proposed, through which an alternative network sizing is obtained by relying on smart grid functionalities, provided by the so-called "fulfillers", instead than by conventional network expansion or reinforcement; cost comparison is easily made through standard items that have been defined for both conventional components and fulfillers.

The strategic plan of KEPCO regarding Microgrids is exposed in **Paper 0043**. Seen from outside, a Microgrid can be seen as a cluster of loads and generators operating as a single controllable system, representing the elementary cell of a power system; from the inside, the Microgrid can be designed to meet users' specific needs, such as to enhance local reliability, reduce feeder losses, support local voltages, etc. The paper describes KEPCO's views about Microgrid, starting from planning concepts, including generation mix coverage, control system features and optimal energy management, up to case studies related both to grid-connected and to islanded modes. Possible operating strategies for a Microgrid according to regulatory and market framework are finally exposed.

Paper 1193 describes the future Smart site of Nordhavn, a large area near Copenhagen which will be developed virtually from scratch to host 40.000 new homes and 40.000 new jobs. It will be equipped entirely with smart and integrated low, zero or plus energy solutions for all energy services. The main features of future EnergyLab Nordhavn and the experimental activities that will take place there, ranging from Demand Side Response to EV charging infrastructure integration, from storage use to local service markets development, are then exposed.

Fig. 14: The future Smart Site of Nordhavn as described in Paper 1193

As Smart Grid are designed to integrate all users' contribution to the operation of the electrical system, then inverters' required features are just as relevant as any other tool to ensure voltage performances; however, they must be designed in order to minimize the possible loss of income for generator operators. **Paper 0661** analyzes the effects of a Voltage Based Droop (VBD) P/V regulation in LV networks, comparing it to the more conventional practice of being disconnected while reaching the upper limit for voltage, through a probabilistic analysis framework that considers the time fluctuation of the PV generation and of the voltage at the MV/LV transformer as well as the randomness of the consumption loads. Results show that P/V regulation, besides being obviously the most effective for overvoltage mitigation in LV lines (featuring higher R/X ratio than MV ones), is also less impacting when it comes to energy curtailment for generation operators.

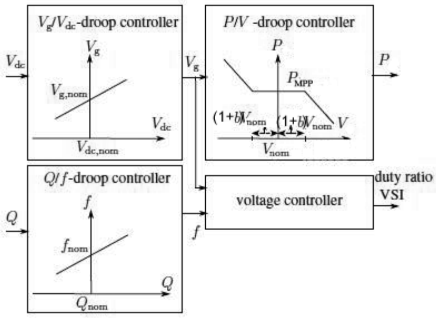

Fig. 15: Scheme of Voltage Based Droop (Paper 0661)

Curtailment is extensively investigated by **Paper 0740**, delivering a comparative analysis of results coming from different simulation tools currently adopted in curtailment evaluations and decisions. The study reveals that, although all tools substantially converge when it comes to results, time of calculation and easiness/flexibility of use may radically differ from one tool to another depending on the specific cases analyzed: spreadsheet-based tools, quicker and easier to use, can therefore be preferred in the case of simple networks, while Scripted methods must be chosen while dealing with more complex systems.

Sub block 3: DC Distribution Systems

DC distribution in LV networks has come to attention in recent years, as virtually all new generation and new significant load are represented by DC equipment, which would easily suit a DC grid. At the same time, proper integration of DC portions with the existing, conventional AC grid must be investigated and ensured; that's why the interest for DC distribution potential has its peaks in areas in which massive construction, or reconstruction after exceptional events, is taking place. In any case, the fact that translating principles into planning criteria, concepts into standard components and intuitions into operational guidelines inevitably takes time cannot be overlooked.

Sub block 3 goes deeper into this topic and delivers some interesting hints about DC implementation strategies and global system evaluation.

Paper 1174 approaches LVDC from a system perspective, investigating the optimal choice for voltage levels to be adopted in DC distribution: based on available technologies for new components (e.g.

converters), the existing physical network infrastructure (poles, possibly cables, etc.), the characteristics of the loads and the topology of the grid, the authors describe the possible use of LVDC to expand existing network capabilities. Examples on both Finnish and Korean LV grids show range extension and capacity extension effects can be achieved through already standardized DCLV levels.

In **Paper 0604**, a reference model for designing and constructing LVDC grids is detailed. The paper embraces the whole planning process, from the detection of network conditions which trigger the adoption of DC network standards, to the choice of the most appropriate voltage level and network structure, to the design of the earthing and protection system, to the selection of AC/DC converters. Future plans include the construction of pilot installations for LVDC systems, the execution of tests and the go-live for one of the low-load, high-distance pilot installations as the first step towards the deployment of a proper LVDC system.

Paper 0937 addresses the challenge of limiting voltage drop and energy losses in LVDC lines that, while used as an alternative to conventional AC MV lines, result in a significantly weaker performance. The authors investigate the possible use of a battery energy storage system (BESS) to help reducing voltage variations. The procedure to design BESSs in LVDC systems, in which optimal location and size of the BESS are defined, is introduced; power flow calculation and economic analysis for LVDC systems are also presented.

Potential scope of discussion

Storage systems rank among of the most promising components in future grid; their flexible behavior can be useful both in market-based activities and in grid-related applications. However, all benefits cannot be achieved at the same time as some behaviors may exclude others: strategies aimed at maximizing individual profits do not necessarily ensure the general interest, and pursuing collective benefits may not *per se* grant economical convenience to storage owners. How could economical treatment of storages be defined in order to achieve both targets?

Table 2: Papers of Block 2 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0043: Microgrid's Strategic Planning in KEPCO				X
0120: Comparing the integration of innovative aspects in Smart Grid demonstration projects				X
0219: CITYOPT - Holistic simulation and optimisation of energy systems in smart cities				X
0414: Determination and origins of reactive power flows in HV/MV substations				X
0431: Wind farm operation and control strategy based on battery storage system				X
0604: Design and Construction of Korean LVDC distribution system for Supplying DC power to Customer				X
0605: Conclusions from smart grid field tests - deployment of results, methods and new technologies				X
0633: New ancillary services required to electrical storage systems for correct network planning and operation				X
0661: Probabilistic Assessment of P/V Droop Control of PV Inverters				X
0682: Voltage Control in Intelligent Secondary Substations by Voltage Observation Methods Based on Local Measurements				X
0701: Smart Grid Taxonomy - A System View from a DSO's Perspective				X
0737: Concept Grid: a new test platform for smart grid systems. General presentation & Experiments				X
0740: Curtailment Assessment Methods Characterisation and Definition				X
0760: Derivation of Recommendations for the Future Reactive Power Exchange at the Interface between Distribution and Transmission Grid	4			X
0880: Estimation Method for Frequency of SVR Tap Changing by Fluctuation Analysis of PV Generation				X

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0937: Design and Operation Schemes for Battery Energy Storage Systems in Low-Voltage DC Distribution Systems Considering Voltage Control and Economic Feasibility				X
0981: Selecting Sites for FUN-LV field trials				X
0991: Future vision of Transmission and Distribution 2030				X
1006: Cost analysis from Smart Grid implementation in Medium Voltage distribution grid				X
1033: Distribution Network Planning for Commercial and Industrial Areas: the Realisation of Flexible and Modular Smart Microgrids				X
1035: Increasing power generation capacity on meshed electrical grids - GridON's Fault Current Limiter successfully suppresses multiple network faults during two years in service				X
1116: Profitability of underground cabling in the Finnish rural electricity distribution in the future				X
1117: Planning Network Investment in a Smart Low Carbon World				X
1129: Standardised Connections and the Economic Benefits of Fault Current Limiters on Distribution Networks				X
1174: Selection of Voltage Level in Low Voltage DC Utility Distribution System	5			X
1193: New design methods for energy infrastructures in future urban areas				X
1205: Modernizing distribution network management with Linky smart meters - lessons learned in GreenLys project				X
1232: Operational experience of using a Quadrature-booster from UK Power Networks' Flexible Plug and Play project				X
1238: Synergetic effects for DSOs and customers caused by the integration of renewables into the distribution network - Influences on business and national economics				X
1280: Development of Methods and Models for a Study into UK Distribution Systems of 2030				X
1281: On the definition and applicability of Key Performance Indicators for evaluating the performance of smart grids concepts				X
1356: Brazilian Smart Grid Roadmap - An innovative methodology for proposition and evaluation of Smart Grid functionalities for highly heterogeneous distribution grids				X
1530: Interconnected low voltage grid, grid for the future smart grids?				X

Block 3: Distribution Planning

Sub block 1: General Planning

The papers of Sub block 1 refer to planning algorithms that are proposed to solve classical problems as optimal network expansion or location and design of substations; the optimization is generally led by economics or by the need of improving reliability, power quality or both. The process often benefits from technological novelties such as Smart Meters or advanced sensors, or takes into account new kind of loads as electric vehicles and charging stations. However, they remain somehow "behind the scene", offering novel or more sophisticated inputs to a planning process that, nevertheless, still refer to conventional, one-way, passive networks.

A general model for investment projects and portfolios evaluation is exposed in **Paper 0379**: here the problem resides in the uncertainties that affect many of the parameters used in the calculation of investments' evaluation indicators. Demand growth and investment costs are the main uncertainty drivers, and can be better represented by distribution functions than as invariable quantities; furthermore, they also affect expected benefits such as energy efficiency recovery or undelivered energy reduction. The authors propose two different methodologies, both based on a modified NPV analysis: the first one is devoted to individual investment projects and is used to determine the lowest possible project value according to the worst possible outcomes of the uncertainty drivers, the second one is used to determine the approximated portfolio risk, starting from probability distributions of individual projects' NPV values.

Paper 0170 also deals with uncertainties and, more in detail, to those related to load estimation in a long-term planning problem of optimal MV feeder routing. The authors propose a methodology through which the optimal routes of MV feeders are obtained considering load forecasting error, with the goal of minimization of total investment and operational costs subject to the electrical and topological constraints. Results show that the methodology can be successfully adopted for real size distribution networks, and that taking into account uncertainties in load forecasting methods can lead to more robust network design.

An integrated tool, including the evaluation of the regulatory profitability of planned investments, is described in **Paper 1364**. The software supports the whole process, from the identification of network criticalities to the technical analysis of alternative solutions, from the evaluation of the regulatory profitability of individual investments to the budgeting and the completion of a proper investment plan. A case study is also included, showing the results coming from the application of the exposed methodologies to the Porto Velho (Rondônia-Brazil) area.

Paper 0544 describes an approach to network planning that takes into account information coming from billing data of MV customers as well as from feeder load measurements. Starting from these elementary data, a characterization of short-term and medium-term load for planning purposes, generating time series accordingly, has been developed, and load flow calculations have been run. Optimized short-term plan, including eligible measures such as re-conductoring or installation of new switches, as well as more structured medium-term ones, e.g. implying the erection of new substation, are then produced.

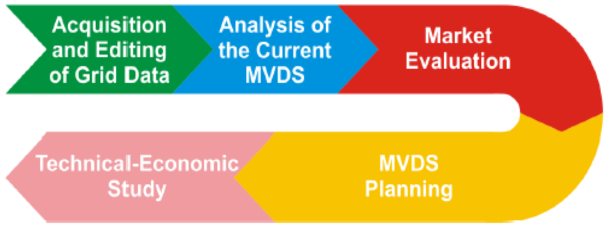

Fig. 16: Implementation stages for the approach described in Paper 0544

Approaching planning activities at different voltage levels independently from each other may allow simpler and shorter calculations; however, the underlying assumption that operation at each voltage level only marginally interfere with the others has never been exact and is becoming more and more questionable every day. **Paper 1167** proposes an approach, based on a multi-agent system, allowing the generation of time series that can be consequently used for a "chronological" approach to planning. The interactions between voltage levels are represented with reference to exchange nodes parameters, allowing simpler and faster calculation. The contribution of subnets to the operations of the main network, as well as the effect of control strategies operated to a voltage level on the management of the others, can therefore be evaluated. Further expansions, and detailed verifications to validate the accuracy of the model, are foreseen.

