Special Report - Session 5
PLANNING OF POWER DISTRIBUTION SYSTEMS

Fabrizio PILO
Chair - Italy
pilo@diee.unica.it

Riccardo LAMA
Rapporteur - Italy
riccardo.lama@e-distribuzione.com

Giovanni VALTORTA
Rapporteur - Italy
giovanni.valtorta@e-distribuzione.com

Session Program and Organization

The session accepted 175 high-level papers (acceptance rate around 55%) divided into four blocks that reflect the S5 topics. The Main Session is stimulated by the oral presentation of selected papers; high research papers are selected for oral presentation in the RIF session. Oral presentations last ten minutes; in the poster tours authors have two minutes presentation followed by Q&A.

Block 1 Risk Assessment and Asset Management

- Sub block 1: Risk Assessment and Reliability Assessment
- Sub block 2: Resiliency
- Sub block 3: Asset Management and Maintenance Strategies

Block 2 Network Development

- Sub block 1: Innovative Power Distribution
- Sub block 2: Smart Grid Systems and Applications
- Sub block 3: DC Distribution Systems and Microgrids
- Sub block 4: Flexibility Solutions

Block 3 Distribution Planning

- Sub block 1: Advanced Planning
- Sub block 2: Smart Grids and Microgrid Planning with Flexibility
- Sub block 3: Optimal Placement of Power and Control discrete Components
- Sub block 4: EV Accommodation Planning

Block 4 Methods and Tools

- Sub block 1: Load/Generation Modelling and Forecasting
- Sub block 2: Network Modelling and Representation
- Sub block 3: Load Flow and Short-Circuit Calculations
- Sub block 4: Energy Losses.

The S5 papers will be discussed in three events:

- **MS** (June 15, 9:00-12:30 and 14:30 -18:00),
- **PS** (June 13, 9:00-12:30 and 14:30-18:00),
- **RIF** (June 14, 16:30-18:00).

Round Tables are organized by S5 or with other Sessions:

- **RT9**: Capacity Management for PV and EV (June 14, 09:00-10:30)
- **RT11**: Getting Authorisations to Enable Energy Transition Fast Developments (June 14, 11:00-12:30)
- **RT13**: New Roles of Smart Metering Functionalities (June 14, 14:30-16:00).

Introduction

Climate change adaptation and mitigation are dramatically impacting the development of the distribution system, that is bound to be the core of the new decarbonised energy system.

Climate change adaptation needs concrete actions to increase the resiliency of systems against natural disasters that should be more frequent. Many papers in S5 elaborate on strategies and methodologies to prepare development plans for making resilient systems. In this context, it is clear from many papers that resiliency is not only about building a stronger system, but it is also about smartness and flexibility. System decomposition in cells, microgrids and local communities can contribute to increase both resiliency and reliability.

Climate change mitigation requires the implementation of actions that will inevitably affect the evolution and the existence itself of distribution systems. The electrification of final energy uses is one of the clearest examples, implying a significant growth of heat pumps and electromobility (cars, trucks and ferries). The challenges faced by the authors in S5 span from managing the uncertainty on those new loads regarding the expected evolution on time, spatial position and temporal coincidence, to the exploitation of automation and control for operating all resources and accommodating more demand with less need of immediate revamping or rebuilding. Again, the use of all available types of flexibility is confirmed by the Papers to be a valuable option still difficult to include in daily DSO's life. Electrification must be accompanied with increasing renewable generation.

Block 1: "Risk Assessment and Asset Management"

Network performance, usually related to its capability of facing single events (reliability), now has to consider also multiple faults due to extreme weather conditions related to climate change (resiliency). As a consequence, many Risk Assessment and Asset Management papers take into account these two aspects. Maintenance Strategies, among others, begin to explore opportunities related to flexibility markets.

Sub block 1: Risk Assessment and Reliability Assessment

Sub block 1 include papers focused on network reliability evaluation to direct infrastructure development or maintenance activities in order to reach continuity of supply targets. Some papers concern risk assessment to evaluate distribution network resiliency.

Paper 10370, deals with a new tool, based on AI and ML, that helps network planners in identifying the most critical network elements in terms of outage probability and impact. The tool suggests the best network development and maintenance activities to reduce the outage probability.

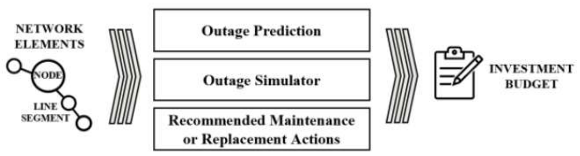

Fig. 1: Methodology block diagram to support network development, as in Paper 10370

Distribution network reliability estimation, based on Markov theory and developed by Enel, is described in **Paper 10474**. The aim is to define development plans for new network infrastructures and to identify how to improve the performance of existing ones in order to reach the continuity of service target levels in different reference networks (urban, semi urban and rural).

Paper 11279 assesses a data-driven methodology to quantify the weather impact on SAIDI which can be significantly useful in both planning and regulatory processes. Actually DSOs are interested in quantifying the effectiveness of their investment as well as Regulators need to evaluate in an objective way extreme weather conditions in calculating properly continuity of supply indicators.

In **Paper 11076** the operational strategy to let distribution networks face natural hazards is presented. It is based on an adjacency-resource matrix and an unsupervised machine learning algorithm to first identify vulnerable nodes. These are utilized in the mitigation stage to optimize the allocation of mobile energy resources and operate separate network islands in order to minimize the expected energy not served.

Risk assessment and opportunity analysis, according to ISO 55001, are the focus of **Paper 11202**. The faults in the medium and low voltage grid, due to weather influences, are analyzed applying classical statistical methods and artificial intelligence processes. The influence of changes in climatic conditions on the disturbance occurrence is simulated, neglecting planned grid replacement strategies. The results of the analyses are used to develop asset strategy measures, for example coordinating cabling of overhead lines and to prioritize the digitization of MV/LV substations in individual network areas.

Sub block 2: Resiliency

The papers presented in Sub block 2 address the distribution system planning including assessments related to extreme weather conditions and solutions to improve its resiliency, including microgrids.

In case of extreme weather events, the risk of multiple failures in the power systems increases. The methodology, proposed in **Paper 10306**, aims to provide an effective and objective statistical approach to discriminate those events that shall be targeted with resilience intervention with respect to those concerning a reliability perimeter. Such events' identification would allow the DSO to map those risks and plan actions boosting risk prevention.

Paper 10739 includes a comprehensive workflow and validation framework to evaluate resilience capabilities and cost-benefits exploiting multiple microgrids. The proposed methodology has been applied to specific use cases. Analyzing outage scenarios and a selection of possible operational constraints, the ability of microgrid networking to provide significant added benefit has been evaluated.

A methodology to assess the power distribution systems resilience as well as the solutions to increase it are described in **Paper 10794**. Extreme heat, wildfires and floods are the main hazards considered and the paper builds on experiences from projects in Benin and Democratic Republic of Congo.

Fig. 2: Benefits of resilience planning as in Paper 10794

Paper 11015 aims to identify the most applicable resilience adaptation solution, starting from the time when a project is planned with a potential location, In the presented case study, hazard maps have been created for two future climate scenarios, respectively RCP 4.5 and 8.5

for the 2050 horizon in order to consider the lifetime of new investments. The list of recommendations should then be consulted to detect the priority adaptation measures to be considered for the specific hazard level. The objective of the analysis is to ensure that the investments made today will be able to face expected hazards over their lifetime.

The definition and application of resilience metrics for Brazilian distribution companies is presented in **Paper 11457**. The defined metrics are specifically focused on the infrastructure resilience, measured through the percentage of weather-based outages lasting longer than 12 hours as well as on operational resilience in terms of the system's degradation and restoration time in case of an extreme weather phenomenon.

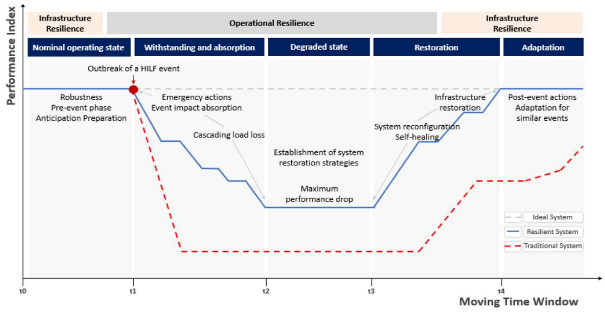

Fig. 3: Power grid resilience stages during extreme weather events according to Paper 11457

Sub block 3: Asset Management and Maintenance Strategies

In Sub block 3 methodologies are proposed to evaluate asset management and maintenance strategies taking care of technology obsolescence (e.g. SF6), sustainability, safety, climate change, fault prevention/prediction as well as new opportunities like local flexibility markets.

In order to provide more accurate results than the usual deterministic over-estimation due the lack of long-term experience with novel insulation gas technologies in GIS, **Paper 10234** presents a probabilistic calculation model considering the default probability of SF6- and SA-insulated equipment in service. Calculating the costs for a generic 110/10 kV local substation shows that both models provide plausible results. Different scenarios considering the variation of interest rate and fault probabilities have been considered by the authors.

Paper 10255 is relevant to distribution network refurbishment investment efficiency assessment. The proposed method consists of defining appropriate weights for the un-refurbished segment lines group to make it statistically comparable to the refurbished segment lines one. Evaluating the difference between the outages after treatment between the refurbished lines group and the control group, it is possible to estimate the performance of the investment.

The Design to Shared Value methodology, presented in **Paper 10347**, shows how to develop medium-long term strategies to maximize the value of network solutions for electricity distribution. A multidimensional approach, based on technical performance, economy, sustainability requirements and safety values, also incorporating aspects related to purchasing strategies is envisaged by the authors.

Paper 10383 explains the methodology used by Enel Grids to estimate the impact of climate change effects on the networks and define actions for an adaptation plan. Critical events are mapped by area and adaptation countermeasures are evaluated. Solutions are applied on a practical example, in case of heatwaves on the Italian distribution grid.

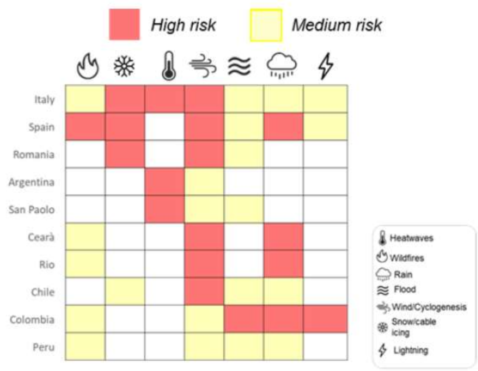

Fig. 4: Climate risk mapping by geography according to Paper 10383

A methodology to support decision-making to schedule maintenance activities in the network, taking advantage of local flexibility markets, is presented in **Paper 10908**. The use of local flexible markets enables performing maintenance works during periods when otherwise would not be possible to energize all the nodes without violating network technical constraints. This allows moving maintenance activities from more expensive times (like Sunday's mornings) to normal working hours without affecting the end customer's service, hence accelerating the overall maintenance works' schedules in the networks.

Paper 10922 analyses the changes in distribution load profiles due to PV, residential EV charging, and electric space heating. This paper further analyses the respective changes in the thermal ratings of five real distribution substation transformers introduced by the load profile changes. As the load profile is a key factor in the determination of transformer ratings, decarbonization initiatives could have a significant impact on transformer ratings.

A novel, modular approach for modelling the risk of imminent failure of underground LV cables is presented in **Paper 11302**. The authors have implemented a first version of the model described in this paper, in which physical models, capable of rapidly processing large volumes of data, and statistical ones are combined. The key innovation of this approach is that it allows analysts and planners to integrate analyses of cable condition and degradation with analyses of cable loading and capacity.

Paper 11356 shows how improved asset monitoring and modelling capabilities enable DSOs to improve their asset management methodologies for OH lines and UG cables. Utilizing different technologies such as partial discharge monitoring for cables, improved inspections for overhead lines, simulations in digital twin platforms, among others, have further paved the way for DSOs to prioritize their budget on capital investments and operational expense to further improve their service to the community.

Managing the whole lifecycle, including construction, operation and decommissioning of huge number of assets, represents a challenge for DSOs in terms of coordination among different stakeholders, complex design, wide material supply, together with safety, environmental and timing issues. **Paper 10975** describes the new digital solution, fully integrated, developed by Enel Grids: "LEONARDO", a Common Data Environment platform for project management, enabling BIM, and "AURORA", the tool for complex project monitoring.

Potential scope of discussion

What role for AI in asset management and maintenance? How can the different dimensions of resiliency be included in planning? Is it time to include safety as a topic for CIRED? What's the relationship among flexibility, novel network schemes and resiliency?

Table 1: Papers of Block 1 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
10234: Case Study: Using A Probabilistic Calculation To Determine The Lifetime Costs Of Assets With Alternative Gas Insulation				X
10255: Investment Efficiency Assessment On The Electric Grid by Group Of Control	4			X
10306: Six-Sigma Technique to Identify Resilience Events on Electrical Networks				X
10347: Design to Shared Value Methodology Applied to Power Grid Technologies Adoption				X
10370: Data-driven AI Network Analysis				X
10383: Climate Adaptation Plan for Distribution Networks	5			X
10474: The Reliability Of The Electrical Distribution System Using The Markov Modeling Methodology	1			X
10739: Quantifying Resiliency Benefits of Networked Microgrids using PowerModelsONM.jl	3			X
10794: Towards Resilient Electricity Distribution Systems in Africa				X
10908: MV Network Maintenance Planning Decision Support Tool Considering Flexibility Of DER				X
10922: Distribution Asset Thermal Ratings with Evolving Load Profiles				X
10975: Digitized Complex Project Management				X
11015: A Climate Change Adaptation Action Plan For The Electricity Sector: E-REDES Experience				X
11076: Machine Learning-based Identification and Mitigation of Vulnerabilities in Distribution Systems against Natural Hazards	2			X
11202: AI Supported Analysis Of Faults Caused By Atmospheric Exposures In Medium and Low Voltage Grids For Evaluation And Development Of Asset Management Strategies				X
11279: Identification of a Causal Weather-QoS Model for Analysis and Planning of Distribution Networks				X
11302: Integrated Physical And Probabilistic Modelling Of Low Voltage Cable Temperatures, Stress Cycles, And Damage			X	X
11356: Overhead Lines and Underground Cables Asset Management – Best Practices and Challenges	6			X

11457: Measuring the Power Grid Resilience: A Case Study Applied to Brazilian Distribution Companies				X

Block 2: "Network Development"

Block 2 introduces papers describing original applications within the distribution business. They may relate to the integration of new components or technical solutions, the delivery of innovative systems or the implementation of state-of-the-art functionalities.

The majority of the presented applications result from the combination of large or small power systems and OT/IT infrastructures, either for developing advanced automation functionalities, typical of Smart Grids, or for making flexibility options available as a service for the grid. Off-grid solutions, such as isolated microgrids, are also included.

Sub block 1: Innovative Power Distribution

Sub block 1 includes innovation not explicitly connected with "mainstream" topics; therefore, the paper hosted show a high degree of diversity often dealing with specific, Country-based, projects including multi-source energy systems or referring to the adoption of a specific new component and/or technical solution.

Paper 10509 exposes a comprehensive grid planning strategy, named Grid Futurability, adopted within Enel Grids and defining a sustainable technological roadmap for future grids to be developed. It takes into account long-term investments and includes initiatives that are under development or to be developed to advance the grid level. The described framework makes clear and measurable all the objectives for the implementation of a portfolio of projects and interventions through an integrated approach that considers all the key aspects defined by the 12 drivers, representing the guidelines that need to be developed in the grid evolution process.

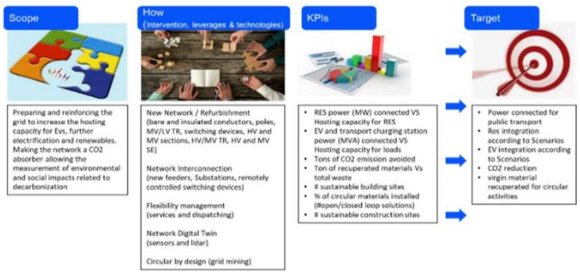

Fig. 5: Example of driver definition for energy transition and decarbonization, according to Paper 10509

Paper 10921 exposes the strategy carried out by the Indonesian electricity company in Nusa Tenggara Timur (NTT) province to achieve 100% electrification in the area. The strategy focuses both on grid expansion and on the utilization of renewable energy sources, the latter representing the primary solution for electrification in scattered islands and other remote areas located far from the existing grid. The final goal of the strategy is to contribute to energy security, energy sustainability and energy equity in the region.

In **Paper 10828**, the portuguese Distribution Automation Roadmap (DAR) in presented, as well as some key initiatives identified to accelerate the energy transition, guaranteeing solutions that promote the evolution of the grid in terms of energy, control, automation and protection. By means of systematic feedback coming from each project implementation and operating challenges to optimize the following projects, DAR is intended to evolve into a dynamic tool supporting grid evolution towards a digital distribution grid.

Paper 11345 deals with IANOS, a project related to the development of efficient and decarbonized electrical systems in islands. In one of IANOS demo-sites, located at the Lighthouse Island (LI) of Terceira, in the Azores – Portugal, three use cases will be implemented, addressing fast response ancillary services provision, power quality and congestion management support, and transport sector decarbonisation. A short description of IANOS reference technologies is also provided.