The adoption of an effective communication about large-scale projects implying the involvement of all significant stakeholders is just as significant in the delivery of a complex investment as the technical quality of the investment itself: in **Paper 1002**, a multi-dimensional approach to communication towards main stakeholders regarding the erection of a new HV/MV substation is proposed. For each significant project a risk evaluation is performed, ranging from the planning phase to the licensing stage to construction and dismantlement: main criticalities are highlighted and a Communication Plan is developed accordingly. Case studies are provided showing how the communication initiatives suggested by this methodology resulted in being much more focused and effective than those coming from a generic, standardized approach.

The coordination between technical decisions taken in the planning phase and the operational activities performed during project management in the construction phase is obviously one of the key factors in every successful investment plan. **Paper 1021** describes how the integration of a network information system (NIS) and an Enterprise Resource Planning (ERP) system can be a powerful tool in helping utilities to make effective investment decisions acting in a structured way. Some references to the experience of Elenia Oy, the Finland's second largest distribution company, are then provided.

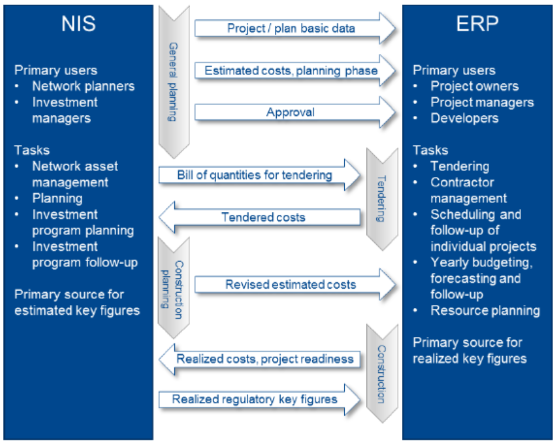

Fig. 17: Roles and data sharing of NIS and ERP in the planning process outlined in Paper 1021

Paper 1337 presents a computer-aided tool for the capacity planning of MV networks. The proposed approach is based on the systematic analysis of possible expansion options that satisfy topological, geographical, and operational constraints, starting with all possible ones and then reducing their number by using expert rules based on established network planning practice. Practically feasible expansion options are modeled automatically to evaluate if they offer a solution to bottlenecks. Finally, a performance indicator is calculated to evaluate feasible alternatives and select the best options. A case study is finally exposed to illustrate the planning tool's main features.

Paper 0425 presents a comparative analysis of probabilistic LV planning with a chronological one, based on time series coming from Smart Meters. Results show that the availability of time series of real consumption data and their use in network planning lead to a better use of the existing network infrastructure and to a greater connectivity of both new generation and load. The Paper also compares different charging strategies for EV (direct, minimum cost, renewable following and a combination of those) in terms of network losses, capacity used, voltage violations, cost of energy, etc.: results show that a Renewable Following strategy, if adopted by EV users, would provide the minimum impact on the network and therefore favor the integration of EV themselves.

Paper 0753 proposes a methodology for LV planning based on Cluster Reference Grids: according to this methodology, the behaviors of portions of LV network are simulated by performing detailed analyses on a reduced number of reference LV grids that can be considered as representative of a cluster of grid population. The paper describes the construction of the clusters and their use in planning simulations, showing how a limited amount of data can be effectively used in LV network planning, increasing the accuracy of evaluation also in case complete information about real LV network are not available.

A simulation tool for integrated planning of distribution networks with high presence of electric vehicles (EVs) is presented in **Paper 1382**. The tools is intended as an advanced support for network planning of a distribution grid with high shares of plug-in EV and is based on a detailed model of land use: simulations can therefore be created and run according to assumptions about land use configurations and EV penetration levels. The energy demand of an EV fleet can thus be characterized and its interaction with land use, transport networks and charging infrastructure can be analyzed, in order to verify their impact on the electricity distribution network. Remedial actions to mitigate the negative effects can therefore be defined and planned.

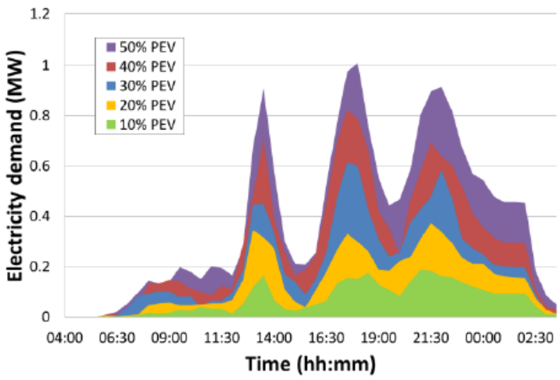

Fig. 18: PEV power load (with mixed land use) for different level of PEV diffusion in Paper 1382

Paper 1418 describes an integrated simulator developed to support planning of conventional as well as innovative initiatives. The SIRIS software includes not only traditional planning tools, such as load flows and short circuit calculations, optimal allocation of power and control components, but also communication performance evaluation modules, fault behavior simulations and forecasting algorithms. The paper focuses on a general description of the modules and summarizes their functionalities; some use cases are then outlined.

Paper 0686 deals with the optimal expansion planning of an urban distribution network. As the execution of street works in urban contexts often results in complex interactions with the existing infrastructures, and minimizing the extension of necessary workings is generally preferred, the paper proposes a methodology that takes into account the topology of the streets as well as the existing networks, which are modeled using tools from the graph theory. The routing of the power lines among the streets is calculated by an adapted simulated annealing, and then the minimization of the workings for the expansion plan is made taking into account, through corrective coefficients, the different costs of the streets. The case study refers to an application of the proposed methodology on a part of the distribution network of the city of Grenoble in France, as a part of GreenLys project.

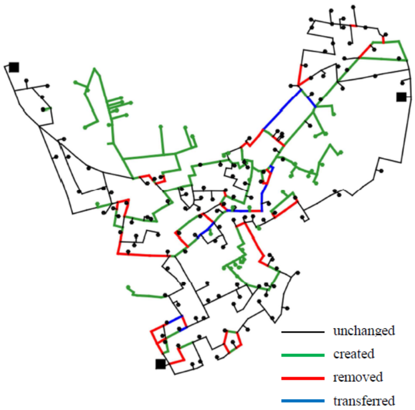

Fig. 19: Results of optimization of expansion planning according to Paper 0686

A system reliability assessment method for distribution grids, which has been used to implement selective restructuring of networks in combination with automation techniques in order to achieve a more secure energy supply, is described in **Paper 1008**. The method is based on system component availability values, load flow calculations and Monte Carlo simulations and aims at increasing the reliability of the network; automation features, such as self-healing capabilities, are also considered. An application of the method, that has been developed within the framework of the Austrian national funded research project “REstrukt-DEA”, is shown for a test urban distribution grid in three different scenarios, which are based on real grid investment cases.

Planning high-cost renewal investments, such as the replacement of HV equipment, is a challenging activity as it implies the evaluation of many complex technical alternatives and involves huge amount of money in investment decisions. **Paper 0336** proposes a methodology for approaching these issues in general terms, starting from analyzing existing criticalities and possible alternatives, then modeling technical solutions alternatives, defining investments strategies and their economical parameters, determining investments’ NPV and choosing the suitable solutions. A case study, based on investment decision in HV network in Portugal, is then described.

Paper 0916 analyzes most commonly used cost recovery mechanisms for distribution network (extent of use and long run cost charge) and proposes an algorithm for a fair allocation of costs both of existing installation and of newly developed ones. A location-specific evaluation of Long Run Incremental Cost (LRIC) is defined through an accurate Long Term Distribution Network Expansion Planning exercise, i.e. applying incremental variations in the interested node to an already defined expansion plan related to the base case and evaluating the increased network development costs. A case study is shown, illustrating the application of the proposed methodology to a 747-bus network in Queensland.

Paper 0420 describes the challenging activities performed in order to acquire valuable topographical information to implement a Geographic Information System for LV networks and Public Lighting systems at affordable costs. Geo-localization of network components, such as street cabinet, LV feeders, and Points of Delivery was operated with the systematic use of existing information and public sources, thus limiting onsite access only to selected, unavoidable cases. Maintenance personnel, through the use of their mobile devices, had done street cabinet geo-localization, while adjustment of underground cables path was done centrally through software with negligible loss of information. The result was that a multi-million Euros project was completed with a few dozen k€.

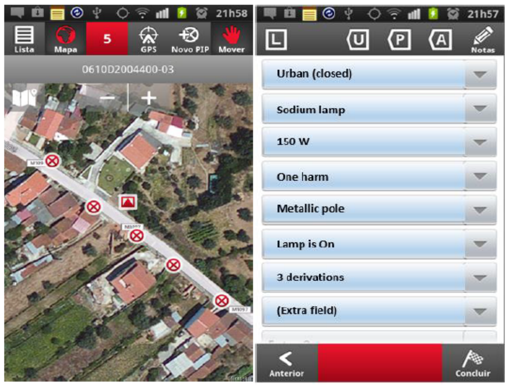

Fig. 20: App workflow view for PL points acquisition as in Paper 0420

In **Paper 1426**, a complex refurbishment plan for a MV network is exposed. The system upgrade has been approached through a careful and detailed analysis in order to avoid unnecessary expenses, maximizing the use of existing assets and benefitting from new technologies. Migration from 10 kV to 20 kV, MV automation, current and voltage sensors integrated in the cable terminations, data transfer by means of wireless network communication are some examples of the action that have been, and will be, performed in order to enhance network performance in terms of reliability and continuity of supply but also to support advance system management as well as Smart Meter deployment.

Sub block 2: Planning of Active Networks

Planning taking into account the presence and contribution of distributed generation has quickly become DSOs' everyday activity. Notwithstanding the increase in penetration of generation units connected to MV and LV grid did not change in principle the foundations of electric systems theory, it must be recognized it challenged most common practices regarding network management; planning procedures and techniques need therefore to be changed in order to make them suitable to the new world.

Sub block 2 deals with methodologies and algorithms that have been studied and proposed in order to include in the planning process the already available or foreseen capabilities and/or roles, resulting in a more efficient use of the infrastructures, an increase of the expected level of performance and/or an enhanced interaction between the different sets of users.

An all-in-one approach to network planning in the presence of DG is presented in **Paper 0133**. The authors propose a planning workflow which includes: a scenario definition phase, exploring possible evolutions for demand and generation in the long-term and evaluating their probability; a load generation combination phase, in which use cases are defined, based on the possible contemporaneity of demand and generation; a "hot spot" analysis, evidencing the critical points in the network; an optimization phase followed by the composition of a risk matrix including all possible solutions, supporting the final decision process. Further evolutions are finally described.

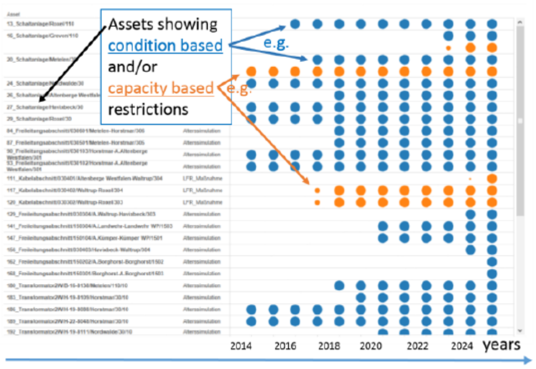

Fig. 21: Hot spot analysis on a yearly basis in Paper 0133

Paper 0933 presents an integrated tool for the planning of active distribution network, whose aim is to maximize the benefit coming from the presence of high shares of renewables as well as from customer engagement and new technology implementations. The tool has two main processing parts: "optimization" and "forecast". The "optimization" part is an automated and integrated planning framework to optimize the net present value (NPV) of investment strategy for electric distribution network augmentation over large areas and long planning horizons, based on a modified particle swarm optimization (MPSO). The "forecast" is a flexible agent-based framework to produce load duration curves (LDCs) of load forecasts for different levels of customer engagement, energy storage controls, and electric vehicles (EVs).