Paper 10455 introduces hybrid AC/DC interlay grids, obtained by coupling different medium-voltage grids via DC connections. Several possible alternatives for coupling points, DC structure and degree of coupling are then examined, in order to define reference structures to be used for planning purposes. These structures are compared in terms of impact on the medium-voltage grid and related costs. Results show that hybrid AC/DC underlay grids are able to reduce the usage of customer flexibility and thus also support the compliance with the technical limits of the grids. As the effectiveness of this nonconventional solutions strongly depends on the topology of the grid and the points of DC connection, further studies are expected to develop robust methods to evaluate this solution.

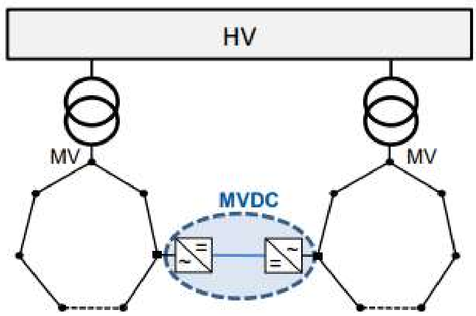

Fig. 6: Structure of a DC connection in an AC/DC underlay grid as in Paper 10455

In **Paper 10510**, an approach to network solution and equipment standardization using an Open-source design (OSD) is described. The authors' basic idea is to leverage on BIM methodology and to rely on the Open Power Grids association, an initiative promoted by Enel to share and develop innovative technical standards. The paper summarizes the results and benefits already achieved and outlines possible future implementations within the approach, with a special focus on the constructive part that will be the next step of the project.

Paper 11048 investigates the future power demands in seaports from the increased electrification of ships, verifying how the power capacity can be improved by including an energy storage system (ESS). To do so, an ESS sizing algorithm has been developed and used for a case study based on a cargo terminal in the port of Oslo. The case study showed to what extent different sizes of the ESS can reduce the maximum power peak. As it can be shown that the number of energy cycles required to reduce the peak power is relatively low, it is important that further uses for the ESS can be found besides peak shaving.

Paper 10657 deals with a similar context, focusing on the electrification of heavy-duty vehicles within a port infrastructure. The case study presented embraces the different aspects of such a complex project, starting from the types of installation needed in order to minimize the impact on the distribution grid; the possibility of combination with local generation (PV) is also considered, and economic calculation are performed to verify the optimal solutions.

Paper 10707 deals with two collaborative projects on peer-to-peer (P2P) trading of roof top solar in Uttar Pradesh and Delhi in India. Both projects aim at investigating how Blockchain enabled distributed structure can empower prosumers to trade energy among themselves at commonly agreed and negotiated prices. The two pilots were conducted for a respective period of 6 and 9 months, and results are presently under evaluation in order to develop a suitable business model for Blockchain enabled P2P energy trading. Scale-up proposals are also being examined.

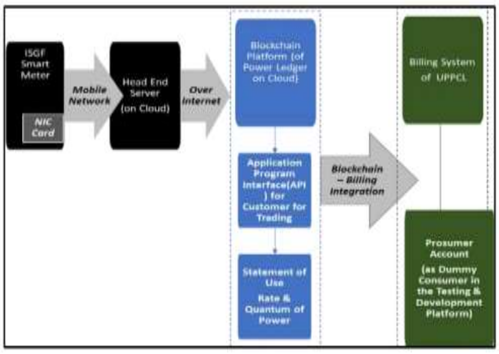

Fig. 7: Block diagram of the process described in Paper 10707

Series compensation techniques are the focus of **Paper 11405**. Series compensation can be adopted in MV systems to reduce system impedances, increasing the short-circuit power and the capability of the system to serve critical loads in distribution systems. The paper describes three standardized installations, inserted in 15 kV and 25 kV networks and ensuring a degree of compensation between 85% and 110%, showing the behavior of the systems in terms of voltage, current and service provided to some critical customers.

Sub block 2: Smart Grid Systems and Applications

Sub block 2 includes papers explicitly dealing with Smart Grid topics, ranging from strategic development plans to infrastructures and architectural novelties, to specific functionalities' delivery. It must be appreciated that LV networks are also considered.

In **Paper 10833**, the future evolution of distribution grid in N-ERGIE Netz, due to the changes in consumption patterns following the massive development of EV and Heat Pumps, is examined. The solution adopted include optimized conventional reinforcement of the grid as well as active control techniques reducing the investments needed. The whole process implies the development of digital models for all low voltage grids, automated processes for the evaluation of grid states, the planning of possible solutions for occurring congestions and the determination of likely investment needs and, finally, the integration of measured data into the evaluation and planning processes. First results show the benefits in terms of time and saved grid reinforcements that can be achieved by considering digital solutions in an optimised approach to grid development.

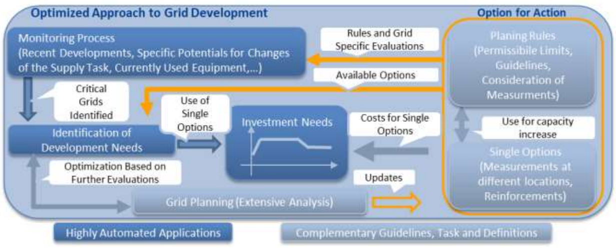

Fig. 8: Concept of a monitoring process described in Paper 10833

Paper 10567 describes the voltage management program and the related test results operated in the distribution network of Korea Electric Power Corporation (KEPCO). Advanced voltage management is a typical Smart Grid functionality that can allow an enhancement of the hosting capacity avoiding network reinforcement and the related capital investment. In detail, the program calculates and provides the operational settings for voltage control devices such as load tap changer (LTC), line regulator (LR) and distributed energy resources (DER). The tests confirmed that the voltage of the distribution system was improved by changing the operation setting of LTC and LR, thus increasing the hosting capacity of the network.

Paper 10860 focuses on Distributed Local Automation (DLA), intended as a key functionality delivered by Active

Secondary Distribution Substations (ASDS). Authors describe how DLA can allow DSOs to increase the observability and controllability at distribution network level, creating value for the customers in terms of reduced interruption number and fault clearance time, also increasing the hosting capacity of the grid by means of an increased situational awareness. The value for customers, and the related willingness to pay, can be linked to different degrees of automation and intelligence ranking from "Bronze" to "Silver" to "Gold" according to an evolution of the functionalities from "measuring" to "indication" (one-way comm.) to "control" (two-way comm.).

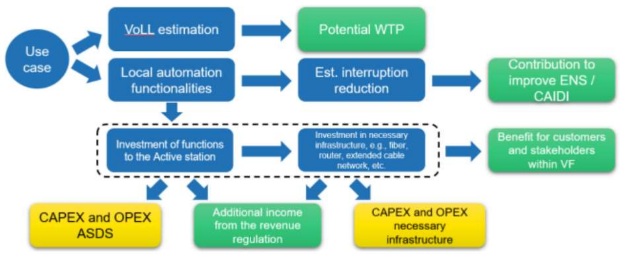

Fig. 9: Methodology for the Business Case Analysis according to Paper 10860

Paper 10753 describes the realization of a smart recharging infrastructure located in the parking facilities of a private company in Italy. Workplace recharging is an optimal solution for enabling the adoption of EV in densely populated urban areas through simple - yet effective - smart-charging schemes. The recharging infrastructure has been operated for one year, leading to an accurate description of the typical patterns of workplace recharging and to a quantification of how much flexibility can be offered with the scheme adopted. Results show that an infrastructure composed by a mix of 7- and 22-kW AC recharging points is able to cope with all the needs of a company's fleet. Furthermore, by controlling the charging process thus avoiding charge completion long before the need for vehicles' use, it is possible to reduce unnecessary peak consumption occurrences and to increase the potential to offer flexibility services.

Paper 10837 presents a method for sizing a power electronics-based converter device (PED) to be connected to the LV busbar of a distribution substation in order to regulate the voltage in the LV distribution grid, in a context of increasing penetration of PV power plants and EV charging stations in residential installations. The PED regulates the grid voltage by manipulating its reactive power while connected in parallel downstream of the MV/LV transformer. Different case studies have been chosen to represent significant conditions in terms of penetration of PV and EV, identifying the reactive power injection and absorption required capabilities of a parallel-connected PED that complies with current European standards.

Sub block 3: DC Distribution Systems and Microgrids

While the second half of 20th century has been spent integrating and interconnecting previously separated distribution systems, the effort of expanding the electrification of extremely rural, isolated or desertic areas has made standalone network up to date again. Of course, the technology involved is more and more sophisticated than decades ago, including renewable generation, storage systems, DC connections and so on, reinforcing the link between electrification and sustainability. The same approach of self-sustaining distribution sub-systems can also be integrated into the wider picture of the conventional distribution network in order to increase its level of resilience in case of extreme events.

In **Paper 11001**, starting from the benefits that can be related to the introduction of an MVDC system into distribution networks, several scenarios applicable to Korean case are presented. By economic feasibility studies, necessary conditions for securing economic feasibility for MVDC were investigated: in more detail, for overhead distribution lines an economic feasibility has not been presently found, while some cases exist in which underground lines can be evaluated for MVDC introduction. In particular, economical convenience will be further investigated to address long MVDC new lines built instead of MVAC ones.

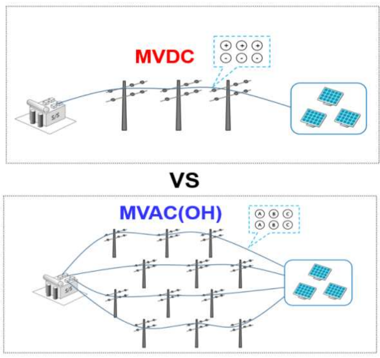

Fig. 10: Comparison Concept at MVDC vs MVAC(OH) according to Paper 11001

The introduction of MVDC to facilitate the penetration of renewables is the focus of **Paper 11043**. Authors describe a reference MVDC architecture based on 20 kV AC cables, fully developed and able to be operated in the examined case, connecting a wind farm in combination with hydrogen and water processing. The DC system is designed in order to benefit from the use of existing AC components, when possible, and makes use of storage to provide inertia and primary power to the transmission grid.

eNeuron, an Horizon 2020 EU-funded project whose main objective is defining a framework for optimising the design and operation of local energy communities (LECs), is described in **Paper 10398**. The Project includes four demonstration Pilots: the Polish City of Bydgoszcz, the Skagerak Energilab in Norway, the Lisbon Naval Base

(LNB) in Portugal, and the UNIVPM University Campus in Italy. This paper focuses on the Portuguese demo pilot, describing the development of the demonstration phase so far and outlining a balance of all supporting activities (such as Use Case definition), technical activities (asset definition and installation) and social activities (stakeholder engagement).

Paper 10440 presents a techno-economical study of non-conventional solutions, namely constructing a Microgrid for rural areas in Oman and comparing this standalone alternative to an interconnection with the main interconnected system. The project is carried out in Khwaimah, the closest area to Mazoon Electricity company networks, and includes the design, modeling and simulation activities needed to identify a technically viable and economically feasible system for the selected area. The two alternatives were compared, showing that a microgrid may result a suitable solution both in technical and in financial terms.

Paper 10521 introduces decentralized DC microgrid planning issues, for the specific application of the electric operator Nanoé, in the North of Madagascar. The goal of the paper is to detail planning issues that arise in such DC microgrids and to highlight a few tools and preliminary results used as basis for further studies, starting from the description of the structure of Nanoé DC microgrids. A DC load flow tool adapted to such microgrids is then presented, leading to preliminary results using Minimum Spanning Tree (MST) algorithms and Sequential Opening Branches (SOB) algorithms, which will be used as a starting basis for comparison with further developments.

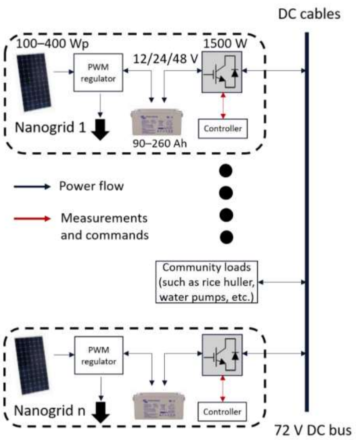

Fig. 11: Structure of the microgrids installed by Nanoé as described in Paper 10521

Paper 11250 described a project developed by EJE SA (Empresa Jujeña de Energía S.A.), operating in Jujuy, in which "isolated" small towns are supplied by micro networks connecting renewable energy sources. The program, called "Solar Towns", is developed in order to change the model of producing energy, with the social added value of increasing the quality of service.

Paper 10789 investigates on the possible uses of battery energy storage systems (BESS), in combination with PV, in different architectures. More in detail, authors focus on the reduction in sizing of the BESS while shifting from a single-user configuration to a virtual community (BESS installed on AC grid) to a real community (BESS inserted in LVDC backbone); while it is obvious that the growth in the share of the resource leads to a higher self-sufficiency ratio (SSR) of the system, an accurate quantification of the parameter is not intuitive and needs a specific analysis. Results show that virtual community BESS leads to an increase of SSR, implying a better battery use and hence a slightly longer lifetime, and that a real community BESS results even more favorable in terms of losses reduction, with improvements going up to 10 percent points.

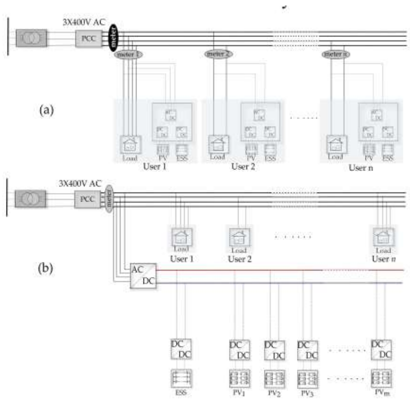

Fig. 12: (a) Traditional LVAC and (b) LVDC architecture as in Paper 10789

Paper 11413 introduces an optimization planning model for designing a campus microgrid. The proposed model aims to determine optimal size of renewable distributed energy resources (DER), Battery Storage System (BSS) as well as coordinating load shedding when needed. The optimization model is formulated as Mixed Integer Linear Programming (MILP) Problem and carried out using CPLEX software. Both grid-connected and islanded modes of microgrid operation are considered in the model development. University of Colorado at Colorado Springs (UCCS) is adopted as a case study. Simulation results have confirmed the effectiveness of the proposed model.

Paper 10764 examines the problem of designing an optimized technological solution to supply a single building, more specifically an individual house with only three loads: a 2000 W washing machine, a 3000 W oven and a 7400 W charger for an electrical vehicle (EV). The installation is connected to the distribution LV grid and to a 5 kW PV. Two configurations are then studied and compared, the first one being a DC nanogrid and the other a conventional AC with single-phase distribution, in terms of costs, efficiency and environmental impact.

In **Paper 11426**, the development of a hardware-in-the-loop (HIL) setup is detailed. The abovementioned HIL includes a DC interface for industrial and residential applications and DC sources and loads together with a real-time simulator to emulate different events in the grid, such as a disturbance leading to islanded operation, in a testbed environment for testing and proof-of-concept demonstrations. The described setup makes possible the testing of applications and further development in the topic.

Sub block 4: Flexibility Solutions

Sub block 4 deals with projects and tools related to the use of resources connected to the distribution network in order to support grid operation. The experiences shared include use cases of real generation/load dispatching as well as market platforms to achieve network services or decision support tools to evaluate the economic feasibility of flexibility options.

Power system resilience is a concept covering the whole process of management of power systems, from design and investment decisions to planning, operations, maintenance and asset management functions. Flexibility concerns the power system's ability to manage changes, with flexibility features able to improve the resilience characteristics of the system, provided that they are integrated into grid planning, in defense plans, and evaluated adequately in the energy market design. **Paper 10714** provides an analysis of ongoing worldwide initiatives on how flexibility can support resilience, introducing four innovative concepts (alternative grid development, system integrity protection schemes, next level of flexibility and LINK holistic approach to flexibility for resilience) as solutions contributing to improving future power systems' resilience.

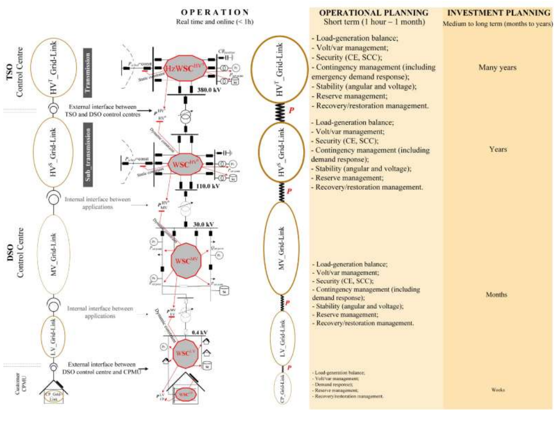

Fig. 13: Flexibility for resilience based on the holistic LINK approach of Paper 10714

Paper 10105 introduces Platone, a Horizon 2020 funded European project that aims at defining new approaches to increase the observability of renewable energy resources and of the less predictable loads while exploiting their flexibility. The solutions developed in Platone are tested in three European demonstration examples; the paper describes structure and use cases implemented by the German demo. This demo is located in a rural area in the northwest region of the Lower Saxony, characterized by an increasing number of distributed energy resources that are causing a change of behavior in the energy consumption and generation patterns. Within such a framework, local energy communities can introduce additional sources of flexibility contributing to mechanisms that increase efficiency and safety of supply in distributions grids.

Paper 10512 describes Charge, an OFGEM funded Network Innovation Competition (NIC) project delivered as a partnership between SP Energy Networks, Smarter Grid Solutions, PTV Group and EA Technology. In the Charge project, innovative connection solutions, providing an interim capacity-management solution ahead of future network reinforcement and accelerating public EV charging connections, have been introduced. The paper delivers key learnings from this 5-year innovation project, providing distribution system planners with the tools and insights to deliver innovative flexible solutions for expanding EV infrastructure within highly congested networks.