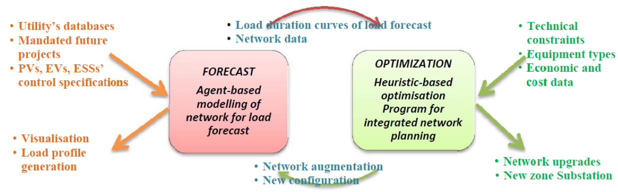

Fig. 22: Integration of Forecast and Optimization modules in Paper 0933

A hybrid planning model for the planning of active networks is presented in **Paper 1110,** in which a probabilistic load flow (PLF) is coupled with a deterministic contingency analysis. The proposed approach combines therefore the more accurate definition of critical situations, typical of the probabilistic approach, with the established contingency evaluations, that are performed in a greater but nevertheless limited number of worst-case scenarios. The approach is then tested on a real 110 kV grid: results show that conventional, entirely deterministic planning, may underestimate specific loading conditions, leading to under-dimensioning of critical HV lines.

The need for a shift of paradigm from deterministic network planning, centered on assumed extreme scenarios, to time series-based methodologies is expressed in **Paper 0140**. Authors propose a multi-agent system algorithm, which generates time series for distribution grids, according to a model taking into account the presence of nonconventional entities such as distributed generation, electric vehicles, storage systems, etc. A real LV grid is then analyzed in an initial - entirely defined - and a future scenario, in which a main task (connecting a specific amount of new DG) is given, but possible alternatives in terms of penetration of EV, storage behaviors, etc., can occur.

Paper 1320 compares the most commonly adopted methodologies to determine the hosting capacity of a distribution feeder. The main evaluation criteria and practices are exposed and compared with analytical algorithms for determining "Worst Case Hosting Capacity"; after that, an evaluation about the contribution of grid and DG control to the increase of hosting capacity is provided. Results show that, in MV rural distribution networks the practical criteria generally applied provide mostly conservative results, similar to the ones obtained by the application of the worst case HC metrics. Furthermore, the adoption of simple grid or DG control schemes (e.g. OLTC or DG reactive power control) can significantly increase the hosting capacity of the grid.

The modification of established load profiles due to the increased penetration of DG may potentially relieve real network conditions, leading to benefits that can be captured in network planning if tools evolve accordingly. **Paper 1527** aims at demonstrating the value of sequential-time simulations to better estimate the positive contribution of variable generation. Some examples are given about the impact of real load profiles on specific system components (conductors, transformers, etc.); results show that when there is a longer thermal time constant for the power delivery system asset under consideration (e.g. transformers) it can withstand overloads for a longer time until generation recovers and can offset loading. If the time constant is short, as it is with lines and cables, less credit can be given.

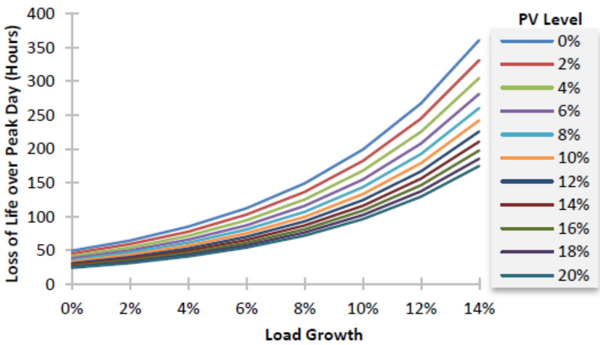

Fig. 23: Transformers' thermal aging with load growth and PV penetration according to Paper 1527

Paper 1103 presents a tool to evaluate alternative network and "no network" solutions to the problem of accommodating DG in distribution networks over multi-year horizons. The proposed methodology allows the comparison of different possible connection rules to integrate RES, also taking into account the reciprocal influence of MV and LV contributions. The tool has been tested in a real French 390-bus network composed of one 90/20-kV primary substation, four 20-kV radial feeders, and 114 20/0.4-kV secondary substations, presently supplying a peak load of about 9 MVA and that is expected to host at least 20 megawatts of RES over a 10-year time horizon.

Presently, most DG consists of small scale PV and Wind farms that are, and will be, connected to LV network; it is not unexpected, therefore, that many papers deal with this specific topic. **Paper 0124** compares a probabilistic approach to LV planning with the conventional one: the proposed methodology takes into account residential households, DG, storage and eventually electric mobility. The performed simulations provide quantiles of probabilistic peak power, which are obtained by means of simulations considering the distribution functions, generated on the basis of measured data of electrical power consumption from residential households in typical days and periods. A relation between statistical analysis and conventionally coincidence factors is given: results show that generally the peak power due to the standard for a high amount of residential households is higher than the peak power quantiles, leading to a significant over dimensioning of grid components (99.999 quantile).

In **Paper 0042**, the assessment of maximum DG penetration in LV network is performed. The authors compare usual planning techniques and conventional planning solutions with the results that can be obtained by extrapolating Monte Carlo simulations. Results show that, due to the statistical nature of load and DG behavior, probabilistic approaches may provide evidence of an existing hosting capacity that cannot be exploited by sticking to classical deterministic planning criteria: in case a 5% risk is accepted and innovative solutions are adopted (Q=Q[U] regulation for DG, MV/LV with OLTC), the hosting capacity of a sample LV feeder can be more than tripled.

Paper 0187 presents the process of setting new planning criteria for LV networks in presence of a high penetration of RES. A study is detailed through which the increased hosting capacity of LV feeders due to the introduction of controlled MV/LV distribution transformers with line drop compensation (L-CDT) is shown. Their voltage improving effect allows developing simple and cost-effective LV radial feeders, overcoming to some extent the most common limitations in accommodating RES. It is in fact demonstrated that an enlargement of voltage limits in planning can be achieved.

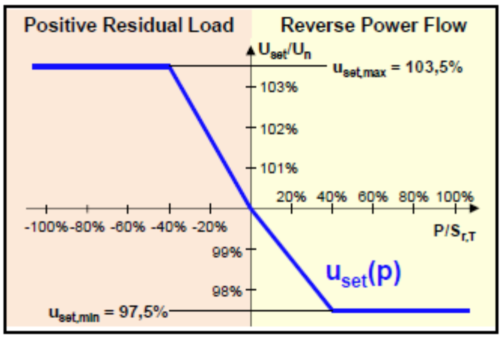

Fig. 24: U=U(P) characteristic for L-CDT in Paper 0187

Paper 0915 presents an algorithm to perform systematic calculations of overvoltage in LV feeders, starting from the LV network information available in a GIS system. The proposed methodology has been applied to a real UK LV network associated with 28,642 MV/LV transformers, limiting its application to residential urban networks where the most PV is likely to be installed: 9,163 networks were selected, which met feasibility criteria for PV installation, resulting in a grid containing 43,816 LV feeders and 1,292,960 homes with south facing roofs. The study ends with the estimation of the refurbishment costs for LV, which results in being quite limited while compared to the overall investments that would be needed in case of massive, unfocussed LV repowering.

In **Paper 0402**, a simulation model is discussed for a LV mesh-connected grid in which many household customers are expected to install PV panels. A scenario study is done when all the PV panels are producing their peak loads and are exporting the electricity simultaneously to the grid. The voltage profiles of different node points and the loading of various network components such as cables and transformers are found from the simulation results. Possible bottlenecks of the grid are identified where the network components violate the standard regulations and design criteria. An application is shown to a real case, in which the LV network supplied by two MV/LV transformers is analyzed.

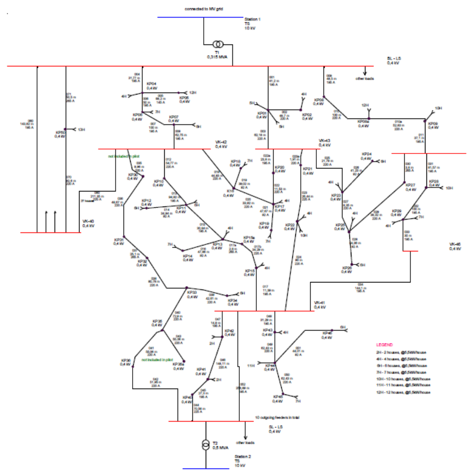

Fig. 25: Simulation model of the network analyzed in Paper 0402

Large-scale integration of PV-systems and heat pumps in an existing LV-grid in a workmen's quarter is discussed in **Paper 300**. For the evaluation of the impact of these systems on the LV grid, a general design procedure has been defined: by applying this procedure, a seasonal behavior in the LV grid resulting in loading- and voltage problems during summer time and loading problems in winter time has been discovered. In detail, the expected penetration of heat pumps and PV leads to the overloading of existing cables to such a degree that cable replacement is the only option, resulting in a reduction of the overvoltage. The introduction of MV/LV transformers equipped with OLTC also proves beneficial in reducing voltage variation in the LV grid.

Sub block 3: Optimal Placement of Power and Control discrete Components

Installation of advanced components in a finite number of network sites, such as substations, ranks among the most effective ways to enhance network performance. It may be done to improve voltage profile, to increase continuity of supply or to reduce short-circuit currents or voltage dips, but the process is more or less the same.

Sub block 2 deals with specific planning problems, often related to optimal placement and sizing of discrete components such as actuators, fault passage indicators, capacitors' banks, storages, and so on. In most cases, therefore, the content of the paper consists in newly-developed or adapted algorithms to find optimal placement conditions.

Automation of MV feeders is one of the key applications to improve continuity of supply in distribution network; however, while introducing an automation system in an existing network, it is crucial to define exactly where the devices must be installed to maximize the benefits of the introduction of the technology. **Paper 1171** describes the automation optimization model used in Helsinki and the process of how the existing information system was used together with the optimization model to find the optimal MV/LV substations for the installation of the automation devices, also taking into account already automated substations.

Paper 1228 deals with remote control in MV networks with the aim of improving continuity of supply (namely, frequency and durations of customers' interruptions). The paper start analyzing existing network, clustering them in defined zones (urban, mixed and rural) for which quality standards, defined as maximum acceptable values in specific sections of the network, apply. Then the methodology is applied taking into account SAIDI and SAIFI expected enhancements in performance. Finally, the economic assessment of investments is provided based on the benefit/cost ratio methodology.

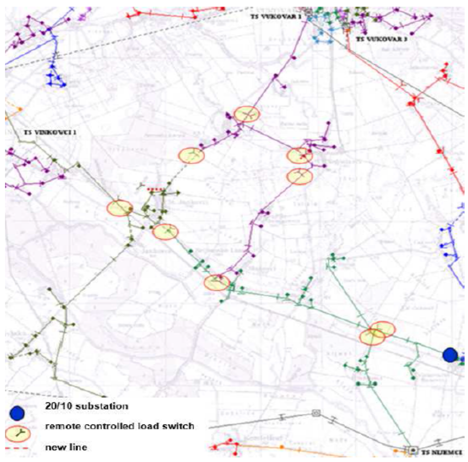

Fig. 26: Locations of load switches and other investments improving quality of supply according to Paper 1228

In **Paper 0147**, the problem of optimal placement and sizing of capacitors in three-phase unbalanced distribution systems is afforded. The authors propose a highly-performing algorithm in order to approach the problem in probabilistic terms, and at the same time to reduce its complexity, allowing huge computational savings. The problem is solved into two steps: in the first one, the reduced feasible region of possible candidate busbars for capacitors installation is determined by applying the Inherent Structure Theory of Networks

(ISTN); secondly, the optimization is run through a Simultaneous Perturbation Stochastic Approximation (SPSA) algorithm, applied to the set of candidate busbars determined in the first step and to the standard capacitors banks' sizes. Result show the proposed algorithm proves still reliable in terms of results while faster in calculations with reference with established methodologies.