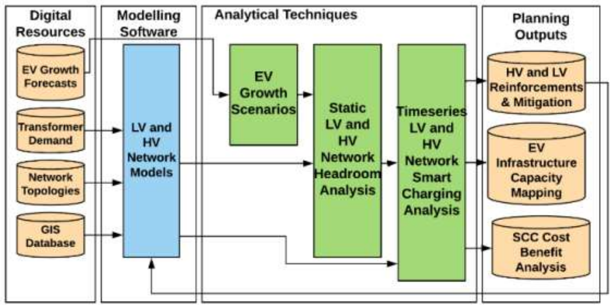

Fig. 14: Smart Charging Connections Trial Methodology according to Paper 10512

With the increase of the renewable capacity connected to the distribution grid, the need for curtailment is also increasing and the consumers may face an extra cost for curtailment payments. In order to help grid operators in managing network stress while increasing the amount of distributed renewable energy, domestic demand can represent a potential solution. **Paper 11273** outlines the demand shift trial conducted by SP Energy Networks (DNO) and Octopus Energy (Retailer) in the Dumfries, Galloway and Ayrshire area electricity distribution network which is constrained with high Distributed Energy Resources (DER) penetration. Customers were instructed to power up their usage when green energy supply was highest, households used more energy across the six two-hour trial windows. Trials concluded that a total of 20 MW demand response was secured with maximum response per event recorded at 2.84 MW and an average turn up per even being 1.7 MW.

Paper 10692 points at the lack of tools and methods available to the DSO to enable the use of flexibility in grid operations. A relevant decision support tool is a digital twin of the power grid which contains information about the assets in that grid and their mechanical and electrical state, combined with information about local flexibility resources available in the grid. This principle was illustrated by a case study which used a digital twin of an industrial distribution grid, including grid and load data. The digital twin was used in a technical and economical assessment of the value of flexibility for the DSO in this case, taking transformer lifetime into account when evaluating if flexibility measures should be put in place to reduce a bottleneck. The results show that the value of flexibility for the DSO is comparable to market prices of flexibility in GOPACS. Future work includes developing a more comprehensive decision support methodology, including other relevant cost factors in the assessment.

Paper 10159 deals with EDGE, a multi-year project testing a DER marketplace framework, including roles and responsibilities, for efficient integration of DERs at scale into the electricity systems and markets in Australia. Within EDGE architecture, DERs are aggregated, bi-directional offers that can be submitted and dispatched as if they were scheduled resources. The DER offers are constrained by dynamic operating envelopes designed to safeguard the integrity of the supply network. Flexibility services provided by DER fleets provide a value staking opportunity.

Fig. 15: Conceptual diagram for project EDGE as described in Paper 10159

Paper 10695 describes the methodology introduced in the Horizon 2020 project GIFT and further improved in the following project MAESHA to develop an interoperability-by-design framework for demand response (DR) and deals with every aspect of interoperability in the abovementioned system. Use cases for DR and the system architecture are firstly defined, relying on relevant frameworks and reference architectures. Then, semantic and syntactic interoperability of the various components of the DR system is pursued through the use of standards, and reference protocols, that aim at ensuring a smooth, reliable and secure communication. Finally, interfaces are tested to verify the compliance to the selected standards and a final integration test ensures that the system operates as expected. The results from applying this methodology show a fully interoperable system, ready for deployment.

In **Paper 10755**, a common data layer (CDL) for flexible operation in multi-source cellular energy systems is introduced. The proposed CDL consists of standardized equations for three different organizational entities (energy cells) that allow decentralized energy dispatching for arbitrary energy forms. Particularly, flexible demand, wind power, photovoltaic power, electric vehicles, heat pumps, storage units and power to gas units are addressed. Illustrative applications of some technologies used in an example industrial cell are presented to demonstrate the concept. Further work is needed to improve the models by adding more details and fully include the dependencies between flexibilities as well as testing and verifying them against real devices.

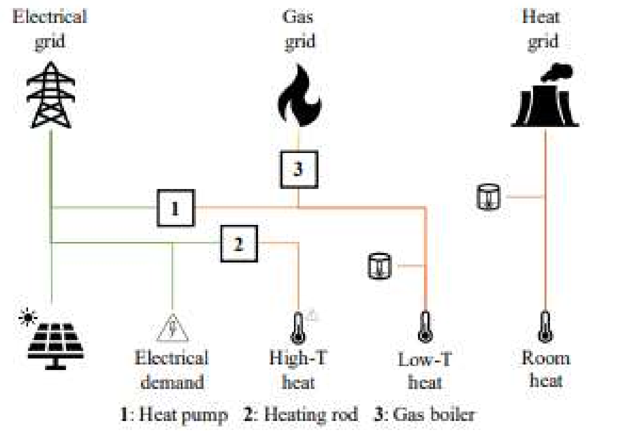

Fig. 16: Schematic of industrial energy cell as in Paper 10755

The aim of **Paper 11133** is to illustrate how service stacking can potentially enhance the value of a grid connected energy storage system (ESS). This includes implementing an ESS scheduling optimization to create a more complex service portfolio that includes two or more services that may overlap in time. The intended outcome is also to illustrate the complexity of service stacking by adjusting a set of active constraints in addition to show how storage degradation can affect the capacity to add services to the portfolio.

Paper 11501 proposes a methodology for a flexible operation of Electric Mobility Facilities (EMF) considering the optimized operation of Battery Swapping Stations (BSS) while supplying its own load (battery swapping service) meanwhile supporting the grid. The paper methodology is divided into two parts. The first one deals with the recharging strategy of the depleted battery, and it is solved by using a meta heuristic technique called Evolutionary Particle Swarm Optimization (EPSO) along with a swap scheduling approach. The second part handles the grid support situation, where (throughout an energy contract with the grid) the BSS must, when necessary, dispatch a percentage of its own installed capacity to alleviate the load demand on the grid during the On-Peak period of the day. Under the proposed study case, the applied methodology was able to improve the economic metrics of the system, presenting an increase in the final cash flow of 11.55%, by reducing operational costs and increasing revenues from energy sales.

Finally, **Paper 10540** describes a specific case of a rural area in Portugal, in which the problem of overcoming voltage issues arising in case of failure of the MV busbar of the Alcanede substation is analyzed in full detail and complete neutrality with reference to the flexibility provision, considering both load curtailment and DG contribution. The authors conclude that, although further work is still needed to consolidate a robust methodology that not only provides case-by-case evaluations, but allows systematic opportunities' identifications, the present paper represents a significant starting point for flexibility use in distribution grids.

Potential scope of discussion

What's about low voltage system development? Can the Smart Grid be an option? What's the future of MVDC?

Table 2: Papers of Block 2 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
10105: Innovative Digital Solutions That Enable Local Energy Communities to Provide Flexibility Services to the DSO: the Avacon Approach				X
10159: Enabling Distributed Energy Resources to Participate in Wholesale Energy Market and Provide Flexibility Services				X
10398: ENeuron Project – Facilitating The Energy Transition In A Military Campus By Optimizing A Local Energy Community				X
10440: Main-Grid Versus Renewable MicroGrid Energy Supply. A Case Study of Isolated Rural Areas in the Sultanate of Oman				X
10455: Planning Principles for Hybrid AC/DC Underlay Grids in the Medium-Voltage Level	7			X
10509: Grid Futurability - Network Development Strategy				X
10510: Primary Substation Open Standardisation Through Building Information Modelling (BIM) Implementation				X
10512: A 2030 Snapshot of Public Smart EV Charging Stations	9			X
10521: Planning Methods For DC Lateral Electrification In Rural Africa				X
10540: Conceptualization of Flexibility Solutions as an Alternative to Traditional Investment				X
10567: Increase Hosting Capacity through Voltage Control Devices Setting Optimization Technology				X
10657: Investment Planning For Electrification Of Transport In An Industrial Port				X
10692: Decision Support for Matching Flexibility Measures to Flexibility Needs in Power System Planning				X
10695: How To Ensure Interoperability In Demand Response Systems: The Examples Of The European Projects H2020 GIFT And MAESHA				X
10707: P2P Trading of RTPV Energy on Blockchain Platform				X
10714: How Can Flexibility Support Power Grid Resilience Through The Next Level Of Flexibility And Alternative Grid Developments	10			X
10753: Smart Recharging Infrastructure for Companies' EV Fleets: Technical Realization and Load Balancing Potential				X
10755: Generic Technology Models To Simulate Flexible Operation In Multi-Energy Cellular Energy Systems				X
10764: Towards the Optimisation of a DC Nanogrid Considering Technical and Environmental Criteria				X
10789: Self-sufficiency and Lifetime Improvement of Community BESS on an LVDC Backbone Compared to Individual BESS				X
10828: The Portuguese DAR (Distribution Automation Roadmap) Toward a More Demanding Electricity Grid				X

10833: Optimised Approach to Grid Development under Consideration of Digital Solutions				X
10837: Sizing Of A Power Electronics-Based Voltage Regulating Device To Support The Integration Of Photovoltaics And Electric Vehicles In LV Grids				X
10860: Increasing Network Intelligence: Implementing Distributed Local Automation to Reduce Power Interruptions in Distribution Networks				X
10921: Leveraging Solar Energy Development To Achieve 100% Electrification Ratio In Nusa Tenggara Timur - Indonesia				X
11001: MVDC Distribution System Application Scenarios and Economic Analysis				X
11043: MVDC Grids to Facilitate the Roll out of Renewables – Findings of CIRED-WG 2021-1	8			X
11048: Dimensioning And Sizing Of An Energy Storage For Ports When Considering Both Fast And Slow Load Variations				X
11133: Optimal Scheduling of Energy Storage System in Distribution Grids Using Service Stacking				X
11250: Experience In The Implementation Of Isolated Electrical Energy Generation Systems From Renewable Energy Sources- Solar Villages				X
11273: Domestic Demand Shift Trial for Local Network Management and Distributed Generation Curtailment Avoidance	11			X
11345: IANOS Project: Integrated Solutions to Decarbonise and Improve the Resilience of Electrical Power and Energy Systems in Geographical Islands				X
11405: Systematic Application of Series Compensation in Distribution Networks with Control and Protection				X
11413: Optimal Planning of University Campus Microgrid with High Penetration of Renewable Energy and Storage: UCCS Campus Case Study				X
11426: DC Interface For Industrial And Residential Applications				X
11501: Flexible Methodology for Battery Swapping Stations Planning Operation in Support of Distribution Grids				X

Block 3: "Distribution Planning"

Distribution planning is at the very core of Session 5. It deals with strategies, criteria and methodologies to define the evolution of a distribution system.

During the years, the concept itself of planning has evolved and still does, incorporating nonconventional solutions that open the path for an expanded context in which operational practices are considered in the planning phase, while operation itself starts including short-term planning techniques.

Sub Block 1: Advanced Planning

Advanced planning includes methodologies that, albeit innovative, do not specifically refer to a specific topic, but stick to the general planning problem. They often include sophisticated mathematical models and operation research techniques.

Integrating power and gas networks is a key factor for the energy transition. **Paper 10574** proposes the application of integrated power and gas distribution grid planning. The authors proved that grid expansion costs could be saved with integrated planning, and the energy grid infrastructure can be utilised more optimally. In addition, it can be estimated whether reducing the energy infrastructure of one sector in favour of an expansion of the other offers an advantage. It was shown that in future scenarios, gas power could be used for local energy balancing and thus reduce the demand for energy transport. Especially in combination with a locally available hydrogen grid, the potential for decentralised, medium-sized power to gas is estimated to be high.Load forecast is a crucial activity of distribution planning. The energy transition is making this activity more complicated and even more crucial. Indeed, historical information is less useful since the electrification of final uses of energy for heating and transportation is changing the paradigm, and, on the other side, the level of uncertainty is incredibly high, making planning even riskier than usual.

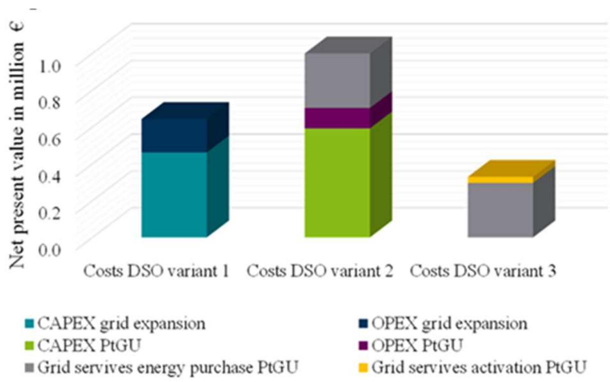

Fig. 17: Investigated variants for grid planning and resulting costs for the DSO in Paper 10574

Paper 10480 proposes a methodology for integrating network data with public information to forecast the future scenarios of heat pumps, air conditioning, electromobility and photovoltaic generation. The impact on the Milan distribution network shows that Air Conditioning is particularly critical for the coincidence of heat waves in summer. EVs can be an issue for MV/LV transformers due to the possible clustering of high-power charging stations. Heat pumps can lead to significant local violations, especially for larger plants. Finally, the presence of PV systems improves network conditions, reducing the power flows on network components.

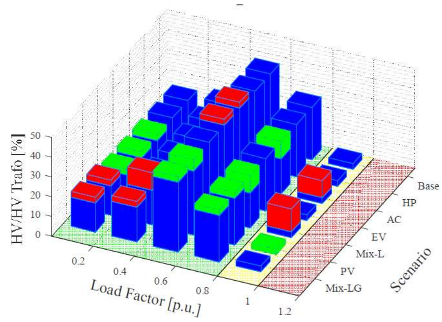

Fig. 18: Example of expected violations in MV/LV transformers in Milan (Paper 10480)

Paper 10570 offers an alternative planning option to face the challenges of the energy transition in distribution systems. In weak networks, where non-wire alternatives do not work, the proposed planning approach compares the network reinforcement with AC DC networks. The first preliminary results show an advantage to conventional planning strategies from the point of view of a DSO. Anyway, the cost models and the case studies do not allow generalising the conclusions.

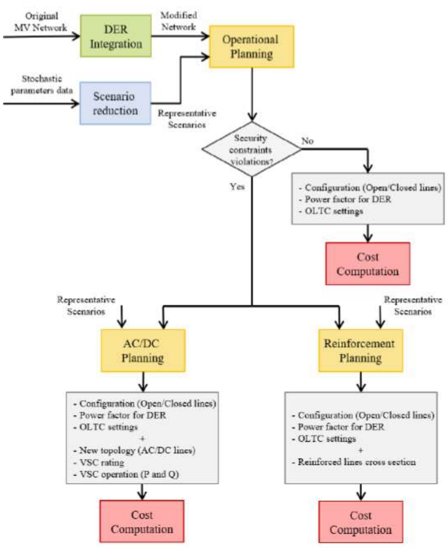

Fig. 19: Flowchart of the planning approach proposed by Paper 10570

Paper 10315 offers a meta-study of 10 MV and 46 LV distribution networks for assessing the potential of Voltage Regulating Distribution Transformers (VRDT). A total of 244 grid plannings with various scenarios are examined.

More than 22 criteria and more than 25 grid structure parameters are analysed. The result of the study is a simple approach to identifying the validity of VRDT alternatives compared with traditional planning. VRDT have the potential to give significant cost-savings. Figure 19 shows the general decision path for deciding about the use of VRDT obtained with a correlation analysis on the planning database.

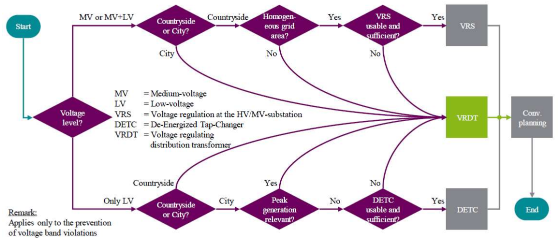

Fig. 20: The general decision path proposed by Paper 10315 for VRDT

Paper 10108 deals with the development planning of radial distribution networks in the presence of load and generation uncertainty. The proposed approach considers maximum and minimum loading levels in the network simultaneously to obtain a set of different network development plans. The obtained plans are evaluated. The best is the one that minimises the risk of financial losses according to the Hurwitz criterion and the decision maker's risk preferences. The presented results show the importance of employing risk-based approaches and the correlation between uncertain quantities (loads, DGs) for obtaining the best network development plan in the presence of uncertainty.

The largest part of flexibility resources will be in the distribution systems, and the highest share of new renewable generation will be connected to the distribution systems. Thus, as well observed by the authors of **Paper 10976**, power system planning can no longer neglect the role of distribution systems. The paper proposes an original heuristic algorithm that allows TSO to consider the role of distribution systems in their planning studies. The main idea is to model the distribution systems with surrogate models that bring all the necessary information for capturing the flexibility provided to the transmission network. Using this approach, the TSO can plan the transmission system, including the distribution role, with a speed-up of two orders of magnitude higher than the one needed for integrated planning.

Revamping HV/MV substations, as pointed out in **Paper 10506,** requires the availability of high-voltage transformers, but the manufacturing time has been increasing since 2019. The short-term procurement plan has to be changed, considering the current market capacity and the impact of the energy transition on distribution development. The paper proposes a methodology based on tendering slots of transformer production for three years, split into semesters.

Paper 10966 deals with high-level planning for increasing the hosting capacity of HV/MV primary substations that must accept power from new RES. The planning process considers the connection of RES to the two closest HV/MV stations and examines different options such as traditional development (e.g., new transformer capacity) or flexibility from generation (e.g., generation curtailment) or a combination of both. The number of combinations in an area with dozens of HV/MV rapidly increases (it grows exponentially with the number of RES connection requests). The procedure developed in Enedis allows making decisions objectively at reasonable times following the path described in Figure 20.