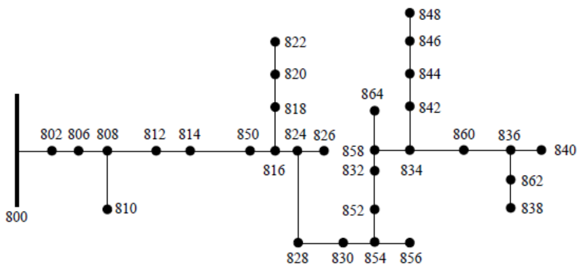

Fig. 27: IEEE 34-bus distribution test system analyzed in Paper 0147

Storage systems are a valuable tool to consider in network planning, as they can provide a large variety of network services. **Paper 0534** presents a study on the use of storage to ensure reserve supply in the case of relatively rare events in rural areas, as an alternative to expensive underground cabling. The study firstly provides some information about network behavior and techno-economical performance indicators in major disturbances, and then compares storage and cabling solutions by assuming the same level of continuity of supply is ensured to final customers. Results show that, for extremely dispersed populations, there are niches in which storage can be a cheaper solution both from the DSO's and the individual customer's point of view.

Paper 1307 compares three planning variants of network expansion, consisting only in the installation of storages to compensate the voltage fluctuation due to the connection of new DG in objective year 2050, which differ for the degree of integration of planning activities at different voltage levels (no integration, integration of MV and LV planning separate from HV planning, full integration of planning processes). Results show that full integration may lead to economies up to 20% for the given network, the abovementioned reduction in size eventually resulting also in the change of the most suitable technology for the storage system itself.

Paper 0960 exposes the results of a study about the consequences of a symmetrical reactive power injection by a 6 MVA generator in case of an asymmetric fault. It can be expected that this operational practice, which has recently been introduced in Portuguese network code, may have different impacts in case the plant is connected to a HV or a MV network. Therefore, in order to determine possible overvoltage, two reference situations were evaluated for a wind farm connection to the distribution network: HV network (60 kV) and MV network (30 kV). The modeling and subsequent simulations were performed using the software EMTP-RV and three types of asymmetrical faults (line-to-ground, line-to-line and double line-to-ground) and two types of reactive power injection (symmetrical and asymmetrical) were considered. Results show the calculated overvoltage remains within system insulation levels and that asymmetrical reactive power injection is in fact more effective on voltage support in case of an asymmetrical fault.

The optimization process and algorithm proposed in **Paper 0599** aim at minimizing network losses, while maintaining adequate levels of continuity of supply for final customers. In order to achieve this result, a two-step process is implemented. Firstly, an innovative use of the screening process of the Design of Experiments (DOE) methodology is applied. Then, a pre-sizing of these devices is performed in order to obtain a first estimate of the overall capacity to be installed. This second step allows thus the DSO to evaluate whether the envisaged solution is cost-effective. The proposed approach is then carried out on an existing Belgian MV network and a sensitivity analysis for assessing the robustness of the results is performed.

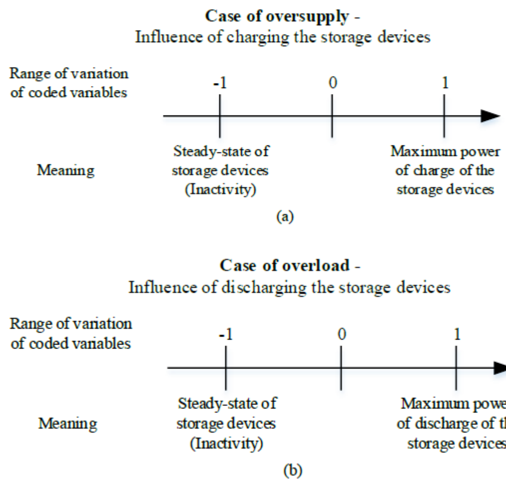

Fig. 28: Decomposition of two-step optimization process described in Paper 0599

The use of meters or sensors has indeed become strategic in recent years, as they represent a crucial device to increase gird observability, resulting in a satisfactory accuracy in network state estimation. **Paper 0976** exposes an approach to optimal meter/sensor location in order to minimize the voltage uncertainties of all buses across a distribution grid, making use of a boolean convex optimization. The problem is posed under the framework of optimal experimental design, by minimizing scalar-valued functions of the state error covariance matrix. Its performance has been tested on a 55-bus distribution network also hosting distributed generation, proving the method is able to find optimal meter locations in simple and computationally efficient manner.

Paper 0779 describes the testing of a sensor placement algorithm developed to determine measurement strategies for distribution grids. This testing was performed on a laboratory microgrid at the University of Strathclyde. The ability of the algorithm to choose the optimal subset of measurements was tested by comparing the estimated power flow with the measured power flow of a fully instrumented grid. The chosen subset is found to have the close to the lowest overall error and all estimates agree with the rejected measurements within the calculated uncertainties.

Sub block 4: EV Accommodation Planning

Papers in Sub Block 4 deal with the planning of distribution infrastructure as influenced by exogenous factors as the foreseen growth of electric vehicles for private mobility, the load growth and RES and DG fast growing penetration. Different approaches are proposed and some papers show a very high level of innovation of the used planning methodologies.

Paper 0709 comprehensively deals with urban planning by looking at the possible integration of Super Conducting Cables (SCC) in mega cities development plans. The paper proposes a planning approach very well aligned with recent CIGRE activities and include control strategies in planning. The strategic long term planning is applied to Megacities and several optimal structures are proposed with the adoption of SCC (see **Fig. 29**).

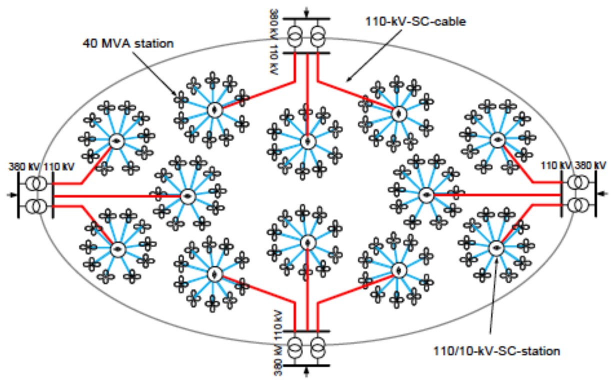

Fig. 29: Long-term planning for a 4800 MVA megacity with HV and MV SCC as in Paper 0709

Also **Paper 0076** deals with the long term, strategic planning of distribution systems. The authors propose novel software, Smart Sizing, to help the planning engineer to determine the ideal target network, which acts as a concrete vision of the future distribution grid. Smart Sizing fully supports the new smart grids context by optimally using smart functionalities such as distributed generation curtailment and load flexibility. At the heart of the tool lies an optimization algorithm, that finds an optimal smart distribution network, taking into account all of its complex interactions, such as the trade-off between investing in new electrical equipment and investing in ICT and load flexibility, and the trade-off between decreasing substation density and decreasing network length.

Cities and Mega Cities will very soon experience the connection of fast charging supply equipment (EVSE) with rated power up to 50 kW. Many of these novel stations will be connected at low voltage with a considerable impact on power quality. **Paper 1092** investigates on the positive impact of reactive power support in German LV networks by adopting a probabilistic load flow to take into due consideration the uncertainties. If EVSE is installed close to a substation no particular requirements are necessary but, as the length of the line connecting EVSE increases, the use of front-end converters with reactive power control to compensate line length becomes necessary. Reactive power control with hysteresis, by offering capacitive power during high power consumption as well as inductive power during high-distributed generation, can be recommended (see **Fig. 30**).

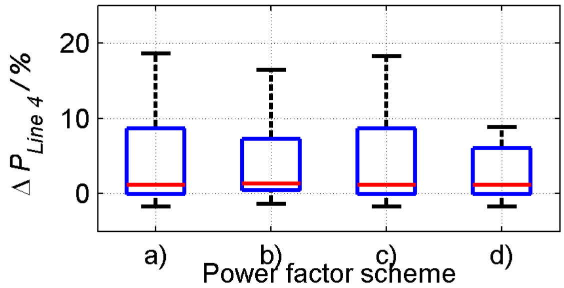

Fig. 30: Additional losses caused by Reactive Power according to Paper 1092 as a function of different control schemes

The impact of electric vehicles in LV systems is a good reason to develop a LV long-term strategic planning under the new paradigm of smart grid as proposed by **Paper 0312**. The authors propose to use a hybrid methodology based on a Gaussian local search and a genetic algorithm to solve a multi-stage optimal distribution planning problem. ICT investments to manage EV charging are included. The proposed approach leads to an optimization of the costs of network expansion (ICT infrastructure and reinforcement) through suitable allocation in time of the possible investment choices. Results show that ICT costs and EV charging methods influence the planning process and modify the share between OPEX and CAPEX.

Paper 1198 deals with the optimal location of different EV chargers into the distribution network. The authors propose an interesting algorithm to allocate charging station without creating too much problems to existing distribution networks. It is worth noticing that the software is based also on socio-economic (geographic and demographic variables) and mobility (expected behavior of EV drivers) criteria.

Paper 0501 deals with the impact of EV in the Netherlands where EV are becoming very popular (45.000 EV have been registered up to 2014 and 200.000 are the target for 2020). From the simulation results performed by ENDINET and ALLIANDER, an optimum solution is suggested for a typical mesh connected low voltage network that can maximize the societal benefits with minimum network investments. It is found that under normal situation when only charging at homes is done, the network can supply the required load demand without violating network standard design conditions. However, when public charging at streets is also included, the network becomes overloaded. To avoid network congestion and defer investments, it is recommended to introduce a dynamic tariff system and smart charging policy in the networks.

Paper 1505 investigates on EV impacts on both distribution networks and railway station parking lots. Firstly, the effect of uncontrolled recharge is analyzed with respect to economic indicators. Then, by using mixed integer linear programming and interior point for non linear optimization, the high interests of using coordination charging techniques and V2G technology for grid service providing is well demonstrated. For railway stations serving EV charging infrastructure, the presence of energy management system leads to increase number of EVs that can be hosted by parking while the annual energy bill paid by station can be reduced significantly.

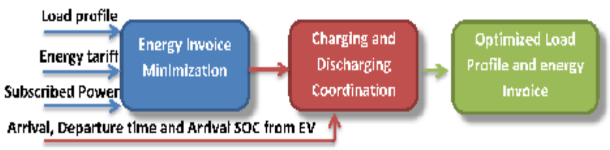

Fig. 31: Optimization process for energy cost minimization in Paper 1505

For a proper planning of grids that supply EV the knowledge of drivers' behavior is fundamental. **Paper 0793** proposes an EV load model that can be useful in modern planning tools. The model is based on Markov chains and data sampling for creating individual daily plans for each individual of the vehicle population. By using statistical mobility data, the method provides a high degree of adaptability to local data or offers the possibility to perform simulations in data-poor areas by using a set of default values. From the grid planner perspective, only the definition and classification of the charging infrastructure is required.

LV distribution is under observation also in **Paper 0608**, where the focus is on the integration of storage. The main result is that storage is too expensive for decreasing the peak of MV/LV transformer substations. Anyway, it is worth to notice that urban areas can benefit from storage much more than rural or semi-urban areas.

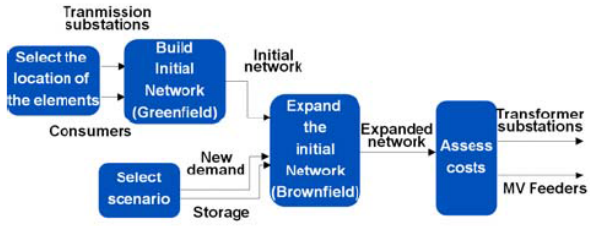

Fig. 32: Methodology for planning with storage included as described in Paper 0608

When the batteries are installed in the secondary substations, the savings are larger in the substations than in the MV network. This is especially the case when the peaks of the low and medium voltage consumers are coincident.

Sub block 5: Smart Grid Planning

The planning of Smart Grid has been dealt with in several papers form different point of views. Anyway a common thought exists in all contributions: the Smart Grid will change the distribution planning due to the inclusion of operation in planning that allows deferring in some cases CAPEX. This is in very good agreement with the general framework for novel distribution planning as proposed by CIGRE C6.19 and presented in previous CIRED. The main novelty is now that the first practical applications of those ideas are used in distribution companies and for this reason innovative and sophisticated planning tools are proposed.

In this sense **Paper 0746** proposes novel design and planning techniques to allow DG being connected at least cost by eventually adjusting its production level. This is a practical application within a major distribution company (ERDF) of what stated in CIGRE C6.19 report. The boundary between planning and operation is vanishing and effective planning methodologies have to include operation. In this context, the most innovative contribution from the paper is about the wise use of time series in planning integrated with probabilistic calculations. The authors underline that in many countries, as in France, there is still a big gap between what is possible and reasonable to do and what law and regulation allow. Anyway, ERDF is looking for new options for the connection of producers that take into account the availability of control systems and therefore increase the hosting capacity of the network without requiring massive expenditures for new infrastructures.

Paper 1026 completes and integrates Paper 0746 by showing how different generation curtailment techniques can be included in planning. The paper focuses on generation curtailment based on measurement and short-term forecasts. The authors prove that in case of simple generation curtailment the operation of network is guaranteed with simple measures (that is like to say that the problem happens before it is fixed). Short-term forecasts are necessary with more complex active distribution systems where DER offer more system services (e.g., voltage support, reactive power compensation, etc.).

Strategy	P base	P measure	P forecast
Constraints suppression	Curative		Preventive
Curtailed energy	↘	↘↘	?
Limits	Constraints during activation		Error on forecast
Material	Comm DSO → DG	Comm DSO ↔ DG	Forecast generation system, comm DSO ↔ DG

Fig. 33: Comparison of different curtailment strategies presented in Paper 1026

Paper 0564 presents the usage of Strategic Investment Model (SIM) in the Flexible Plug and Play project to determine the optimal network investment portfolio. The studies, carried out on the 33 kV distribution network in the FPP trial area covering 700 km^2 between Peterborough and March in the east of England, focus on a spectrum of applications of smart grid technologies including Dynamic Line Rating (DLR), Quadrature-boosters (QBs), Static VAr Compensators (SVCs), novel protection relays, smart generator controllers, Active Network Management (ANM) and smart commercial arrangements in order to improve the economic and technical efficiency of DG integration into the UK Power Networks' distribution. The analysis, carried out using the SIM, demonstrates its capability to:

a) Determine the optimal portfolio and location for implementing smart grid technologies
b) Evaluate the costs and benefits of alternative distribution network planning strategies considering both smart technologies and traditional network reinforcement over multi-year time horizons; and
c) Inform optimal operating strategies and investment policies.

A very similar subject is also dealt with by **Paper 0958** that studies the role of demand and generation flexibilities to postpone the reinforcement of the network. Special emphasis is given to the techno-economic framework to compare flexibilities and reinforcement.

Also **Paper 1253** deals with the research of a compromise between substation investment and distribution-side generation curtailment. The proposed decision-support tool finds the optimal compromise under uncertainty between two technical solutions to handle a power constraint. By contrast, potential gains probably depend significantly on the quality of the forecasting model according to the stochastic behavior of the real parameters.

Paper 1377 presents an up-to-date planning study applied to the distribution grid of EKZ (Switzerland). The authors underpin the need for novel grid simulation and planning tools that allow the evaluation of advantages and disadvantages of conventional and, in particular, novel Smart Grid reinforcement strategies. The presented simulation platform DPG.sim (Distributed Prosumer and Grid Simulation) overcomes today's lack of industry-grade simulation, analysis, and optimization software for active distribution grids. Time-series simulations of a MV feeder comprising an LV network are performed and an assessment of innovative versus conventional grid planning options is proposed. Several grid reinforcement options using conventional tools or Smart Grid elements, such as curtailment, energy storage, and reactive power control, are simulated and evaluated with respect to their technical performance. The unintended side-effects that the mitigation of overvoltage can have, namely under-voltage events at other buses due to OLTCs and increased line loading due to reactive power control are a novelty normally not-presented in smart grid planning.

Paper 1623 deals with a smart distribution toolbox for distribution system planning. The toolbox exactly follows what is suggested by CIGRE C6.19 and include in planning options demand side integration, the integration of RES, the role of EV, the static storage as well as traditional grid reinforcement and feeder reconfiguration. The sources of uncertainty have been identified and stochastic models for them have been found.

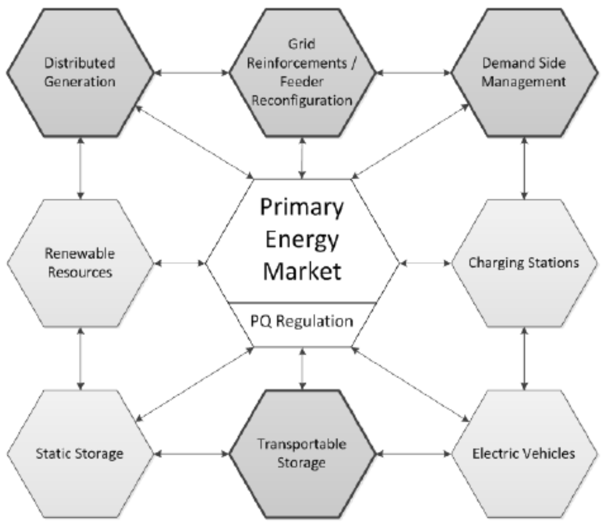

Fig. 34: The planner's toolbox proposed by Paper 1623

Similarly to previous paper, **Paper 0484** investigates recent developments in distribution network expansion planning and aims at providing a starting point for those interested in integrating new concepts and technologies in the planning process to develop a new future proof 'Smart Planning' approach. The use of more detailed load models is necessary to properly taking into account the impact of new (stochastic) generation and loads and accurately assesses the benefits brought by smart grid technologies. A modern planning approach should also be able to account for the impact of the smart market and, to achieve a true optimum, include the costs and benefits for all involved stakeholders.

Finally also **Paper 1394** proposes a planning method for the planning of LV- and MV-network structures under consideration of innovative operation equipment such as tap-changed transformers, voltage control elements as well as storages or DSM. The results show the functionality of the new planning method, based on a genetic algorithm (GA) with proposed "Smart Operators" integrated in the standard GA.

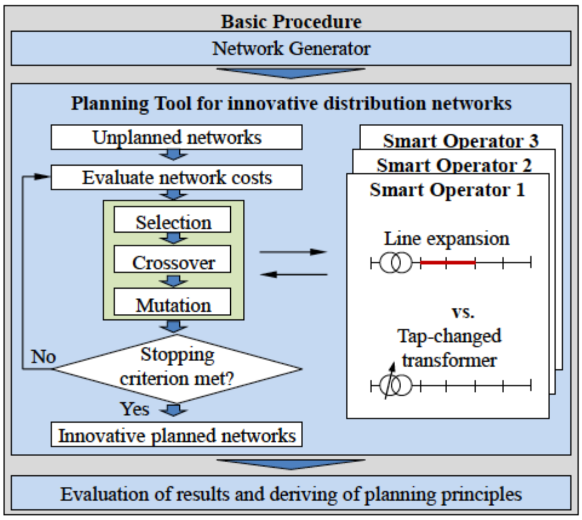

Fig. 35: The Genetic Algorithm proposed in Paper 1394

Paper 0953 deals with the contribution that demand side response can give to network security and, more generally, with the role of demand in distribution planning. This paper presents a new methodology to evaluate the capacity contribution of Demand Side Response (DSR) to distribution network security whilst maintaining the philosophy of the current distribution network planning and design standards. The methodology is based on a hybrid approach that combines simulation techniques for the random selection of the operational regime of a DSR facility with analytical techniques for the evaluation of reliability metrics and capacity value of DSR.

The role of ICT in distribution planning is dramatically increasing. As **Paper 0795** clearly shows, the choice and the planning of ICT infrastructure has a direct impact even on power distribution planning. The ICT planning model provides ICT solutions that can be used to avoid conventional grid reinforcement. The technologies and their associated costs are a function of the use case and communication requirements defined by the grid planner. ICT networks are evaluated through cost-benefit analysis and directly propose promising ICT solutions for the given distribution network.

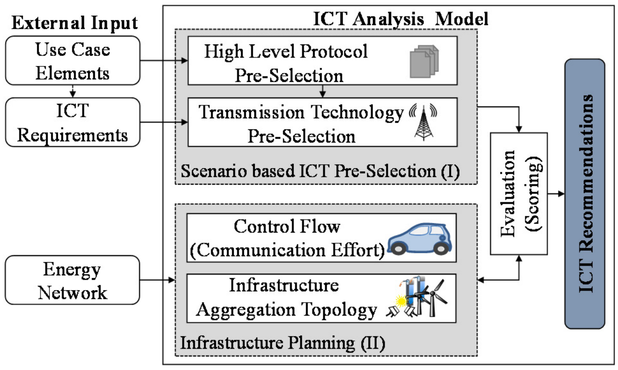

Fig. 36: The ICT model for distribution network planning (see Paper 0795)

Paper 0666 also deals with the optimal planning of the ICT infrastructure for Smart Grids. Particularly, since a Smart Grid must process information using data aggregators and smart meters, the paper propose an interesting system that assists planners in the positioning of those devices in order to provide coverage and good communication links. The system also allows users to use RF-Mesh technology and automatically generate an initial planning which is obtained based on a well-known optimization problem, the Set Covering Problem. Given a set of electric poles and meters, the Smart- Planner can automatically calculate the number of DAPs and its positions in order to maximize the number of meters covered using the least quantity of DAPs needed.

Finally, **Paper 0233** deals with a recent planning process applied to the Bashkortostan distribution network. The process for modernization will lead to a Smart Grid with smart meters and automation systems. Six measures have been identified and assessed. The assessments showed that optimization of network structure using existing 6 kV and 10 kV equipment and GIS technology as well as network automation using feeder condition monitoring, digital power meters and partially remote-control of transformer stations lead to a positive return of investment after 10 years.

Potential scope of discussion

The transition from deterministic worst-case analyses to probabilistic network planning has just started, yet it already seems that an accurate evaluation of network criticalities requires instead serial load flow calculations based on time series made available by, or determined through, Smart Meters' measurements for both final and active customers. This implies new tools, new algorithms but, even before that, huge amount of data to be managed and handled: is distribution ready for Big Data or, maybe better said, is Big Data "big" enough for the distribution business ?