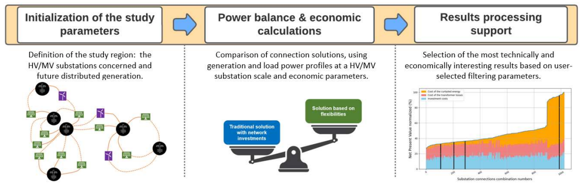

Fig. 21: The multi-substation planning proposed by Paper 10966

Paper 11026 proposes the use of machine learning techniques for PV installation forecasting. Once the forecast has been performed, the cost of currents and newly added distribution facilities according to the PV needs can be calculated and applied. Through these results, it is possible to plan the location and size of the substation for distribution system and the configuration of the distribution network. In the future, the PV installation forecasting and planning optimization methods proposed in the paper will be applied to the distribution planning system of KEPCO.

Paper 10967 gives an interesting contribution to the problem of expansion planning under uncertainty related to DER investments that are influenced by many factors. The paper proposes an agent-based formulation of the expansion MV planning with agents mimicking the behaviour of DG investors and DSO. As a result, the expansion plan is conceived to maximise the DG profits and minimise CAPEX and OPEX in the network. Despite the high theoretical level, the idea of planning the network modelling needs and uncertainty from DG investors is remarkable. As a result, the proposed model guarantees that the attained expansion plan would be profitable for DGOs while the DSO attains the least cost expansion plan of DERs and network assets.

Paper 10346 proposes a planning tool, SENSE, that finds the optimal MV network topology based on the existing and potential newly installed elements, network reconfiguration by optimal operation of switching devices and calculates the needed flexibility that can be provided either by rescheduling the operation of DSOs' assets or engaging a third party. SENSE is open source allowing the upgrade of existing functionalities and the addition of new ones.

Paper 10588 deals with the use of network flexibility to minimise the level of RES energy from distribution to transmission. The operational planning proposed by the authors operates the network reconfiguration of neighbour networks to increase the regional consumption of energy and MV hosting capacity complying with the German technical rules. The application to two real medium voltage grids in a southwestern region in Germany shows that the yearly fed-up energy to the high voltage grid could be reduced by up to 19 %. In addition, a guaranteed free hosting capacity could be added to a grid depending on the base load of the switchable segment. It is also shown that loop-flow currents can occur during switching and can be critical to the grid.

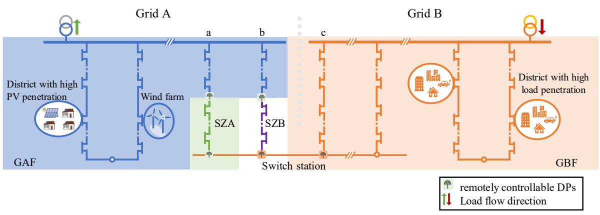

Fig. 22: Simplified sketch of the considered parts of Grid A and Grid B and the four defined zones in Paper 10588: Fixed Zone A (in blue), Fixed Zone B (in orange), Switchable Zone A (in green) and Switchable Zone B (in purple)

Paper 10636 also uses the embedded flexibility for the operational planning of the MV active distribution network (ADN) with the aim to maximise the utilisation of RES. The original idea is based on using reconfiguration operating soft open points based on Back-to-Back Voltage Source Converters. The main challenges addressed by the developed Active Network Management are voltage fluctuations, low efficiency in the use of RES, low network flexibility, and uncertainty on power generation from the RES. The simulation results indicate that the proposed ANM framework can ensure lower operational costs when using network reconfiguration for all cases and increasing the DG use (in conditions of medium and high wind power). Also, it can actively regulate the voltage avoiding fluctuations throughout the DN by using the BTB-VSCs.

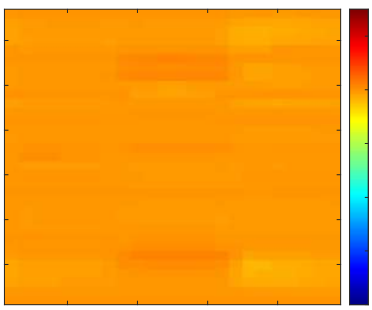

Fig. 23: Voltage regulation with network reconfiguration and soft open points (Paper 10636)

Paper 11006 proposes a novel method for integrated planning in large areas/districts spanning different voltage levels. The main benefit of the approach is the ability to acquire a quick and comprehensive overview of bottlenecks and constraint violations in grid topologies of different voltage levels across vast geographical districts. The approach enables the straightforward assessment of additional generation and demand integration scenarios by simulating randomly dispersed units on top of base-case simulations. The time-series simulation

The success of the energy transition passes through the connection of renewable energy sources. The public knowledge of the network hosting capacity can facilitate private investments in green generation. **Paper 11491** shows an example of a web-based tool that gives detailed information on the hosting capacity level for each network.

Fig. 24: Paper 11491's map of hosting capacity in Brazil

Paper 10874 deals with the problem of LV planning since LV distribution will have a central role in energy transition due to the need to accommodate EV charging and heat pumps. The size of the problem requires automatic planning processes and software applications as those proposed by the authors. This preliminary advanced planning methodology is not yet capable of including flexibility of demand but can now assess the hosting capacity for EV charging stations and give customers crucial information.

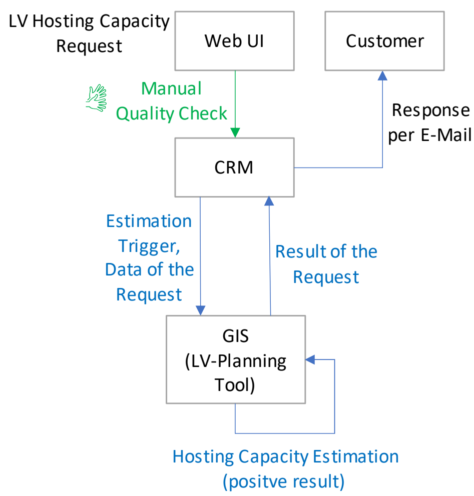

Fig. 25: Semiautomatic process for hosting capacity requests in Paper 10874 (positive results)

Paper 10354 also focuses on the LV expansion planning caused by new demand and generation and observes that often the limited knowledge of existing LV assets prevents planners from producing suitable plans. The authors propose an interesting probabilistic approach that assumes the topology itself as a source of uncertainty. Figure 25 shows the schematic of the prosed approach. The authors demonstrate that relying on the most likely estimate of the grid topology can mislead grid planners, while the proposed method provides a more robust interpretation of the grid feasibility.

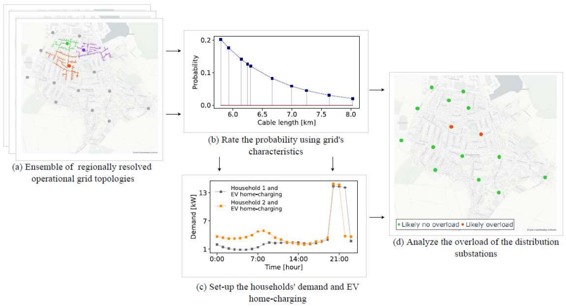

Fig. 26: Paper 10354: (a) and (b) depict the two main modules of the approach. (c) and (d) show the additional information required for the application of the ensemble to analyse the overload of the distribution substations along with the outcome of the analysis

Paper 10593 describes how ESB Networks is planning the evolution of LV distribution networks in Ireland to accommodate one million of EV and 680.000 heat pumps. A proactive methodology is adopted since a simple reactive approach is unsustainable given such a growth of load in little time. Using smart meter data, asset data and recorded customer voltage issues, planners assess areas of the national network where voltage issues are occurring and, in some cases, determine if low-carbon technology is present. Then, using various voltage thresholds and the frequency of voltage violation events, these events can be linked to the nearest MV substation. A prioritisation matrix has been developed to categorise areas where system improvement should be prioritised for the infrastructure development work programme. The acquired data from the smart meter installation programme has made it possible to identify locations where LV work is required before customers make a direct complaint.

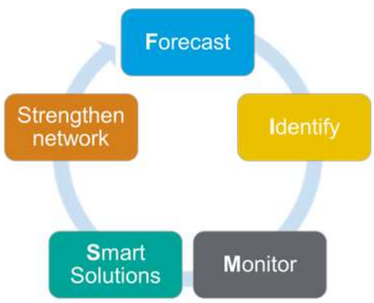

Fig. 27: The ESB Networks proactive methodology in Paper 10593

Paper 10575 proposes the use of Artificial Intelligence for the long-term planning of distribution networks. The idea is to apply AI planning, a sub-field of Artificial Intelligence, as a model-based approach to action selection. It aims to study and design domain-independent general approaches to the problem of finding a sequence of actions to achieve a goal. AI planning takes as input the initial and the target network set by the DSO. The AI planning module generates a list of actions to obtain the desired topology of the target network. The dynamics of the domain, all possible actions and the conditions allowed by the DSO are defined after several interviews with DSOs. AI planning provides a plan of action in a very short time, but the post-process analysis is necessary.

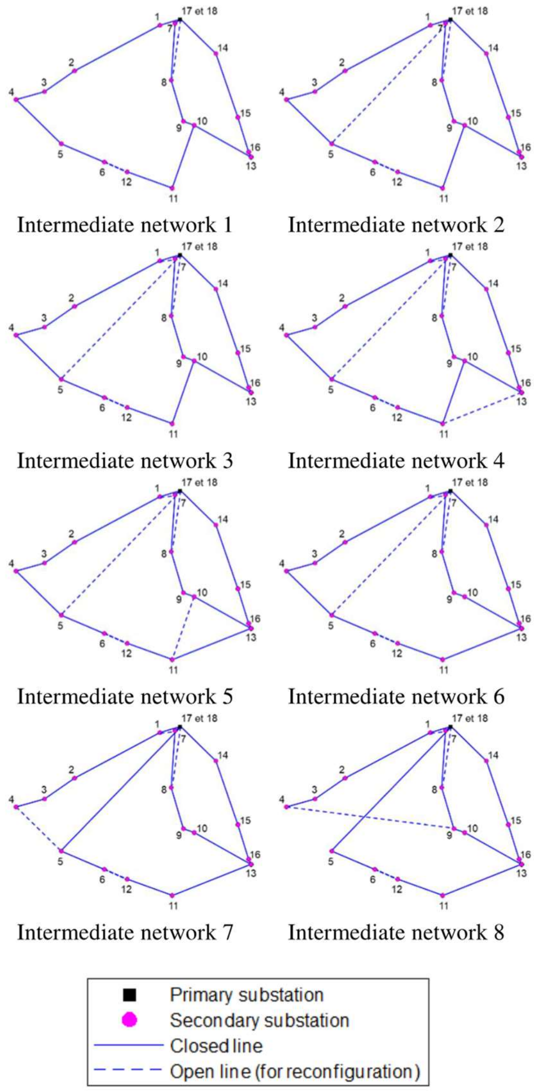

Fig. 28: Intermediate networks obtained with AI planning (Paper 10575)

Planning LV systems, particularly in dense urban areas, is complex, and the geographic diagrams drawn in analysis tools are intricate. For planning engineers, it is a major problem to use these diagrams for network planning studies. **Paper 10891** presents a novel algorithm

(PolyDraw) where the nodes of the network are constructed as the vertices of recursive regular polygons in an efficient way to prevent overlap and clutter of densely populated network designs.

Paper 11069 focuses on the impact of heat pumps, PV installations and electric cars to study the development of an LV network ready for a future that is coming fast. Distinctive investment strategies have been tested in urban, rural and residential cases. Most of grid reinforcements are needed within twenty years, and the main difference in approach is the timing of the individual reinforcement activities; the net present value of investment costs is not very distinctive between the strategies. Proactive investments can reduce costs by combining work and sharing overhead project costs, reducing the net present value. Rework can be avoided by looking ahead 40 years. Less workforce is needed, and the social impact in the neighbourhood is reduced. Since the availability of a skilled workforce is one of the main constraints for grid reinforcement projects, the DSO's facilitation of the energy transition is a key advantage of the proactive approach. The fully proactive strategy seems the most efficient approach, but large-scale realisation in thousands of LV grids within the next few years is impossible. Thus, an optimal combined strategy is necessary.

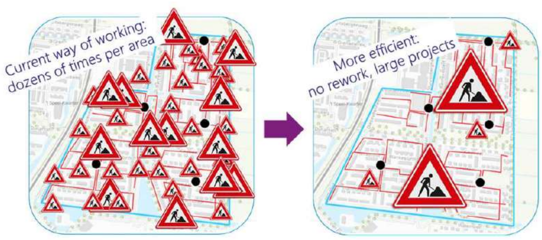

Fig. 29: A proactive large-scale strategy, resulting in a more efficient approach with larger projects and without rework (Paper 11069)

Paper 11143 deals with planning the distribution system to accommodate PV generation in Finland. Particularly, the authors focus on the rule used for calculating the voltage fluctuations caused by PV. The equation provided in the recommendation gives a simple way to estimate if a solar PV system causes problems in a certain distribution network location. Still, it does not consider the combined effect of multiple solar PV systems, a major lack in the approach since the number of PV installations is rapidly increasing. The authors argue that the problem is with the parametrisation and propose a new model for assessing the impact of PV that consider the voltage fluctuation with a proper dynamic.

Paper 11162 applies the regionalisation methodology to forecast the allocation of heat pumps within the electrical network to facilitate Distribution System Operators in the network planning process. Future scenarios (up to 2050) were implemented with the electrical network obtained from three large Distribution System Operators in Austria, with and without consideration of the district heating perspective.

Paper 11329 shows an application of synthetic load curves to predict the impact of the energy transition on RESA's distribution networks when data are not available from the field. The authors used the CREST simulator as a profile generator to simulate four consumption trends. The CREST model allows the simulation of daily load curves for a certain number of households based on electronic equipment distribution. This simulation tool pursues a dual objective of predicting nodal demand and generation while projecting them onto the components that make up the network. Anticipating network operating problems is necessary for planning solutions for network development.

Developing energy communities but also facing the challenges of energy transition, needs to work with local authorities to develop integrated energy planning and increase the social acceptance of the net zero project. This is the topic of **Paper 10412** that deals with EPIC (Energy Planning Integrated with Councils) that devises a process that could be used to agree energy plans between Local Authorities and the local gas and electricity distribution companies. This integrated approach would enable improved, investment planning identifying beneficial trade-offs that are not apparent when planning occurs by all parties in isolation.

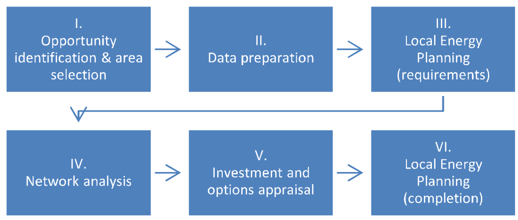

Fig. 30: The EPIC process for integrated planning with Local Authorities in the UK (Paper 10412)

Renewable Energy Communities and collective self-consumption can help reach the decarbonisation goals. **Paper 11425** highlights the most relevant research areas that need to be coordinated for energy transition and the development of energy communities. Planning tools and approaches must work hand in hand with the operations systems of the future to determine the best place for investments and system designs. The planning models for energy communities need to consider the underlying customer and resource models that make up the community while also considering the community-level initiatives and how they can impact the performance of the individual resources. These modelling requirements are obviously becoming increasingly complex, resulting in the potential to use new approaches for complex systems. The uncertainties of customer behaviour, dynamics of distributed control systems, local resilience solutions, electric transportation systems, market interactions and the diversity of stakeholders all add to the complexity. Complexity science deal with approaches for modelling and understanding these types of systems.

Paper 10669 addresses the crucial topic of Energy Communities with an original point of view that correlates technical calculation and social sciences for identifying and engaging the diverse sociological profiles. The new methodology of energy management of a community considers different strategies of flexibility based on various sociological profiles. Participation in an energy community is individually more profitable for every profile, whether they prefer to reduce their bill or their environmental impacts. Distribution of gains to each stakeholder through the Shapley value was proposed, and its limitation in the context of energy management is also proposed.

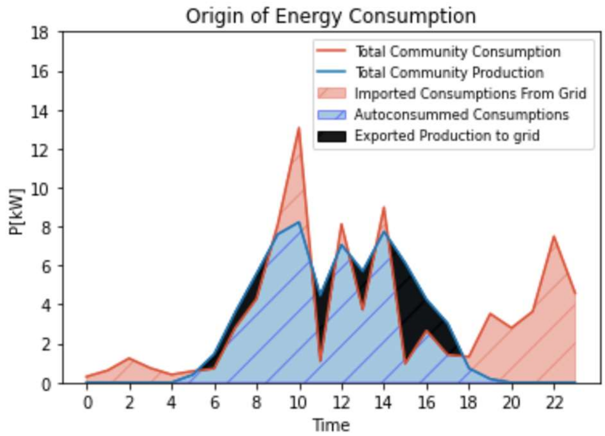

Fig. 31: Example of community operation (autonomy-sensitive community) from Paper 10669

Some interesting new advanced planning approaches are proposed. **Paper 10485** deals with the challenging idea to plan distribution networks with zero down time in Indonesia to support the quality of superior touristic destinations. The paper gives a complete techno-economic assessment that allows comparing the loss of revenues for bad services with customer's surcharges for zero down time network.