Table 3: Papers of Block 3 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0042: Assessment of maximum PV penetration levels in low voltage networks using Monte Carlo approach				X
0076: SMART SIZING - A Tool for Long-term Planning of Distribution Systems	9			X
0124: Modern grid planning – A probabilistic approach for low voltage networks facing new challenges				X
0133: "Smart Planning" - Optimal Balance between Risk & Costs				X
0140: The potential of using generated time series in the distribution grid planning process				X
0147: A probabilistic approach for optimal capacitor placement in a distribution system using simultaneous perturbation stochastic approximation				X
0170: Optimal Medium Voltage Network Planning Under Load Forecasting Uncertainty				X
0187: Techno-Economic Assessment of Planning Principles for Low Voltage Grids in the Presence of Massive Distributed PV Generation				X
0233: Techno-Economic Assessment of Smart Grid Solutions in the Russian Distribution Network of Bashkirenergo		1		X
0300: Large Scale integration of PV Systems and Heat pumps in a Workmen's Quarter				X
0312: Optimal Multistage Planning of LV Networks with EV Load Control: Prospective ICT vs. Traditional Asset Reinforcement Investment			3	X
0336: An Analytical Decision Model To High Voltage Network Planning				X
0379: Risk Analysis Methodologies for Distribution Network Investment Projects and Portfolios				X
0402: Estimating the impact of large scale photovoltaic generations on a meshed low voltage network - a case study results				X
0420: How to zip a multi M€ GIS project into a few dozen k€?				X
0425: Opportunities presented by smart grids to improve network planning, optimising electrical vehicle, DER, and load integration				X
0484: A basis for smart planning: Requirements for expansion planning of future distribution networks				X
0501: Optimizing investment strategies on network's capacity growth for facilitating large scale integration of electric vehicles				X
0534: Reserve Power - Alternative Solution to the Network Investments in Rural Area Networks ?				X
0544: MV planning approach using time series, billing data of medium voltage consumers and substation feeders metering	6			X
0564: Strategic Investment Model for Future Distribution Network Planning		2		X
0599: Optimal positioning and pre-sizing of storage devices for the improvement of MV distribution grid operation				X
0608: Analysis of the Impact of Battery Storage on Power Distribution Systems				X
0666: Smart Grid Deployment Planning: Case Study Covering a Brazilian Feeder in Automation Process		3		X
0686: Optimal Planning of Urban Distribution Network Considering its Topology				X
0709: Network Planning Approach with respect to an Effective Integration of Super Conducting Cable Lines in Distribution Grids	10			X
0746: New Options for Connecting Generation on Distribution Networks and Required Network Control Preparation	11			X
0753: An Application of Cluster Reference Grids for an Optimized Grid Simulation			1	X

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0779: Testing and Validation of an Algorithm for Configuring Distribution Grid Sensor Networks				X
0793: EV stochastic sampling: addressing limited geographic areas				X
0795: Choice of ICT infrastructures and technologies in smart grid planning		4		X
0915: Extraction of 9,163 real LV network models from DNO GIS database to assess overvoltage from PV and consequent mitigation measures				X
0916: Distribution Network Pricing Model for Efficient use of Existing Infrastructure and Efficient new Investments				X
0933: A Flexible Tool for Integrated Planning of Active Distribution Networks				X
0953: Assessing the Contribution of Demand Side Response to Network Security		5		X
0958: An Investment Versus Flexibilities Comparison Framework				X
0960: Reactive Power Injection by Wind Farms during Asymmetric Faults - Application to Portuguese Distribution Grid				X
0976: Optimal Location of Measurement Devices in Distribution Grids via Boolean Convex Optimization			2	X
1002: Communication Project of primary substations and surrounding network				X
1008: The impact of restructuring urban and suburban distribution grids with Smart Grid approaches on system reliability				X
1021: Utilizing a modern network information system in the optimization of network investments				X
1026: A comparison of different curtailment strategies for distributed generation		6		X
1092: Reactive Power Support for Optimal Grid Integration of Fast-Charging Infrastructure in German Low-Voltage Networks				X
1103: An innovative method to assess solutions for integrating renewable generation into distribution networks over multi-year horizons	7			X
1110: New Hybrid Planning Approach for Distribution Grids with a High Penetration of RES				X
1167: Multi-level distribution grid planning process by means of a multi-agent-system				X
1171: Optimization and visualization of distribution automation utilizing advanced network information system				X
1198: Software for the Optimal Allocation of EV Chargers into the Power Distribution Grid	12			X
1228: Methodology for allocation of remote controlled switches within long term medium voltage distribution network planning				X
1253: Curtailment of distribution-side power generation for primary substation investment deferral				X
1307: Energy Storage in Distribution Grids - Needs for Cross-Voltage-Level Planning and Optimization				X
1320: On the DER Hosting Capacity of Distribution Feeders	8			X
1337: Computer-aided distribution network planning using expert rules				X
1364: Development tool for Regulatory Evaluation of Investment in Expansion of Brazilian Distribution Systems				X
1377: Time-series Simulations and Assessment of Smart Grid Planning Options of Distribution Grids		7		X
1382: Integrated planning of distribution networks: Interactions between land use, transport and electric vehicle charging demand				X
1394: Innovative Planning Method for Deriving New Rules for Future Network Planning				X
1418: SIRIs Platform: General Features of the First Integrated Computational Simulator of Smart Grids in Development for Brazilian Electric Utilities				X
1426: Upgrading MV-grids: A compromise between technological development and cost-efficient solutions				X

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
1505: Contribution and impacts of grid integrated electric vehicles to the distribution networks and railway station parking lots				X
1527: Impact of Evolving Load Profiles on Distribution System Assets and System Reliability Assessment				X
1623: A smart distribution toolbox for distribution system planning				X

Block 4: Methods and Tools

Sub block 1: Load Modeling and Forecasting

Load forecast is a planning activity that has been conducted since last years starting from elementary data drawn from historical experience or based on given assumptions about simultaneity of consumption and level of use of appliances. Only recently the availability of huge amounts of hourly data coming from Smart Meters made it possible to evaluate the "atomic" components of consumptions.

At the same time, technological evolution of domestic and/or industrial equipment enables "smart" functionalities leading to rules of combination of atomic loads which may significantly differ from purely statistical ones.

Sub block 1 deals with methodologies to make use of available individual data and of new logics of elementary load management to build models which may accurately represent the complexity of "smart" loads.

Paper 0520 demonstrates a way for predicting customer loads and consumption patterns by having aggregated historical Smart Meter Data. It is useful if the customer Smart Data are provided in aggregated and anonymous formats due to costs, unavailability and privacy concerns.

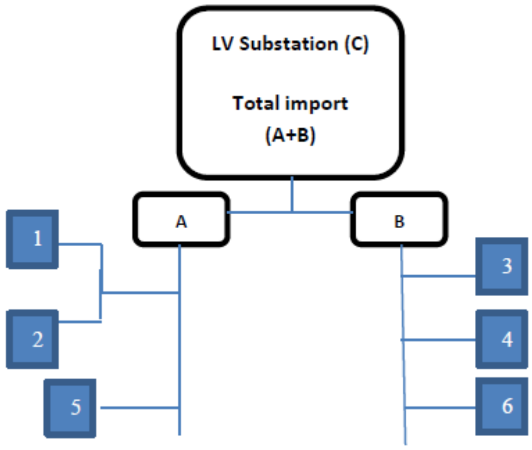

Fig. 37: The LV model with data aggregation points (A and B) described in Paper 0520

Paper 0107 presents a method to estimate a domestic household's hourly electricity load profile from its daily electricity consumption, using multiple Gaussian distributions. The model requires six data input such as number of rooms to generate the load profile. It is possible to quickly estimate the hourly load profile of a household without the detailed statistical data required by other methods.

Paper 0369 describes the use of Automatic Meter Reading for distribution planning and improving customer services: automation of meter reading and billing process, load forecasting and demand response initiatives, loss monitoring, etc. Various applications of AMR data and its benefits are explained in this paper.

Paper 0395 highlights the underlying issues of recording and processing real measurement data for load modeling. Some data acquisition and processing guidelines are provided, aimed at improving the accuracy of developed load models. The paper makes an overview on different aspects to have into account to make a load model based on measured data: the resolution of the measures, the limitation of processing data, the data quality, etc.

Paper 0489 develops a simplified model of photovoltaic (PV) kW output in response to solar irradiance and ambient temperature. A high accuracy level of the proposed model has been verified using smart meter data.

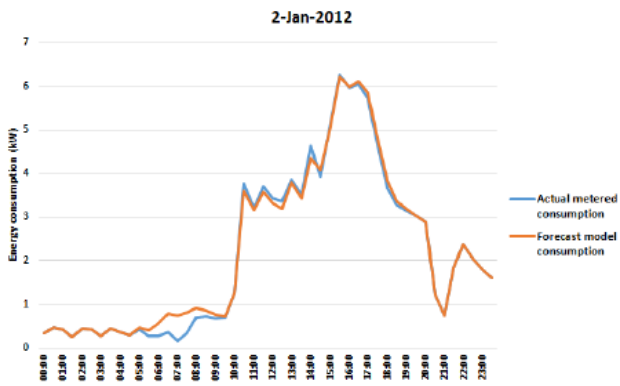

Fig. 38: Estimated and measured load profile for a 1 kW PV site according to Paper 0489.

Paper 1255 develops a model for characterizing photovoltaic generation behavior and estimating generation connection capacity. It is based on solar irradiance, can be used to assess large volumes of LV network and allows determining how much generation can be installed in a given feeder before voltage management techniques need to be considered.

Paper 1261 shows a statistical analysis of data collected over a year from more than 100 residential, underground LV feeders. The parameters investigated were: voltage, power factor and imbalance level. From the analysis, it is possible to conclude that the presence of photovoltaic systems increases the unbalanced nature of LV distribution networks.

Paper 1275 deals with the objective to be able to simulate with very short computation time the individual electricity consumptions of thousands of customers. The work introduces the concept of the aggregation profiles of electrical equipment and consumption statistics in order to forecast the load profile.

Paper 1149 shows that it is possible to calculate a load-model based on hourly energy metering, that consists of an expected variation curve over the year and a statistical distribution function that describes the normal deviation from this expected variation curve. Monte Carlo simulations give information about expected values and probability distributions around these expected values. The paper states that the variations in future electric power generation and demand should be analyzed with probabilistic models in load flow calculations and power system planning.

Paper 0711 proposes new data sources to forecast the energy demands, mainly based on the use of probabilistic models and it exploits geo-localized cellular network traffic as independent variable. It proves that cellular network data are a strong indicator to forecast in real-time the energy consumption and demand.

Paper 1279 compares two types of analysis for the creation of a household load model: top-down and bottom-up approach. The top-down generates load patterns for hundreds of MV/LV transformers. The bottom-up model models the household load based on the occupancy of a household, and on the behavior of the members of the household. It can be seen that the accuracies of the different models are similar.

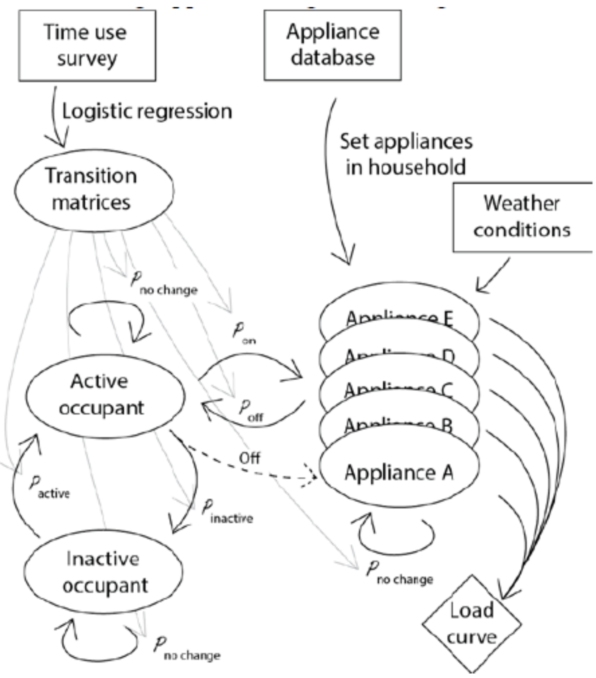

Fig. 39: Markov chain model for the bottom-up determination of the household load as in Paper 1279.

Paper 0835 presents a methodology for disaggregated substation peak active and non-compensated reactive power forecasting. It is shown that the peak active power has a linear relation with monthly energy. On the other hand, the peak reactive forecasting is based on artificial neural networks.

Paper 1180 describes the fact that the forecasting of long term load profiles must have into account the effect of new energy technologies. These new technologies in the future require new load modeling and forecasting tools.

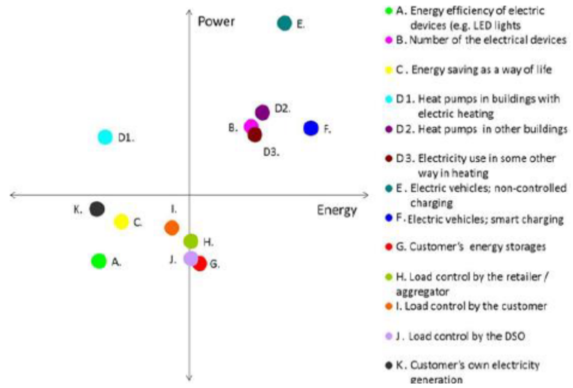

Fig. 40: Possible changes in electricity end-use chart as shown in Paper 1180.

Sub block 2: Network Modeling and Representation

The combined effect of non-conventional behaviors as in DMS and of new grid users such as EVs and RES-generation makes load forecasting a more complicated activity than in the past; at the same time, the access to large amounts of data may support the verification and validation of forecasting methodologies, allowing the adoption of wider sets of possible algorithms and eventually leading to an increase of the level of accuracy in the forecasts.

Sub block 2 deals with the development of innovative or the refinement of established load forecasting criteria in order to grant the best possible inputs to the planning process; forecasts may be defined at a disaggregated level (e.g. for a specific category of users, such as EVs or DGs) or may represent a complex entity (e.g. a substation).

Paper 0680 describes a method to ease performing planning analysis of great amount of feeders of LV networks using clustering techniques. The idea is to avoid the need for making a countless number of individual analyses over each LV feeder by only performing the calculations over a finite set of "representative feeders" obtained using clustering techniques. The method is applied over a real LV network of Liander (Dutch DSO), comprising about 88.000 different feeders. The risk level is calculated based on the 94 resulting clusters, taking into account the occurrence of such classes in real network.

	High risk	Medium risk	Low risk
Voltage	1.54%	5.91%	92.55%
Overloading	0.97%	2.88%	96.15%

Fig. 41: Risk level assessed on real LV network from clusters analysis results, as determined in Paper 0680.

Paper 0237 deals with the problem of automatically establishing a correspondence between two databases, a SCADA system and a geographical information system. This problem is abstracted as a graph matching problem, where each database is represented in an abstract way as an undirected graph. The method is applied in Resa (Belgian DSO). The work evaluates a method to link the information between two databases that usually are maintained independently for historical reasons.

Paper 0800 presents a MV/LV distribution substation classification method based on readily available fixed data, in order to group LV networks with similar characteristics. The results from the method can be used to apply similar planning and operation strategies for distribution substations in the same group. It classifies the LV network to different location and customer dominant types without the need to collect large scale of connecting customer information.

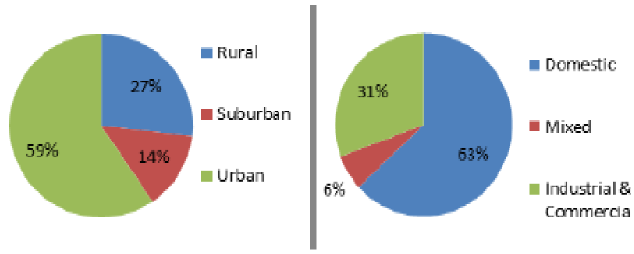

Fig. 42: Substation classification location and customer dominance presented in Paper 0800

Paper 1239 shows the main obstacles when simulating different networks and devices in real-time simulators. Complexity of the networks increases the processing time for calculations. The real time simulators are designed to operate with relatively high simulation time-step to allow simulations of large-scale networks. To optimize operation, multiple parallel processors are engaged which introduces additional issue with the delayed exchange of signals.

Paper 1498 shows arguments to review cable ampacity ratings. In order to do so, a large data basis of soil configurations in Bavaria has been established, and the effects in the cable ampacity have been quantified. This procedure allows getting the maximum use of the cable population, and shall lead to cost-efficient investment policies.

Paper 0946 presents the development that was included to the software EPRI - OpenDSS. This simulation mode is used for evaluating the behavior of harmonics at a certain point when the load changes in time. Since March 2013 the load model for harmonics studies can be modified by the user in OpenDSS. In 2014 the simulation of harmonics mode was introduced too. In this paper both items are described.

Sub block 3: Load Flow and Short Circuit Calculations

Sub block 3 deals with specific electrical calculations widely used in network planning or in components' sizing. Some of the papers refer to specialization of well-known methodologies in order to assess individual problems; in other cases the challenge is to simplify existing models in order to be able to manage large volumes of data; furthermore, new methodologies are eventually proposed to approach emerging topics.

Paper 0461 presents a method developed by the Dutch DSO Alliander to evaluate long term capacity of its LV network to face with future load and distributed generation to come, simulating future scenarios. This method includes electrical modeling of new LV infrastructure by exporting GIS data to the simulation software in an automatic way and customer load profiles by means of energy usage patterns provided by the Energie Data Service Nederland scaled with the desired annual energy consumption level (current or future). After modeling, network calculations are performed and results geographically presented.

Paper 0238 analyses how active power flow from the HV network to MV network has been reduced or even reversed by the increase of DG, while reactive power has not. This behavior of power flows has lead to increased voltage levels in the HV network, difficulties in HV/MV voltage control and fines payment by DSO for reactive power surplus at transmission grid connection point level. To avoid these issues, the paper propose request applying reactive operating curves to DG connected to the distribution grid, investing in reactive compensation and proposing changes in regulation to adapt it to new grid operation conditions in presence of DG.

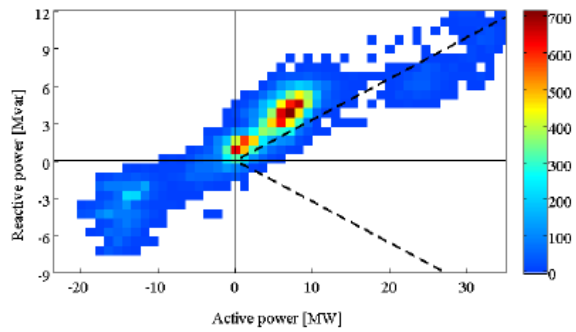

Fig. 43: PQ profile of a 10.5 kV primary substation with a cable network of -1.2 MVAR and with 39 MW of DG (Paper 0238)

Paper 0110 analyses in a cross-validation study the suitability of two steady-state new methods for short circuit calculation, superposition of current approach and load flow based approach, to be applied in distribution grids with high penetration of distributed generation connected through inverters. Both methods are implemented in test cases for diverse located three phase faults and DG penetration level and results are shown. According to DG penetration level considered, differences where evidenced within a 0.02 p.u. margin. Nevertheless, bigger differences in results (up to 0.16 p.u.) where influenced by control design choices made by manufacturers in the inverter fault behavior to accomplish with the capability of Low Voltage Ride

Through required in technical guidelines. Paper evidences both methods are similar but any of them can provide needed accuracy to sc calculations since unknowns in inverter behavior during faults is still a task to overcome.

Paper 0641 analyses a probabilistic approach to simulate LV networks with distributed generation using Monte Carlo techniques to determine PV units' behavior instead of the traditional worst-case deterministic way. Smart meters measurement series analyses are used to characterise the production of each PV connected to grid by its statistical distribution function. In this way, overvoltage probability and voltage imbalance risk in each network node can be calculated for a studied period. The method is tested on an existing 19 nodes LV network in Belgium, where node by node overvoltage and imbalance probability is obtained after considering and processing SM data recorded on a 15-min basis over a period of 2 years.

Paper 0692 presents a new system developed by Schneider Electric that is able to determine the relationship between all the LV customers, initially dispersed and not linked with their corresponding supply circuit, and each of the individual feeder/phases of the LV network by means of the analysis and processing of smart metering data provided both at the customer side and at the origin of each LV feeder in the MV/LV secondary substation. An algorithm based in the Conservation of Energy principle in each feeder fits all customer consumption values with the measurements provided by feeder meters so as to determine the most probable electric connectivity between them that meets the condition of energy conservation for each time-frame considered. To deal with metering needs at the origin of each feeder a new easy-to-install meter, also delivered by Schneider, is presented. Practical experimentations have been made in France whose results are also shown in the paper. Having such a metering system in a LV network is said to provide further added value to utilities in terms of LV outages detection, monitoring of LV network, loss allocation and even non-technical losses detection using data mining and pattern recognition techniques.

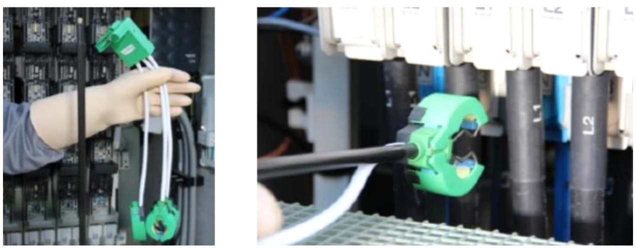

Fig. 44: Easy-to-install feeder meters as described in Paper 0692

Paper 0837 presents a methodology to characterize LV current imbalances in feeders based in the analysis of large volumes of monitored data through calculation of a new metric proposed and so to detect opportunities of increasing the capacity headroom in them by redistributing customer between phases in the feeders where it could be profitable. The metric proposed is

Imbalance ratio for phase X:

$$= \frac{current\ on\ phase\ X}{average\ current\ of\ the\ three\ phases}$$

The method has been evaluated in 233 LV feeders of Scottish Power Energy Networks distribution area during 6 months, and 22 feeders were identified as potentially suitable for a deeper cost-benefit assessment on the basis of their imbalance ratio and loading level. Results of cost-benefit assessment based on SPEN reinforcement costs show that for LV OHLs, redistributing customers between phases is the best techno-economic approach but in case of cables the best solution should be changing of LV feeder link-boxes configuration.

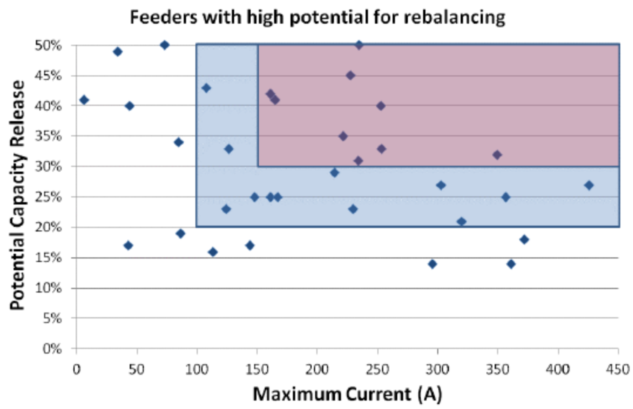

Fig. 45: Candidate feeders for rebalancing, according to the analyses performed in Paper 0837

In **Paper 0845** an approach is proposed to trace and quantify the individual contribution of distributed generators (DG) to the security of the grid where they are connected, from the point of view of the upwards transmission level in the grid supply point (GSP). Currently the capacity of DG is estimated by applying a scaling factor provided by technical guides. A new factor is introduced to take into account also technical curtailment to the potential generator production due to technical reasons and sensitivity individual factors for each DG power unit to properly assess its individual contribution to provide capacity in such grid supply point.

Paper 1178 presents a new method to increase the observability of the distribution network and the knowledge of its current state or characteristics by using voltage and power measurements at all LV end-user connection points provided by smart meters. Comparing estimated voltages at end-user connection points that results from power flow calculations based on power measurements with the real measured voltage at same points is possible to check accuracy of network model or find unexpected situations. The method was tested in a 7.000 customers LV network in Norway.