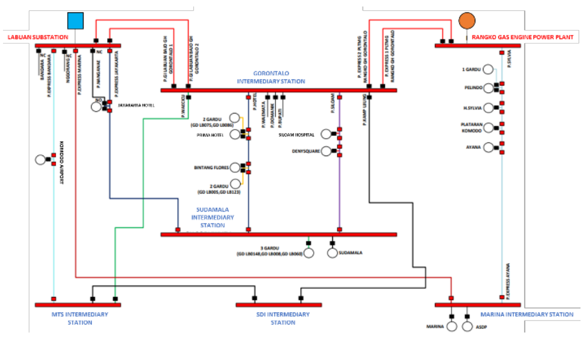

Fig. 32: Single Line Diagram of a Zero Down Time Network (Paper 10485)

Working with local authorities is crucial when the use of land is considered for power and energy applications. **Paper 10360** investigates the regularity and rationality of urban distribution network spatial layout and define reasonable quantitative indicators to assess the consistency between grid planning for the urban grid and spatial layout. Quantitative indicators evaluating the consistency between urban distribution grid planning and spatial layout are defined based on fractal theory and provide a quantitative direction for determining the geographic scale of the grid and a guidance for the grid future planning. An interesting application of the methodology clearly explains how the methodology can help integrated planning.

Fig. 33: Plan of the 10 kV network development in Paper 10360

Paper 11484 proposes a methodology for analysing and defining electricity distribution system's attributes in specific and how local characteristics impact each business unit in relation to the efficiency of the DEC Scheduled indicator during the execution process of works for the improvement, expansion and maintenance of the system.

Not only must the energy transition be accompanied by the advancement of computing technologies, but a new planning paradigm is also needed to address the challenges of modern distribution networks. DSOs must incorporate operational aspects into planning to capture the time-variability of new intermittent generation from DERs and EV loads as part of this transition. Additionally, they will need to consider all the possible factors of uncertainty affecting the planning scenarios, including the effects of extreme weather events on the networks, the unpredictability of the location and size of future EV loads and DERs and, in a wider perspective, the rapidly changing global climate policies. **Paper 11443** describes a great innovation in planning distribution, Grid Blue Sky, a new platform operating model to design, plan and operate the 2.2 million kilometres of ENEL's distribution networks in eight countries worldwide that incorporates or will incorporate all the above-described features.

Paper 10193 uses the theory of causality and complex networks to identify the functional connectivity between the nodes of portioned microgrids. It is clearly shown that the DER connection changes the dependency variation. With the help of observed dependencies, the critical nodes of the system which would behave as controlling nodes for other nodes can be identified. The variation in critical nodes could positively or negatively impact the power flow in other nodes and determination of these causality helps in comprehensive monitoring and planning of the distribution system with appropriate DERs introduction.

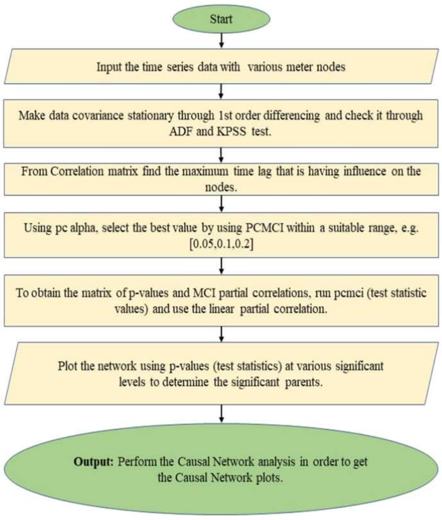

Fig. 34: Computational flow diagram for the causality network application in Paper 10193

LV is at the DSOs' centre of interest because of the impact of electrification on final uses that will cause a significant proportion of the network to run closer to, if not exceeding, its thermal and voltage capacity. **Paper 10984** summarises the finding of a UK project named SILVERSMITH, about analysing modern technologies to face the LV network challenges. The study concludes that the solutions that release voltage rise headroom, thermal transformer and thermal cable capacity are all required to resolve network constraints across the LV network. Novel technologies, deployed widely together with traditional ones, can delay the resort to traditional infrastructural actions. The most commonly deployed novel solutions are (in descending order of prevalence): LV Network Data Monitoring, Active Network Management, Active Transformer Cooling, and real-time thermal rating for HV/LV transformers.

Sub Block 2: Smart Grids and Microgrid Planning with Flexibility

The exploitation of the inherent flexibility of load and generation is the key to making the energy transition faster and more affordable. Indeed, following the path defined in the EU by Directive 944/2019, flexibility can play a crucial role in deferring investments and unlocking the maximum hosting capacity of distribution feeders. Many EU and non-EU DSO are exploring new methodologies to plan the development of the distribution systems differently. One crucial point is the comparison of flexibility services with the "copper&iron" solutions.

Paper 10454 shows the impact of flexibility on the DSO's day-by-day life. It is clearly analysed that the inclusion of flexibility in ENEDIS's industrial model, as for any other DSO, is not only about the visible part of the flexibility iceberg but it causes pervasive and transversal changes in many company's activities.

Paper 10272 proposes a simple methodology to assess if flexibility can compete with network investments helping the planners to focus on promising flexibility only. This methodology, used by Enedis in France since 2021, is based on the CritFlex criterion that is capable of avoiding deep analyses on flexibility services.

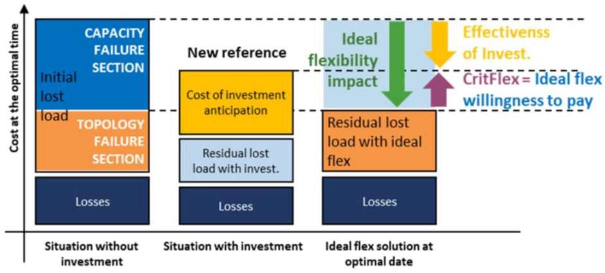

Fig. 35: Example of the CritFlex criterion to fast assess the worth flexibility compared with networks investments (Paper 10272)

Paper 11231 presents a cost-benefit analysis methodology to evaluate new grid planning solutions against known grid planning methodologies, such as grid reinforcement. It allows the determination of the total cost of each solution and computes relevant improvement indicators. The methodology also includes a sensitivity analysis of flexibility activation prices and an assessment of the impact of short-term forecasts on decision quality.

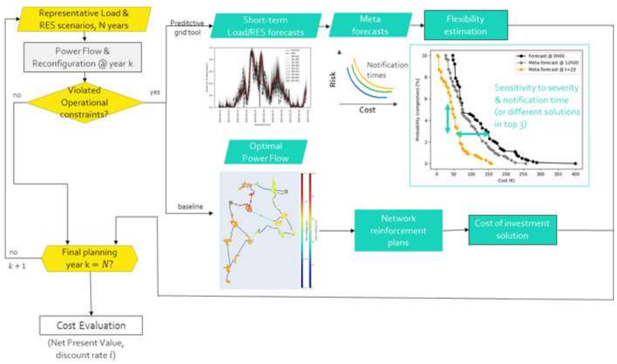

Fig. 36: Assessment of flexibility-based network development and comparison with traditional grid investments as proposed by Paper 11231

Paper 11066 proposes an interesting approach to analyse large-scale power systems and the impact of traditional and new planning options. The methodology supports quantifying the impact of the growth of PV, EVs, and heat pumps. Moreover, different measures can be compared to each other, for example, how often it is better or not suitable to use OLTCs or SVRs, which standard cable diameters to use, or how much reinforcement can be saved in LV grids due to Q(U)-control in comparison to costs for additional reactive control in the MV networks.

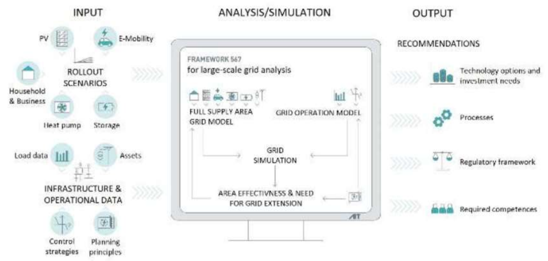

Fig. 37: The methodology for large-scale distribution system analysis in Paper 11066

Paper 11406 proposes a planning methodology based on an integrated method to analyse the effects of residential technologies with various operational strategies on the need for expansion and reinforcement in electrical distribution grids.

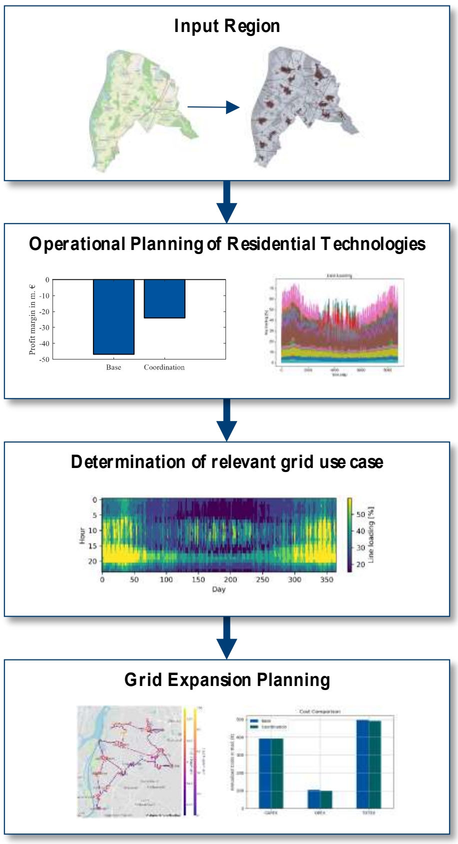

Fig. 38: Flow chart of the planning process proposed by Paper 11406 to consider the operation of loads

Paper 11462 also deals with the inclusion of flexibility in distribution planning. The paper proposes flexibility market models based on the reinforced learning of autonomous agents. It is clear from the paper that planning with flexibility needs accurate market models. In one case, the market mechanism causes more resources to participate, bringing the DSO to purchase more flexibility compared to the solutions with fixed prices defined a priori. In another case, it is clear that the peculiarities of distribution can lead to a constrained market, with no competition among the few resources available and high prices that reduce the worth of flexibility.

Paper 11456 contributes to the use of flexibility in combination with non-wires solutions with particular reference to including demand-side management (DSM) programs in modern distribution planning for relieving thermal violations during a forecasted time horizon. Given the challenges of some planning studies, planners can utilise DSM as a mitigation alternative for building investment plans that better represent the feeder's features and the utility's goals. In distribution planning, each study is unique, and by diversifying the mitigation alternatives, utilities can find the best investment plan that fits each case's needs. The application case presented in the paper shows DSM working as expense deferent, non-wires operational range extension and cost reduction for a slightly overloaded utility feeder.

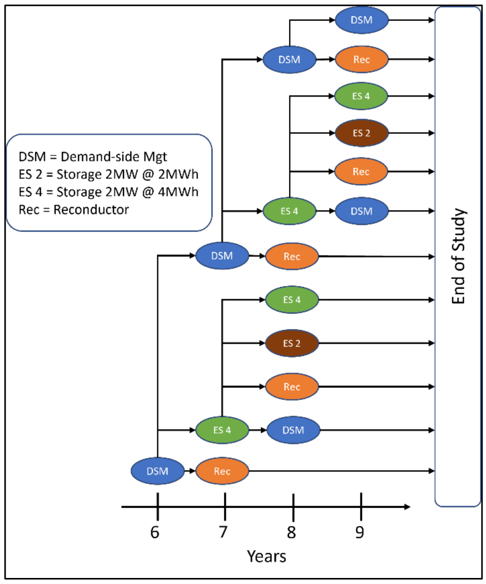

Fig. 39: Section of resulting investment plan for the case study in Paper 11456. DSM allows deferring investments and reducing costs

Paper 10144 gives an interesting co-simulation method addressing the control and modelling of electric distribution and buildings' energy systems. The paper shows that heating control increases power capacity in the system and improves voltage regulation. The discomfort for home temperature reduction can be kept to acceptable levels by increasing the participation of heat power users.

Percentage of adhesion to flexibility	Percentage of heat power (adherents only)	Gain of apparent power	Minimal voltage (% of V_{nom})		Discomfort coefficient (K.h)	Duration of discomfort (hours/week)
			$V_{min\_withoutflex}$	$V_{min\_withflex} - V_{min\_wihoutflex}$		
100%	30%	20%	-9.6%	2%	15.67	24.67
90%	27%	20%	-9.6%	2%	18.58	29.17
80%	24%	20%	-9.6%	2%	24.92	30.5
70%	21%	20%	-9.6%	2%	28.42	33.5
60%	18%	20%	-9.6%	2%	36.39	34.33
50%	15%	20%	-9.6%	2%	44.58	36.83
40%	12%	19.9%	-9.6%	1.1%	62.83	40.33
30%	9%	17.3%	-9.6%	1%	74.5	42
20%	6%	14.8%	-9.6%	0.8%	88.58	43.83
10%	3%	13%	-9.6%	0.1%	95.5	45.67

Fig. 40: Gain of hosting capacity with the use of heating flexibility (Paper 10144)

The integration of energy vectors and systems increases the level of flexibility. **Paper 10251** examines the worth of Energy System Integration (ESI) for DSO, TSO, and players (power producers, gas producers, etc.) in the Netherlands. Network investments and ESI can be cost-effective ways for DSOs to address grid congestion. The study shows that P2G and G2P can be cost-effective solutions to solve future electricity grid constraints.

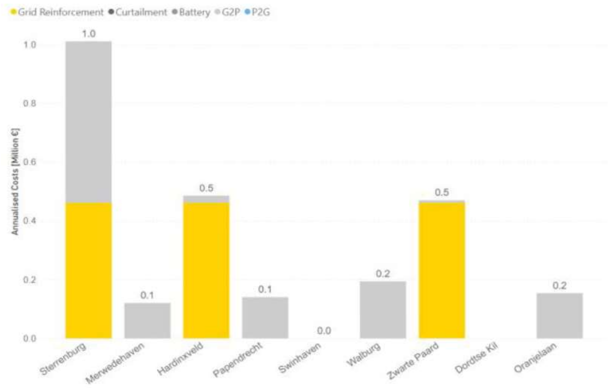

Fig. 41: Lowest annualised costs in 50/13 kV substations in the Netherlands. It is clear the benefit of energy system integration (Paper 10251)

EVs can tremendously impact the distribution systems, particularly regarding the LV part of the distribution chain. **Paper 10943** shows the positive impact for the Australian networks of direct (EC charger management) and indirect (TOU tariffs) smart management of EV charging. The results show that with unmanaged EV charging, the studied MV-LV network can face thermal, and voltage drop issues with 100% EV penetration, typically in the LV part.

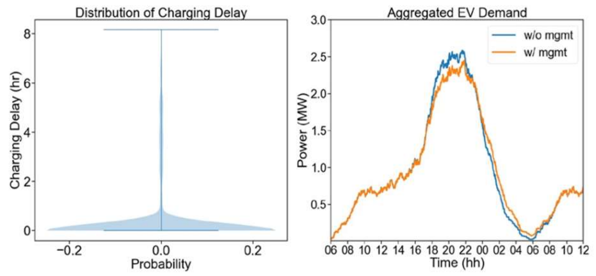

Fig. 42: Impact of EV management on customers (Paper 10943)

Paper 10766 focuses on unlocking the distribution network spare capacity by connecting heterogeneous flexible loads. First, the N-1 analysis is used to identify the maximum allowable fixed demand. Then, flexible demand can be accepted, unlocking the available network capacity, provided flexible loads can be disconnected in case of network reconfiguration. The paper gives an interesting methodology to combine different flexibilities. The result shows the deferral of investments and higher network utilisation rates. One crucial consideration is that new customers can obtain a faster connection.

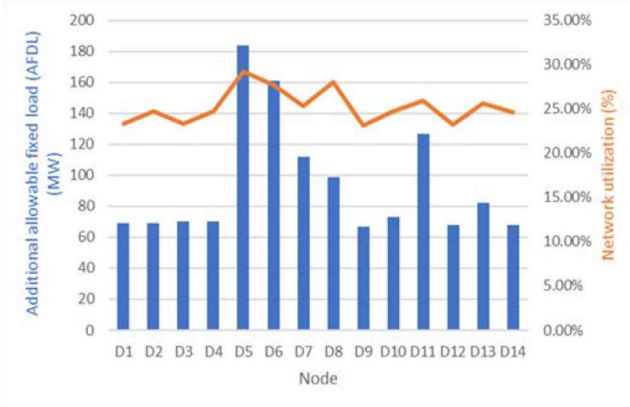

Fig. 43: The flexibility allows DSO to maximise the utilisation rate of the network without compromising the continuity of service to fixed load (Paper 10766)

Paper 11016 and Paper 11030 show how artificial intelligence and big data can help DSOs manage and plan the distribution network by exploiting flexibility. Three services are presented: i) congestion forecast, ii) flexibility forecast, and iii) planning. The contributions of these services are tested in a modified Spanish pilot of the BD4OEPM project. The long-term investments can be reduced with a hybrid approach combining traditional network reinforcement and batteries (or EV) flexibility. Using automated planning tools that consider different strategies allows operators and planners to easily evaluate the costs of different strategies to make better-informed decisions. The use of automated planning tools can significantly reduce the time and resources required for manual planning while increasing the security of the electric distribution system.

Fig. 44: Distribution planning strategies to exploit the use of Li-ion batteries (Paper 11016)

Asset to Reinforce	Base Case	Traditional 1 Strategy		Traditional 2 Strategy		Hybrid Strategy		Flexible Strategy	
	Peak Load	New Peak Loading	CAPEX	New Peak Loading	CAPEX	New Peak Loading	CAPEX	New Peak Loading	CAPEX
L0	17.74 %	15.21 %	6,881 €	8.85 %	6,881 €	14.5 %	6,881 €	16.5 %	10,440 €
SS-299	128.51 %	80.78 %	47,436€	63.67 %	46,344 €	100.4 %	57,240 €	100.4 %	57,240 €
SS-640	117.89 %	73.21 %	46,344€	58.48 %	43,815 €	99.98 %	14,760 €	99.98 %	14,760 €
SS-980	127.93 %	80.43 %	47,436€	63.40 %	46,344 €	100 %	79,920 €	100 %	79,920 €
CAPEX:			148,097 €		143,384 €		158,801 €		162,360 €
OPEX (Installation, Maintenance):			4,087 €/year		3,979 €/year		2,725 €/year		**2,202 €/year**
TOTEX (20 years):			229,837 €		222,964 €		213,301 €		**206,400 €**

Fig. 45: Planning strategies for the Granollers (Span) distribution system in paper 11030 (BD4OPEM H2020 project)

The use of flexibility is a great opportunity for DSO to operate and plan distribution assets resorting to the local ancillary services. Anyway, the flexibility of the distribution of connected resources can also be used by the TSO for global ancillary services with the risk of harmful effects on distribution system operation. This is the case with the residential batteries that offer frequency containment reserve (FCR) and automatic Frequency Restoration Reserve (aFRR). **Paper 10845** presents a methodology to assess the probability of congestion risk on a low-voltage feeder when residential batteries provide primary or secondary reserve services.

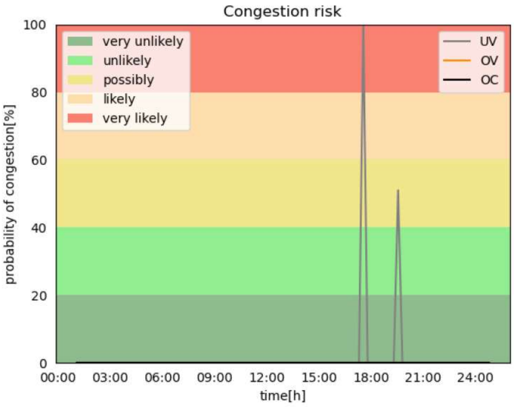

Fig. 46: Congestion risk for 35 batteries providing aFRR in a Belgian LV feeder (Paper 10845)

The network can also offer flexibility using the reconfiguration and new structures such as microgrids. **Paper 10192** uses complex networks and machine learning to find the optimal partitioning into self-sufficient, reliable, and resilient microgrids. Using complex networks to identify the correlation among nodes is useful for identifying microgrids capable of facing adverse conditions.

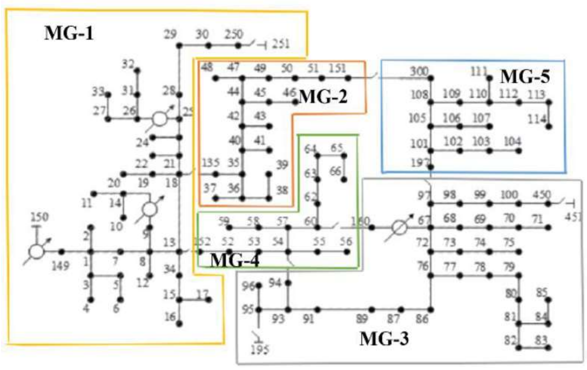

Fig. 47: Optimal topology for partitioning the IEEE-123 bus test network obtained with the methodology proposed in Paper 10192

Paper 10929 deals with the use of DER smart inverter to mitigate DER impact. The paper brilliantly observes that DER operation at the point of common coupling (PCC), is commonly assumed to follow the activated smart inverter function. However, the point, where the DER regulates or maintains the smart inverter function may be at the point of interconnection (POI) at the DER unit or inverter terminals. As there can be substantial per-unit voltage difference between the PCC and POI, the operation of such DER at the PCC may differ from expected. At low PV penetration levels, it may be acceptable to ignore the impacts altogether but whether the number of smart inverters used for network service will be high a detailed modelling is necessary to consider the impact at PCC. DSOs should work with PV developers and producers so that they provide the desired capability at the PCC, particularly for larger plants considered for MV support.

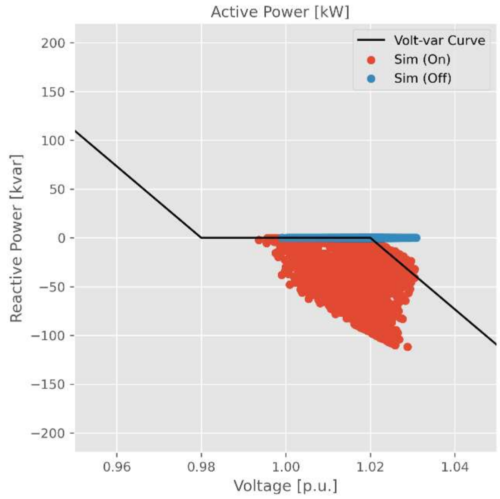

Fig. 48: Comparison of simulated (red) and expected (black) PV reactive power operation at PCC vs. active power/voltage for PV for Volt/VAR (Paper 10929)

Paper 11391 proposes a methodology for designing and operating a single-phase AC microgrid in Brazil to provide energy to Adjarra/Benin community. The grid-connected microgrid has two photovoltaic systems, a small hydropower system, and a battery storage system to guarantee the required energy for the community loads.

Developing distribution systems to favour rural electrification should consider microgrids a valuable option. **Paper 10164** shows PREMO Grid, a program already used for planning new LV networks in Africa and Latin America by EDF. PREMO Grid combines geo-referenced information and power flow tools to reduce CAPEX compared with the design from EDF experts.

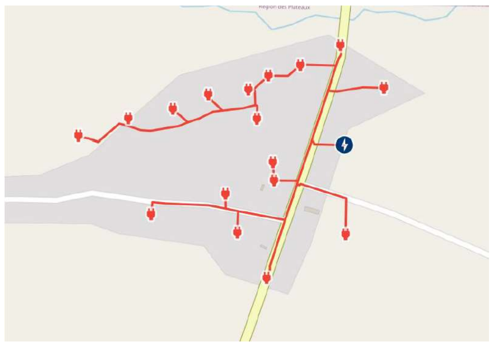

Fig. 49: Example of an optimal LV microgrid designed by PREMO Grid (Paper 10164)

Paper 10297 also proposes a decomposition of a distribution grid with interconnected isolated microgrids. The nested energy management system proposed can manage energy flows from one microgrid to the others and maximise the resilience of the most critical loads. The energy management strategy is called the nested energy management and control system, which is derived from strategically nesting or layering energy management systems of each microgrid in an interconnected microgrid system.

EMS type	Scenarios	Amount of load shed (kWh) L1 MG1	L2 MG2	L3 MG3	Resilience index [1/L,RI^max]
Hybrid	1 - IMG operated with BESS	15	100	0	0.81, 0.97
	2 - IMG operated without BESS	20	150	0	0.80, 0.99
	3 - IMG operated with MG2 isolated	40	90	5	0.79, 0.98
Nested	1 - IMG operated with BESS	0	0	0	0.82, 1.00
	2 - IMG operated without BESS	0	0	180	0.81, 1.00
	3 - IMG operated with MG2 isolated	0	200	10	0.80, 1.00

Fig. 50: Resiliency index with the nested control of interconnected microgrids (Paper 10297).

Anyway, the design of a microgrid requires managing the high uncertainty caused by RES production, energy prices, and energy demand. **Paper 10762** deals with the optimal design of microgrids considering uncertainty deterministic optimisation software PREMO (Paper 10164) to design microgrids with uncertain input and parameters. A Monte Carlo approach allows for assessing the impact of uncertainties. Finally, with specific analysis, the contribution of each uncertain input is quantified to improve the final design. The Paper identifies the most influencing uncertainty factors with different approaches (Uncertainty Analysis and Global Sensitivity Analysis).

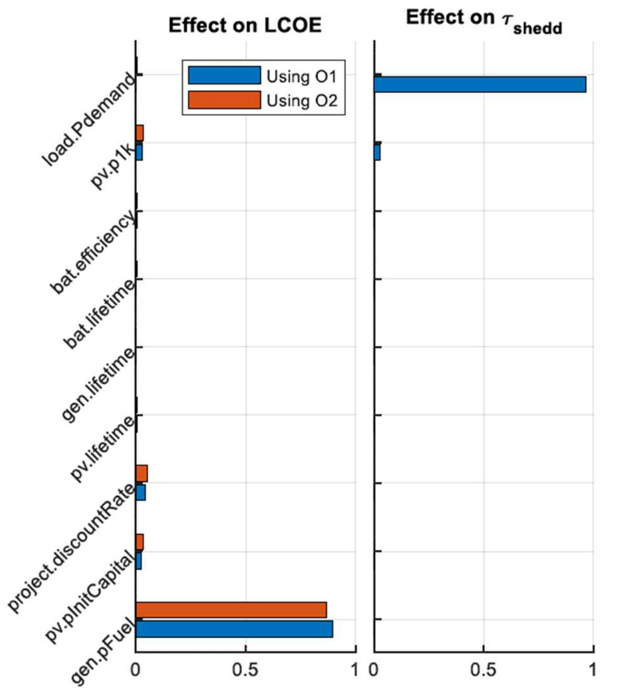

Fig. 51: Uncertainty factors and their role on Microgrid LCOE and load shedding (Paper 10762)

Paper 11034 adopts a reinforced learning algorithm (Q-learning) to solve the operational planning of a microgrid with PV, static and dynamic loads, and battery storage. The paper shows that Q-learning can perform better than model-based approaches and does not need any forecast to estimate the uncertainties in PV production, load profiles and electricity price variation. Voltage quality at the point of common coupling is within the tolerance band, and energy prices are smaller or aligned with those found by other benchmark programs.

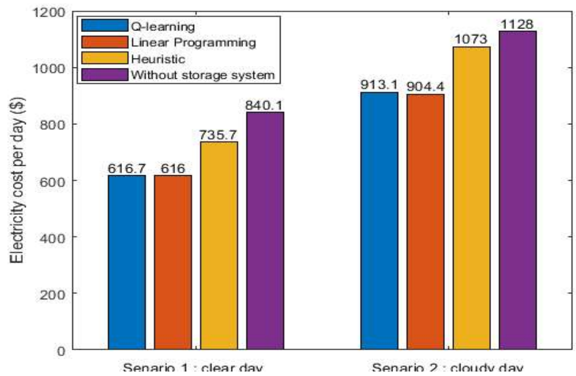

Fig. 52: Energy cost in a microgrid operated by an EMS based on experience learning (Q-learning) as shown in Paper 11034

Paper 10959 elaborates on the impact of the new energy mix based on RES in microgrids traditionally based on the use of thermal power generation. The paper analyses the Maripasoula village microgrid in French Guyana, focusing on the risk of load loss for long-time-lasting failures of power generators. With a Montecarlo approach, the paper shows that RES and batteries can reduce the risk of power failure (80 % RES reduce the expected number of power failures by 5-10 times). Still, a bigger thermal power generation is necessary in case of RES failures. Finally, optimised control algorithms of the microgrid can further improve the security of the electricity supply by prioritising the charge of the storage system when many thermal assets are unavailable.

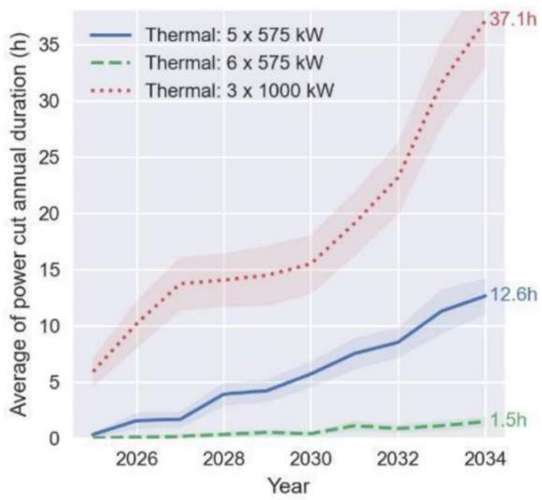

Fig. 53: Average power cuts over time. The shaded area is the 95% uncertainty on the mean (Paper 10959)

Service continuity is an utmost goal for all DSOs (**Paper 10292**). The authors from ENEL Grids show the methodology used to assess the benefit of automation to reduce SAIDI and SAIFI. The methodology applies to any level of electricity grid development and the various local regulations applied by DSOs. The number of automated or remote-controlled nodes influences SAIDI. SAIFI depends on the choice of automation systems. Remote-controlled nodes cannot improve SAIFI (no clients recovered in less than three minutes). Advanced (smart automation) can reduce SAIFI drastically since only permanently interrupted clients are considered.

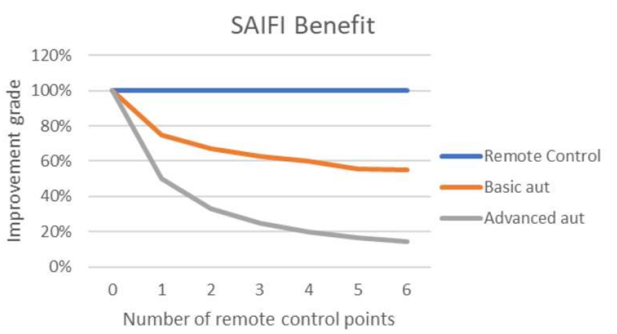

Fig. 54: Relationship between SAIFI benefit (reduction) and the distribution automation level (Paper 10292)

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

Sub Block 3 deals with typical optimization problems related to the insertion in an existing grid, in terms of quantity and placement, of individual equipment, typically for automation, voltage control, overloading reduction, observability, and so on.

Paper 11025 presents an optimization method whose objective is determining the optimal placement for the elements of an automation solution (AutoRMU) in order to improve distribution grid reliability, observability, operational efficiency, and flexibility. A coherent set of key performance indicators is introduced to define the appropriate network automation level and its deployment in order to ensure the desired results. The effectiveness of the proposed method has been demonstrated in several projects under the Egyptian distribution network modernization Program.

Paper 10449 focuses on optimal sizing and siting of DG into distribution networks, based on four different DG types' integration. The problem is address by the application of a nature-inspired technique, an improved one including the Whale Optimization Algorithm (WOA) and the Modified Whale Optimization Algorithm (MWOA). The scope of the study is optimizing the active power losses, the Voltage Stability, and the total costs, considering the constraints, which are represented in the DG penetration level and the DG units' operating power factor. The proposed algorithms have been applied on various benchmark IEEE test systems (30-bus and 118-bus); results show that the MWOA optimization technique is more effective and successful in determining the objectives in a minimum time within a minimum number of iterations.

Paper 10721 also focuses on utility-owned DER systems. In this case, the economic viability of a PV system including BESS to mitigate the negative financial effects due to a distribution tariff mismatch is investigated. To do that, simulations are set up to perform a techno-economic analysis of utility-scale PV and BESS solutions for a sample South African distribution utility. From the simulation results PV, BESS and PV-BESS provide significant improvements in gross profit margin with the PV interventions resulting in 1.54%/MW and 1.52%/MW for two different sized PV system, BESS resulting in 0.41%/MW change in GPM and PV-BESS improving the GPM to 18.83% and 30.25% for the two respective PV-BESS interventions.

Sub block 4: EV Accommodation Planning

Sub block 4 deals the specific planning problem related to the integration in the distribution grid of the public and/or private infrastructures needed to ensure charging of electric vehicles. Due to the specific load profiles of EV consumption, the planning strategies, models, and tools may differ from conventional ones and must therefore be analyzed and validated.

The impacts of PV and EV charging over large geographical areas cannot be easily evaluated without the use of a full grid model and without end-customer consumption data; however, these data are not necessarily available. **Paper 10630** adopts spatio-temporal Markov based models of PV production and EV charging with building footprints, parking spaces and light detection and ranging (LiDAR) data taken from national land surveys and OpenStreetMap to build such scenarios. Time-series are calculated and added to the aggregated consumption, then allocated to a simplified regional grid within the city, to evaluate the impacts of high PV and EV penetration on it. Maximum 10-min power flow that can be allowed with full N-1 redundancy of the transformers is also determined.

Paper 10174 investigates the impact of electromobility on distribution grids by analyzing 15 representative MV grids from six typical urban building structures. To do so, load flow calculations, according to typical private and public charging location types with average daily load profiles, are performed. Results show that the grid integration of 100 % EV can be ensured, through appropriate yet different charging strategies, in seven of the 15 examined grids, the other ones resulting in an overloading condition. It must be noted that due to the urban nature of the network examined, even in the case of overloading due to the combination of electric vehicles and heat pumps leads, the voltage drop remains under control.

Paper 10961 analyzes the impact of increasing volumes of both EV charging infrastructure and heat pumps on time-based load behavior and peak load magnitude. In order to perform this analysis with reference to urban low-voltage distribution, the use of representative grids has been chosen to reduce simulation and load modeling workload. The Paper proposes a method for selecting representative grids based on building structure and topological features, using hierarchical clustering and Ward's linkage criterion. As a result of the analysis, twelve representative grids for the six building structure clusters, identified for the city of Munich, are described and characterized in terms of clustering parameters.

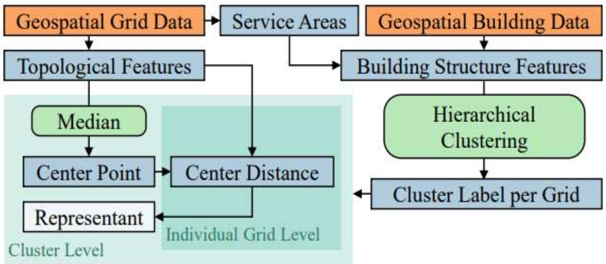

Fig. 55: Process of selection of representative LV grids adopted in Paper 10961

As the size and power of EV chargers increases, it is important to define criteria to ensure their optimal integration in the distribution network. **Paper 11165** analyzes the impact of multi-megawatt medium voltage fast charging stations on the grid, based on the outcome of quasi-dynamic load flow simulations. Grid voltage, line loading, and power losses are used as the key performance indices. The simulations include several scenarios and the possibility of on-site solar photovoltaic and battery energy storage system combinations to provide grid support and foster zero-emission charging. Results show that installing a single multimegawatt charging station on the medium voltage network will have little or no impact on the stable operation of the network, while a large-scale rollout may face limitations. Flexibility options can be used to reduce CO_2 emissions and provide grid support mechanisms, but this is not necessarily convenient.