Paper 1284 suggests abandoning the traditional deterministic way of modeling the behavior of an electric network by shifting to a probabilistic approach in which each generation/load specific value is substituted with a probabilistic description of customer behavior. Considering in each network node the behavior of every generator and/or load connected to it by means of its probability density function, it is possible to substitute in the model their individual values with a nodal probability density function and, therefore, to obtain the network conditions also expressed in probabilistic terms.

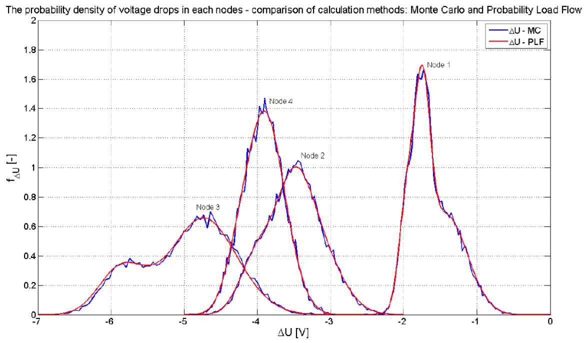

Fig. 46: The probability density of voltage drops in four nodes of a LV grid as showed in Paper 1284.

Paper 1273 presents a way to cope with the current lack of LV network information suitable for load flow calculations by means of a systematic methodology based in obtaining the electric suitable LV feeders models from data stored in the Geographic Information Systems. The proposed methodology makes use of a Breadth First Search Algorithm to determine the topological connectivity between all segments that belongs to a same polyline and a graphical minimum Cartesian distance method, to choose the most appropriate feeder and connection point for those segments or groups of segments that remains isolated after BFS Algorithm application.

Paper 1296 shows how to boost the hosting capacity of LV networks for new DG by means of a meshed operation of LV feeders instead of the current radially operated way. The study compares the behavior, both in radial and meshed operation, of each pair of feeders included in 15 real underground residential LV networks in North-Western England. Maximum benefits in terms of improvement in hosting capability are observed when coupling, in a unique mesh, pairs of feeders with a 2:1 proportion in the number of customers.

Sub block 4: Energy Losses Minimization

The maximization of profits creates the tendency to postpone investments in the network infrastructure, with negative effects on losses. In order to oppose this tendency, several countries adopt regulation directives that reward the distributors if losses are reduced and penalize them if losses increase.

Sub block 4 therefore deals with algorithms and methodologies aimed at evaluating electrical losses, developing innovative models or analyzing specific cases supporting planning or investment allocation.

Paper 0030 proposes using heuristic techniques based on Selective Particle Swarm Optimization to obtain the best topological configuration of the feeders of a MV distribution network in order to minimize technical energy losses, current imbalances between feeders and maximize voltage profile performance. By applying the developed optimization method to a real 6 kV network in Mariupol (Ukraine) comprising 284 branches and 274 buses, a reduction from 7.4% to 6.2% in power losses and from 5% to 4.2% in annual energy losses and also an increase in minimum nodal voltage from 0.79 p.u. to 0.88 p.u. is determined.

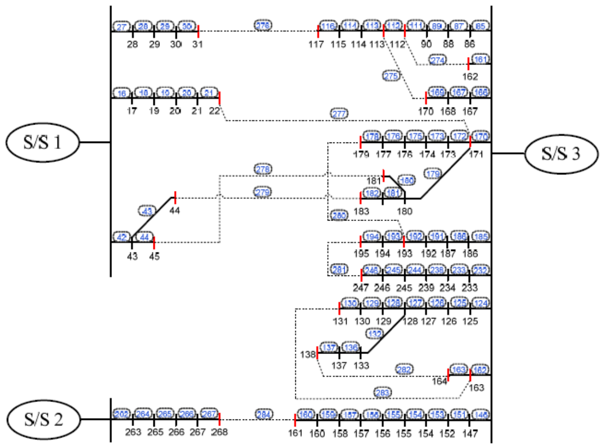

Fig. 47: Loops for reconfiguration according to the methodology described in Paper 0030

Paper 0068 presents a review of diverse known strategies for power losses reduction and gives authors' opinion of each one about the effectiveness and its applicability to distribution networks in the UK.

Paper 0069 describes a feasibility study and cost benefit analysis of applying some of the losses reduction strategies also presented in **Paper 0068** in the 11 kV distribution network of the Isle of Wight in south UK. Among other techniques, like incorporating Energy Storage, network voltage upgrading, Network automatic reconfiguration or Conservation Voltage Reduction, the dynamic connection/disconnection of transformers, by itself or combined with meshed network operation, results to be the best approach to minimize technical losses.

Paper 0255 presents an econometric method to forecast not only energy consumption on distribution network but also the technical losses according to expected energy increase without the need of perform load flow calculations over a network model. A good accuracy between load flows results and losses assessed by the econometric model is said to be obtained regarding overall losses in MV and LV network.

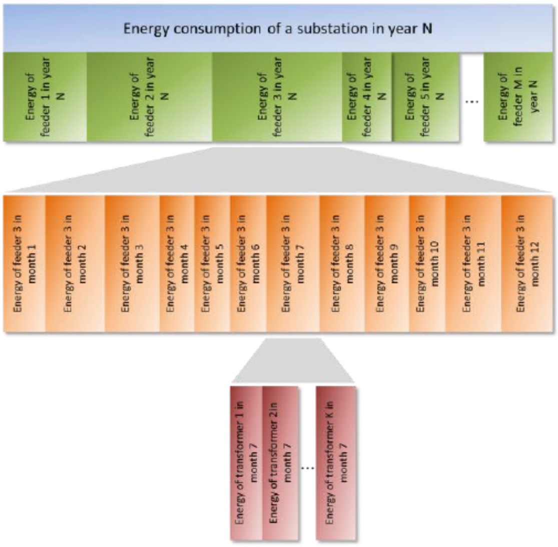

Fig. 48: Transformation of the annual energy of a substation into monthly energy per feeder and per distribution transformer (Paper 0255)

Paper 0634 describes several theoretical methodologies to analyze the effect of prescriptions regarding reactive behavior of grid users based on average energy measurement on a monthly basis. The paper describes how the current regulation leads customers, and even more in presence of DG, to overcompensate reactive consumption by means of capacitors and how these reactive overcompensation could not only result in inducing network criticalities, such as voltage regulation instability, but also increase the number of unintentional islanding cases and resonance phenomena.

Paper 1175 defines different methodologies to set losses referential goals in the fairest way, considering that the distribution utilities do not have the same characteristics and therefore the same potential in losses reduction. In the paper the targets in losses reduction are determined taking into account how efficient the utility is among others, instead of establishing a fixed value, according to a so-called Data Envelopment Analysis. The idea behind the paper is that a distribution company should be compelled to reduce its losses if they are cause of inefficiency, but not beyond a reasonable target according to its concession area characteristics.

Paper 1652 presents a method to ease technical losses assessment in large distribution systems by reducing the number of calculations to be made. For this purpose different approaches are described to calculate losses without having an exhaustive model of network and load measures, using load patterns behavior characterization along different periods of the year, or LV network losses characterization by extrapolating expected values according to the characteristics of a specific MV/LV substation and to the customers connected.

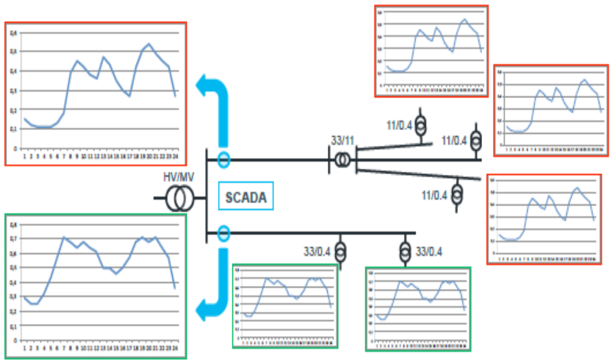

Fig. 49: Allocation of the measured profile at the beginning of the feeder in each supply point according to Paper 1652

Paper 1191 provides a methodology to obtain optimal MV network configuration regarding to power losses, based in minimizing the distance, from a geographical or electrical point of view, between customers and HV/MV substations. The method also provides the sequence of the switches' operation to be made in current network in order to reach this optimal configuration, avoiding critical customers' disconnection during the process and ensuring feeders' currents remain within their maximum capability by means of a branch-and-bound algorithm.

Potential scope of discussion

Smart Grids imply flexibility and adaptability are brought into distribution networks. The new paradigm of distribution management is based on the capability of the network to understand operational conditions and to modify according to pre-defined guidelines. However, to get the full benefits of this evolution we must be able to plan taking into account the expected, and possibly the unexpected, system flexibility behaviors. How can we represent the adaptive strategies a Smart Grid can pursue to make optimal use of them in planning, avoiding unnecessary over-sizing of equipment ?

Table 4: Papers of Block 4 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0030: A Selective Particle Swarm Optimization For Large Scale Practical Distribution System Reconfiguration				X
0068: Distribution Network Losses and Reduction Opportunities from a UK DNO'S Perspective				X
0069: Technical Feasibility and Cost Benefit Analysis of Network Losses Reduction Opportunities in the UK Isle of Wight 11 kV Network				X
0107: Simulation of Domestic Electricity Load Profile by Multiple Gaussian Distribution				X
0110: Development and Cross-Validation of Short-Circuit Calculation Methods for Distribution Grids with High Penetration of Inverter-Interfaced Distributed Generation		9		X
0237: Graph matching for reconciling SCADA and GIS of a distribution network			5	X
0238: Managing reactive power in MV distribution grids containing distributed generation				X
0255: Losses Forecast using Econometric Models				X
0369: AMR data for planning				X
0395: Practical aspects of developing load models at distribution network buses based on field measurements				X
0461: Method to scan the low voltage network flexibility to adapt to future developments				X
0489: Generation Modeling of Residential Roof-top Photo-Voltaic Systems				X
0520: Smarter Business processes resulting from Smart Data				X
0634: Influence of average power factor management on active distribution networks		11		X
0641: Probabilistic Analysis Tool of the Voltage Profile in Low Voltage Grids				X
0680: Clustering of low voltage feeders form a network planning perspective			6	X
0692: From Data Collecting to Business Intelligence and Data Mining				X
0711: Energy consumption and demand estimation from cellular network data: A real world case study			4	X
0800: Classification of Low Voltage Distribution Networks Based on Fixed Data				X
0835: Disaggregated active and reactive Demand Forecasting using First Difference Measured Data and Neural Networks				X
0837: Characterisation of phase current imbalance on three-phase LV feeders to identify opportunities for rebalancing				X
0845: Tracing the Contribution of Individual DG to Grid Supply Point				X
0946: Harmonics analysis using sequential-time simulation for addressing smart grid challenges				X
1149: New planning method for smart and active distribution grids				X
1175: Defining Technical Losses Targets using Data Envelopment Analysis and Technical-Economic Analysis				X
1178: New methods for distribution network monitoring with smart meters - Verifying data in network information systems				X
1180: A novel long-term forecasting process for electricity distribution business				X

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
1191: Optimal Power Distribution Systems Configuration and Switching Sequence Procedure Determinations		12		X
1239: Aspects of Real-Time Digital Simulations of Electrical Networks				X
1255: Improved characterisation of embedded PV generation on the LV network				X
1261: Data Analysis of LV Networks: Determination of key parameters from one year of monitoring over hundreds of UK LV feeders		8		X
1273: Reconstruction of Low Voltage Networks: From GIS Data To Power Flow Models				X
1275: Using simulated predictive load curves to improve DSO's network development planning methods integrating Smart Grids functionalities				X
1279: Assessment of Probabilistic Methods for Simulating Household Load Patterns in Distribution Grids				X
1284: A probabilistic approach to power flow analysis				X
1296: Investigating the Benefits of Meshing Real UK LV Networks		10		X
1498: Ampacity rating of directly buried distribution cables under the consideration of soil properties to improve efficiency of distribution networks				X
1652: Technical Losses Assessment in Distribution Systems with Reduced Measurement Capabilities				X