Paper 11161 assesses the impact of an electric vehicle regionalisation method on the necessary network reinforcement strategies in comparison to a traditional planning approach based on a technical and economic perspective. In fact, considering an homogeneous distribution of EV can lead to and underestimation of the impact of electric mobility on the distribution network, as several economic and social factors highly influence electric vehicle adoption. As a matter of fact, the regionalised approach results in higher degree of localised network asset utilisation and consequently a higher occurrence of network congestion is observed.

Paper 10698 exposes an analysis to estimate the impact of stochastic load behaviors on fast charging stations (FCS) in highways, considering charging prices, operational costs and the business model revenue. The contribution of DER units to the cost effectiveness of the system is also considered. It can be noticed that including DERs units improves the energy balance between FCS and the distribution system, reducing variable (operational) costs but, at the same time, it introduces higher fixed costs independent of the FCS utilization rates. As can be expected, the use of DER units appears to be a suitable alternative in load increased scenarios while cease to be cost effective, compared with mere chargers' installations, in load decrease ones. Further investigations will be needed to define the equilibrium point between the two alternatives.

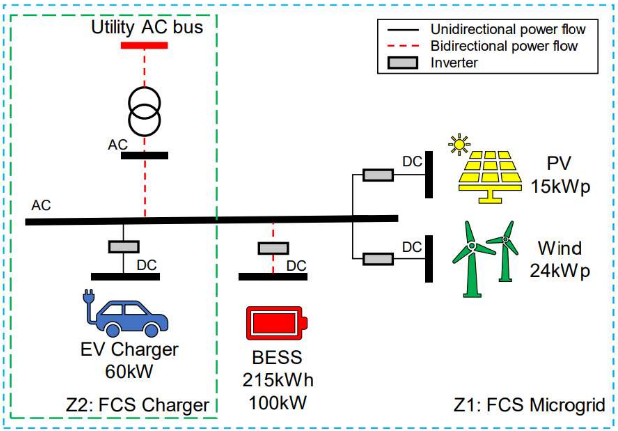

Fig. 56: Representation of case study FCS, considering a microgrid scheme (Z1) and just charge scheme (Z2) as in Paper 10698

Paper 10464 introduces a case study about the effects of plug-in EVs (PEVs) charging on the LV network in Lidingö, Stockholm County, namely analyzing the impact of increasing shares of PEVs. The analysis was performed through steady-state power flow on a digital twin of the LV network for different loading scenarios. Results show that, in the examined territorial area and for uncontrolled charging behaviors, PEV penetration levels equal to or greater than 30% could become a concern for the existing systems due to the increase in power demand, specifically on the aggregated peak power.

Combining and optimizing at local level an electric vehicle load with solar generation and battery storage may allow connecting more EV while avoiding grid upgrades. **Paper 10768** describes EV Minigrid, a planning tool developed by EDF R&D and Enedis, supporting the abovementioned optimization. The tool also provides the capability to generate an EV load according to different scenarios (office location, highway location, etc.). The optimization can be operated with reference to the annual energy cost of the system, or the power peak imported from the grid. It has been that, for a given scenario, EV Minigrid Tool is able to reduce the imported power peak up to ~54%.

Paper 10906 compares two possible approaches, namely network reinforcement and flexibility options, that can be adopted in order to comply with the load increase by EV residential charging. The evaluation has been performed through a set of representative Italian LV distribution feeders, considering the impact of different loads and DG and assessing the LV network state with a 4-wire unbalanced load flow, identifying the lines that would need to be upgraded to solve possible network contingencies; uncertainties in load and DG were also taken into account. Results show that, in the rural areas, due to the feeders' length and the small demand, the main issues are relevant to the voltage profile, while in the urban context, the short and almost fully exploited feeders may eventually suffer from overloading.

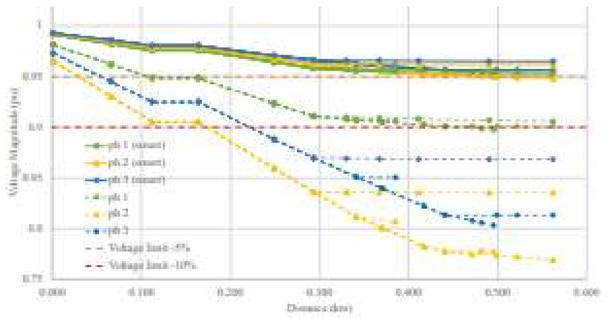

Fig. 57: Rural feeder results: worst case voltage profile at 11:00 PM (i.e., two EVs for every residential customer, no smart charging process, variable Pmax, and start at 11:00 PM) as in Paper 10906

In order to evaluate in the planning phase not only the challenges (namely, increased power demand) but also the opportunities provided by electric transportation (network support by scheduled charging), a specific tool has been developed for long time rest as in airport parking lots. In **Paper 11220** an algorithm, giving priority to charging the electric vehicle(s) closest to departure while minimizing monthly average power demand, is introduced. The algorithm has been applied to a parking facility in the Oslo airport vicinity. Results show that all EVs may be charged with only a small increase in the monthly average power demand and V2G would not provide further benefits for the parking facility owner with the current power tariff in Norway.

Paper 10379 describes a central control algorithm for EV optimal charging management with EV reactive power support, through which the optimal EV charging strategy, including reactive power support to avoid overloading as well as large voltage drops, is defined. More in detail, in case of overload and/or voltage issues, the DSO is able to send signals to EV charging stations to reduce active power charging and to support grid voltage through reactive power support. The case study, developed on a modified IEEE 33-bus network, shows the benefits of including EV reactive power support to reduce curtailment due to distribution network capacity limitations or large voltage deviations in specific operating conditions.

Paper 11445 focuses on a specific type of urban mobility: electric minibus taxi (EmBT). Authors investigate how complementarity between solar PV and EmBT can increase PV penetration. Results show that the introduction of EmBTs can positively affect the voltage issues related to PV development; however, it is important that the increase of mobility loads happens gradually as the PV capacity also increases. Connection solutions that leverage on the utilization of other complementary DERs can also be evaluated to meet the desired level of penetration and maintain optimal network performance.

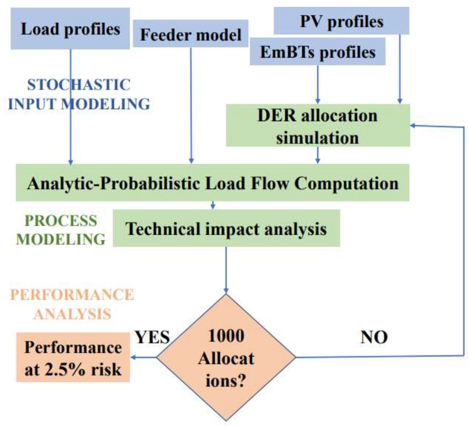

Fig. 58: Process flow for the approach proposed in Paper 11445

As smart charging of EVs parked at airports or at other long-term parking sites can be used for load shifting, **Paper 11428** introduces a python-based program based on scheduling theory and tailored to the specific objectives of charging at a long-term parking facility. The basic concept behind the system is to try to restrict EV charging to night-time, on the assumption that power peaks rarely, if ever, occur during night-time. It can be seen that, for an existing parking facility, the proposed solution does not require any additional equipment and can be integrated into the existing systems at the parking houses.

Using EV batteries for energy storage through vehicle-to-grid technologies can have a negative impact on their life, resulting in degradation costs overcoming the earnings achieved by the application of vehicle-to-grid technology. In general, however, it is assumed that the discharge depth is the same during each V2G-cycle. **Paper 10704** examines the relation between the costs of battery degradation and the selected depth of discharge during the V2G-cycle, controlling the battery's depth of discharge in a way that ensures the degradation costs are not exceeding the profit made by applying vehicle-to-grid technology. Results show that by applying the solution proposed in this paper, owners of electric vehicles can achieve 20% higher annual net income than through a conventional use, which implies a complete discharge of the battery during the V2G-cycle.

Experiencing difficult charging can negatively influence the general perception of feasibility of BEV development. **Paper 11493** introduces a series of studies that have been carried out about optimization of the siting and sizing of fast charging stations (FCS). In order to limit the formation of queues, the charging time for each vehicle can be determined, according to the characteristics of the vehicle's battery, the initial state of charge (SoCin), the desired autonomy and the power of the charger available. The Paper proposes a model capable of determining the charging time of each vehicle that arrives at the FCS based on these variables, which are randomly determined in order to approximate reality. The methodology can be applied to obtain the number of chargers that avoid long queues and, more in general, to forecast the demand for FCS on specific routes (namely, highways), allowing utilities to plan reinforcements in the electric power system.

Net zero water-based transportation is starting to gain international attention and momentum due to the development of electrified vessels. In order to profit from these technological advancements, it is important to pay due attention to the enabling shore-side electrical infrastructure, which will be likely affected by power demand increase. **Paper 11082** describes the process developed to quantify the electrical demand and requirements of net zero water transport and the tool supporting it. A case study is then proposed, examining the electrical requirements for a life-line small-passenger ferry route servicing several off-grid communities in Scotland.

Fig. 59: EV charger deployed for small vessel charging according to Paper 11082

Ferry electrification is also at the core of **Paper 11005**, that introduces a general framework for charging load profile generation, in which a probabilistic method is adopted for electric vehicles (EVs) and a deterministic one for electric ferries. The generated profiles are used to analyze the possibility of a battery energy storage system (BESS) solution for congestion management in the grid, and an optimal battery sizing problem is formulated as a measure for investment postponement for grid reinforcement. Further, a real-life test case is analyzed and four case studies are defined. Two of them include a 2 MW and 9 MW ferry charging facility, respectively, while the other two combine ferry charging with high power EV charging. The ferry charging causes an increase in peak load which could be mitigated by installing a BESS. When high power EV charging is included, the peak demands increase even more: without a BESS, network reinforcing would be needed.

Again, ferries' electrification is the center of interest of **Paper 11266**. The Paper provides a comprehensive assessment of the charging requirement of an electrified ferry fleet based on a real case study, namely the ferries that deliver public transport in the three major Italian Lakes. Actual service schedules have been used to model the daily operation of the ferries and energy consumptions have been evaluated following two different charging strategies ("overnight charging" at the end of the service, for low load ferries, and "opportunity charging" during docking time for high load ones). Two technical solutions for the connection of the recharging infrastructure are compared: standard MV connection and MV connection with the integration of shoreside storage system. Results show that, although the former requires significant lower initial investment, the latter allows significant margins in future operation.

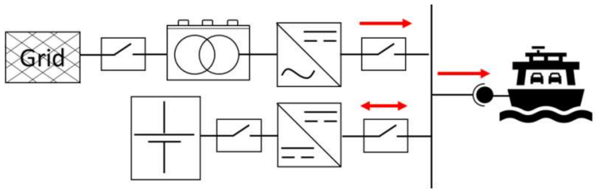

Fig. 60: Schematic of the charging infrastructure integration into the grid as in Paper 11266

Potential scope of discussion

Distribution planning is becoming more complex and uncertain. Complexity increases with the integration of energy vectors. Can planning be improved applying complex networks? Is it possible to leave the planning job to the artificial intelligence?

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 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, the huge amount of data to be managed and handled: is distribution ready for Big Data and Artificial Intelligence or, maybe better said, is Big Data "big" enough for the distribution business? Can data-driven models substitute system models? Is it possible to manage complexity with data analysis? What's the role of AI and ML in planning?

Is distribution planning going to be more and more influenced by the use of flexibility products? The first big revolution on distribution planning is the inclusion of operational options in planning. Is it now to model in planning the market of flexibility? What about TDSO and DSO integration? Integrated planning or coordinated? Priorities on flexibility usage?

Table 3: Papers of Block 3 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
10108: A Risk-Based Approach for Development Planning of Radial Distribution Networks			X	X
10144: Co-simulation Framework for the Provision of Flexibility Services for Distribution System Operators Using Electric Heating Systems				X
10164: Planning Tool Of LV Network Of A MicroGrid Using Geographic Information Systems				X
10174: Hosting Capacity for Electric Vehicles in Urban Medium Voltage Grids with Different Building Structure and Charging Strategies				X
10192: Partitioning of Distribution System into Resilient Clustered Microgrids Using Complex Network Approach				X
10193: Causal Network Analysis To Study Evolution Of Distribution System With DER Integration				X
10251: Mitigating and Preventing Electricity Distribution Congestion and Constraints Through Energy System Integration: an Integrated Energy System Analysis at DSO level				X
10272: Flexibility as a Cost-effective Solution Applied to MV Lines Investment Deferral: Guidelines toStudy and Pinpoint Opportunities		15		X
10292: Technical Benefit Assessment for Network Automation Plans				X
10297: Nested Energy Management System to Improve the Resilience of Remote Interconnected Microgrids.				X
10315: Correlation Analysis on the Application Potential of Voltage Regulating Distribution Transformers in Medium- and Low-Voltage Grids				X
10346: SENS – Tool for Planning and Operation of Smart Distribution Networks				X
10354: Representing Topology Uncertainty For Distribution Grid Expansion Planning			X	X
10360: Consistency Assessment Method of Urban Distribution Network Planning Geospatial Layout Based on Fractal Theory			X	
10379: Efficient Integration of Electric Vehicles Through Optimal Charging and Reactive Power Support		18		X
10412: Integrated Energy Planning With Local Authorities In UK				X
10449: MWOA for Optimal Integration of Hybrid Renewable Resources into the Distribution Systems for Techno-Economic Benefits				X
10454: Flexibility Inside: How To Seamlessly Embed Flexibility In Dso Activity		16		X
10464: Probabilistic Evaluation of Plug-in Electric Vehicles Impacts on the Steady-State Performance of a Distribution Network in Stockholm				X
10480: Assessment Of The Impact Of Future Electrification Scenario On An Urban Distribution Network				X
10485: Techno-Economical Approach on Establishing Zero Down Time Area To Promote Premium Reliability in Super Priority Tourism Destination				X
10506: New Approach into Material Supply Chain to Boost Industrial Capability				X
10570: A Comparative Study of Optimal Planning of Distribution Systems: AC/DC Architecture vs. Conventional Strategies				X
10574: Economic and Technical Benefits of Integrated Power and Gas Grid Planning in Distribution Grids	12			X
10575: Decision Support Tool For The Development Of Power Distribution Networks Based On AI Planning			X	X
10588: Increasing the Renewables' Hosting Capacity by Topology Optimization of Neighbouring Medium Voltage Grids				X

10593: A Novel DSO Approach In Proactively Upgrading The LV Distribution Network For Electrification Of Heat And Transport				X
10630: The Impacts Of Electric Vehicles And Photovoltaics On The Substations Of A Medium Sized Swedish City				X
10636: Network Reconfiguration Under a Stochastic Optimisation Framework for Day-Ahead Operation Planning for Future Distribution Networks		13		X
10669: Integration of Environmental and Economical Impacts of Electricity Consumption in an Energy Community Based on Coalition Game.			X	X
10698: Analysis of Stochastic Load Behaviors on Fast Charging Stations Operational Planning and Business Model				X
10704: Discharge Depth Control as a Solution for the Economic Viability of Vehicle-to-Grid Technology				X
10721: The Use of Distributed Energy Resources to Mitigate the Negative Imbalance Between Bulk Purchase Versus Distribution Tariffs in South Africa				X
10762: Assessing The Impact Of Uncertainties On The Techno-economic Performance Of Microgrids				X
10766: Distribution Network Spare Capacity Unlocking Strategy (scus) to Integrate Heterogeneous Flexibilities				X
10768: Minimizing The Impacts Of EV Chargers On The Power Grid Thanks To An Optimizing Tool				X
10845: Probabilistic Impact Analysis Of Residential Batteries Providing FCR And a FRR On Low Voltage Grid				X
10874: System Integration For Enhanced Network Planning And Operation With A Focus On Customer Interaction				X
10891: Polygonal Optimisation Of Topologies For LV Network Schematics				X
10906: Impact of Electric vehicle charging on Italian LV distribution network				X
10929: Modeling PV Facility Side - Impacts and Recommendations				X
10943: Understanding the Effects of EV Management and TOU Tariffs on Customers and Distribution Networks				X
10959: Future Of Thermal Plants On Microgrids With High Renewable Share				X
10961: Selection of Representative Urban Low-Voltage Grids for Electric Vehicle Integration Studies				X
10966: Integration Of Flexibility Solutions In The Multi-year Planning Of Distribution Grids With Large Amounts Of Renewable Energy Sources: Development Of A Decision-support Tool For The DSO				X
10967: Restructured Active Distribution Network Planning Considering Agents' Investment Budget Uncertainty				X
10976: A Surrogate Model of Distribution Networks to support Transmission Network Planning				X
10984: SILVERSMITH - Potential				X
11005: Challenges and Needs for High Power Combined Charging of Ferries and Electric Vehicles – A Norwegian Scenario Case Study				X
11006: Hierarchical Large-Scale Distribution Grid Simulation Across Multiple Voltage Levels Using Smart Meter Data				X
11016: Operation And Planning Services For Active Distribution Networks – A BD4OPEM Project Use Case: Spanish Pilot				X
11025: A New Optimization Method Brings Distribution Grids Performance To The Next Level Thanks To Digital Transformation				X
11026: A Study of Mid to Long-term Distribution Planning Based on PV Installation Forecasting				X
11030: Distribution Planning Tool using Flexible Strategies: Case Study in Spanish Pilot				X
11034: The impact of Reinforcement Learning-based Energy Management on a microgrid physical structure				X

11066: Methods and Future Scenarios for Strategic Grid Development of Full Low and Medium Voltage DSO Supply Areas				X
11069: Large-Scale Grid Investment Strategy In Low-Voltage Networks				X
11082: A Planning Toolkit to Evaluate Shore-side Infrastructure Requirements for Electrified Water-based Transportation				X
11143: Study of Low-voltage Distribution Grid Connection Dimensioning Principles Considering Distributed Generation in Finland				X
11161: Impact of EV Regionalisation on Network Reinforcement Requirements				X
11162: Regionalised Approach to Heat Pump Allocations and its Impact On LV Network Reinforcement Requirements				X
11165: Integration of a Multi-megawatt Charging Station in the Medium Voltage Network				X
11220: Load Shifting and Two-way Chargers – Criteria for Combined Deployment at Gardermoen parking, Norway.				X
11231: The Benefits Of Smart4RES Predictive Analytics				X
11266: Load Demand and Grid Integration of Electric Ferries: A Case Study in the Three Major Italian Lakes				X
11329: Predicting Local Effects of Energy Transition Through Development of a Network Observation Tool				X
11391: Contributions to Energy Management of Single-Phase AC Microgrids Used in Isolated Communities.				X
11406: Integrated Method for Distribution Grid Expansion Planning Considering Operational Strategies of Residential Technologies				X
11425: Distribution Planning Model Requirements for Smart Community Integration		14		X
11428: Smart Charging of Electric Vehicles Based on Scheduling Theory				X
11443: Enel Grid+: the Advanced Platform for Network Analysis and Planning				X
11445: Coordinated Deployment Of Electric Taxi Minibuses To Enhance Solar Photovoltaic Hosting Capacity Of Residential Networks				X
11456: Effects Of Demand Side Management Programs in Modern Distribution Planning – Challenges and Opportunities		17		X
11462: Flexibility Market Integration in Electric Distribution System Planning				X
11484: Efficiency Comparison of Programmed SAID in Investments in the Distribution System				X
11491: Hosting Capacity Portal of All Voltages Levels				X
11493: Model for Determining the Charging Time of Electric Vehicles in Fast Charging Stations				X

Block 4: “Methods and Tools”

Block 4 papers center on power distribution mathematics, either in modeling phases or in specific calculations. The proposed methodologies may allow accurate representation of grid elements, components or aggregates or simulations of network conditions or state estimations. A specific session, as usual, is devoted to the investigation about losses.

Sub block 1: Load/Generation Modeling and Forecasting

Papers of Sub Block 1 address the load/generation modeling and forecasting issue from various point of views: load clustering, emerging new types of loads (EV, HP) behavior, exploitation of smart metering data lakes, renewables generation forecasting, flexibility provision, pandemic impact.

The continuing transition to electric heat and transport introduce voltage independent loads in the network which are not impacted by voltage control methods. Furthermore, domestic, commercial and industrial load, under eco-design rules are also resulting in voltage independent loads as well. As the voltage-demand relationship lessens, the use of voltage control techniques will lose impact over the years, as highlighted in **Paper 10295**, but may still be useful at specific times of the days when the relationship is stronger.

The improvement in the Latent Thermal Storage modelling and the benefits for its applicability in the demand response programs has been investigated in **Paper 10475**. The work presents detailed modelling of average and discretized methods for Phase Change Material based storage systems. The proposed models can capture the heat system dynamics which are necessary for modelling and enhancing energy flexibility. The simulation model is validated with an actual system to evaluate the potentiality of the concept.

Paper 10453 investigates the dynamic frequency support of an inverter-based generator with fast frequency response in the medium-voltage grid and compares the results in RMS and ElectroMagnetic Transient (EMT) simulations in a simple medium-voltage testbench. The results show that, except for the time delay and the lack of transients in the current and active power curves, the RMS simulation is not less accurate than the EMT simulation.

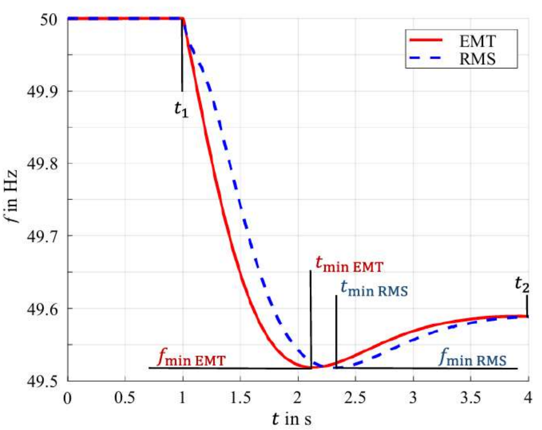

Fig. 61: Comparison of the frequency response after a load step for RMS and EMT simulation in Paper 10453

The increasing penetration of new technology appliances has made harder to comprehend the grid behavior accurately especially on the low voltage (LV). For this very reason, Gaussian mixture modelling is turned to for modelling of LV load models. That's the **Paper 10746** focus. The advantages of this method along with validation for a set of LV networks compared with the secondary substation measurements is done.

In **Paper 10327**, the exploitation of smart meter data, to increase the assessment of Diversity Factor (DF) variations, is analyzed. According to the authors, using real network data, it is possible to investigate and understand how local and global indicators affect the DF and use this knowledge to develop a supervised learn model to predict this value. DF in LV grids can allow a better estimation of hosting capacity and thus, minimizing / delaying / avoiding network investments.

Ireland has an ambitious target of 680,000 Heat Pumps to be installed by 2030. Load monitoring of MV/LV transformers, identified as having a high penetration of HPs, allowed the authors to improve their understanding of the impact of this target on the LV network. **Paper 10765** illustrates the challenges for DSOs due to increased use of domestic HPs. Reinforcement of the LV network will be vital to accommodate the increase in customer demand, and intelligent use of monitoring and data analytics is essential to inform reinforcement decisions.

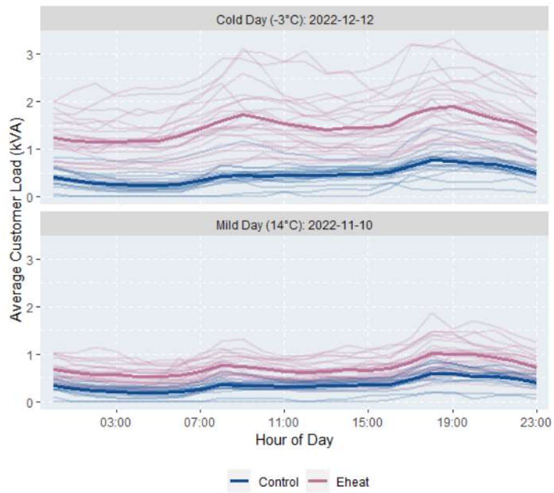

Fig. 62: Average Hourly Customer Demand for all eHeat and Control Transformers on Mild and Cold Days including Overall Means (Paper 10765)

The distribution system operator lacks the knowledge of the heating system used by their customers to make sound grid planning decisions. Energy declaration from buildings and the large-scale rollout of smart meters provides an excellent opportunity to classify the heating system used. **Paper 11427** proposes a machine learning based approach using a support vector machine with daily load curves extracted from smart meter measurements. Three heating types are analysed: district heating, exhaust air heat pump, and direct electric heating.

In **Paper 10800** a new optimization framework is proposed to calibrate the parameters of a bottom-up energy demand model. Actually, the default parameters used in the model result from technical literature, survey, census, and other modeling strategies that may partially represent the effective customers' behavior. So, they had to be tuned making use of a large consumption database composed of hundreds of measurements at the substation level during 3 years. As a first step, the proposed methodology is applied to calibrate the thermal properties of the building envelop.

A data driven photovoltaic regionalization approach providing numbers, sizes and locations of rooftop and ground mounted photovoltaic (PV) systems connected to the grid infrastructure is presented in **Paper 10651**. It focusses on the use and interconnection of different data sets and how to further process them in algorithms and illustrates the benefit in using georeferenced data of power systems combined with other domains to obtain to-the-grid assignable PV scenarios which can be directly used in further power flow studies.

The aim of **Paper 10161** is to identify and evaluate Reinforcement Learning methods for improving the energy properties of buildings through structural changes. For this purpose, a combination problem was formulated as Markov Decision Problem regarding optimal extension decisions in order to test different Reinforcement Learning architectures. The presented experiments are related to structural expansions of different complexity.

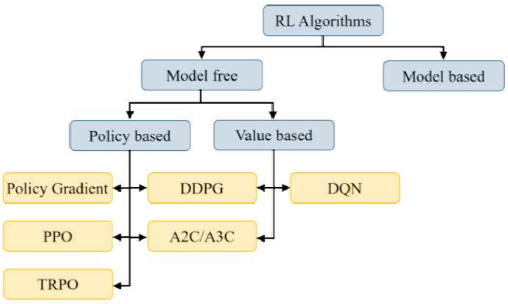

Fig. 63: Overview and categorization of selected Reinforce Learning algorithms as in Paper 10161

The challenge of planning the public infrastructures for EV charging in new city districts or areas without an existing infrastructure is the focus of **Paper 10835**. The work explores the benefit of using socio-demographic indicators to estimate the charging demand based on the existence of specific user profiles. Those user profiles are obtained by applying a clustering methodology to historic records collected in other areas of the city or similar cities (same country and geographic area) based on the connection patterns.

Paper 11123 presents a simulator able to estimate the demand factor for the Electric Vehicle (EV) charging infrastructure of collective car parks based on their characteristics and EV usage behaviors. An accurate simulated demand factor instead of a generic value could significantly help EV fleet owners and the DSO to optimize the sizing of the charging infrastructure and the grid thus reducing costs for the community, notably for upcoming EV charging installations in apartment buildings.

Paper 11188 investigates the challenges and opportunities of forecasting applied to grid planning and operation. Actually, large changes in production and consumption of electricity let grid operation and planning much more difficult than in the past. Forecasting future demand and production is one way to reduce investment risks. The authors provided a questionnaire towards network planners and operators in order to know their point of view about challenges and expected development.

Paper 10821 deals with algorithms and forecasting models for accurate predictions of renewable generation, i.e. solar photovoltaic power and wind power and electric load. The forecasts are developed for short- term and day-ahead operation. The paper analyses the available data needed to perform forecasting, and described the diverse demonstration sites where the algorithms are implemented in. Three different machine learning approaches have been described and implemented to all demo sites.

Paper 10517 identifies the need for abstraction methods to support the planning of future energy infrastructures. For this purpose, a clustering procedure was developed, which allows to consider local conditions in the determination of energy profiles for each individual building, which significantly increases the quality of the energy profiles compared to existing approaches based on standard load curves.

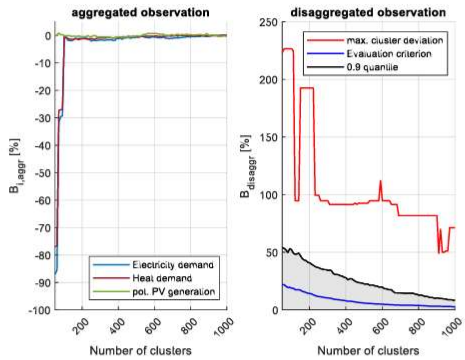

Fig. 64: Determination of the number of building types by means of aggregated and disaggregated evaluation according to Paper 10517

Electricity production from wind and sun, although more mature from a technological point of view, is still difficult to predict because it depends on intermittent sources that introduce high levels of variability and uncertainty in system planning and operation. **Paper 10737** analyses data on variable renewable generation, such as from wind, solar and hydro power plants during 2021 and 2022, and correlation between them. Results have been compared with scenarios currently applied by operators in the connection process. The paper also indicates increase in grid hosting capacity if operator is allowed to limit the production of wind and solar power plants under outage conditions (N-1).

The quality of the numerical weather predictions may widely affect the renewable forecasting and, consequently, the power system performance. **Paper 11241** addresses the need for large-scale forecasting datasets by presenting methods to refine and generate artificial benchmarking inputs. A k Nearest Neighbors based localization approach and a synthetization technique generating artificial PV forecasts for benchmarking purposes are developed and thoughtfully assessed by the authors.

The scope of **Paper 11183** is to investigate the electric vehicle (EV) charging behavior in a cold environment by providing an overview of laboratory tests conducted for several EVs. The laboratory measurements together with the stochastic load modeling show that the energy demand increases significantly over wintertime charging sessions.

In Nordic distribution grids, EV charging peak loads often overlap baseload peaks, creating incentives to manage charging in a smart way. The increased energy content and additional preheating power cause a need to rethink smart charging applications.

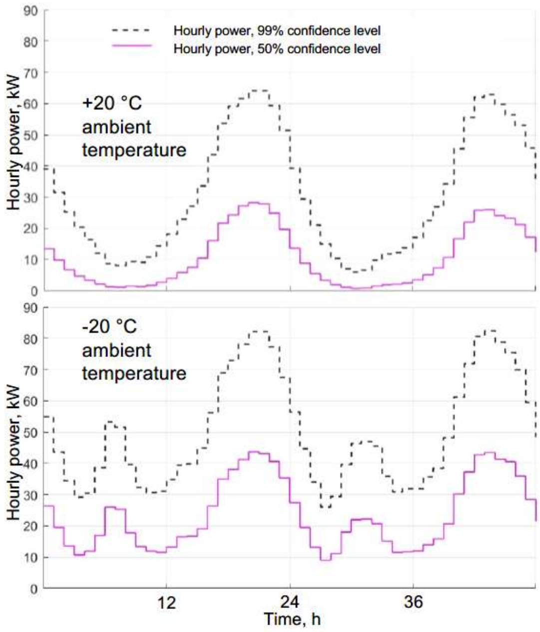

Fig. 65: Comparison of +20°C and -20°C ambient temperature charging paths according to Paper 11183

Paper 10496 introduces a data-driven analysis of aggregated EV charging demand in residential areas and at public charging stations to obtain representative EV charging patterns for flexibility assessment. The suggested approach to initially assess aggregated EV charging demand composition can increase the confidence in accuracy and applicability of the assessed EV flexibility potential in demand response programs.

Paper 11481 presents work carried out in the SIES 2022 ERA-Net project, which is investigating in detail the possible provision of flexibility by different technologies but thorough a lens of different business models. Forecasting is an important element of a Virtual Power Plants functionality and to its commercial success. Forecasting errors are reviewed using real project data and used to simulate an optimization of project assets using both actual and forecast data, allowing a quantification of the effects of forecasting errors on VPP performance.

Paper 11101 presents a new, data-driven based, methodology developed during the pandemic by a Brazilian Distribution Company to predict the needs of new distribution lines to supply customers in the next five years period. To make these predictions, a series of statistical and machine learning predictive models were tested in the search for the best fit. The effects of the pandemic were considered adding external variables to the model, such as increased inflation in equipment prices and increased requests for distributed generation (DG) connections, among others.

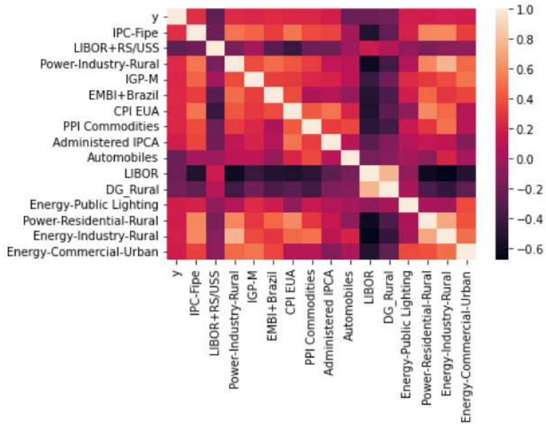

Fig. 66: Pearson's correlation heatmap as in Paper 11101

Electricity consumption has become a key indicator to measure the state of the economy. **Paper 10790** presents the impact of COVID-19 restrictions by estimating a counterfactual baseline electricity consumption against which to compare the observed data. The authors evaluated the heterogenous effects across voltage levels throughout the whole pandemic period as well as the impact of containment measures on electricity demand across economic sectors and regions.

Sub block 2: Network Modeling and Representation

The papers of this Sub block deal with network modeling and representation considering several aspects like voltage profile issues related to renewable generation, ampacity line rating, fault prediction, GIS implementation, making large use of smart meter capabilities and information.

In the last years the photovoltaic generation has increased a lot in the Netherlands together with prosumers complaints about PV inverters shutting off. **Paper 10107** reports how this issue has been addressed. Actually, smart meters have been configured for grid management in the Netherlands, using a code of conduct for smart grid management approved by the Dutch Privacy Authority. When an issue is detected, a detailed voltage measurement can be remotely initiated, saving time and allowing for proactive problem resolution. This supports the integration of PV systems and improves customer satisfaction.

Stability studies of future power systems that are dominated by converter-based generation, typically connected to the distribution system, require high computational effort. Equivalent dynamic models of distribution systems reproduce the dynamic behavior while reducing the complexity of the corresponding detailed network models. **Paper 10501** presents a model of a German transmission system area and connects fourteen distribution grids to several nodes of the transmission system. The distribution grids are represented by three grid models dominated by converter-based generation including grid forming converters.

Transmission and distribution networks need higher capacities to keep pace with the rapid evolution of electricity production and consumption. **Paper 10209** proposes a methodology to develop a quasi-Dynamic Line Rating (qDLR), simulations using weather reanalysis. The methodology can be applied to a set of coordinates representing an existing line, or a grid spanning a geographical area.

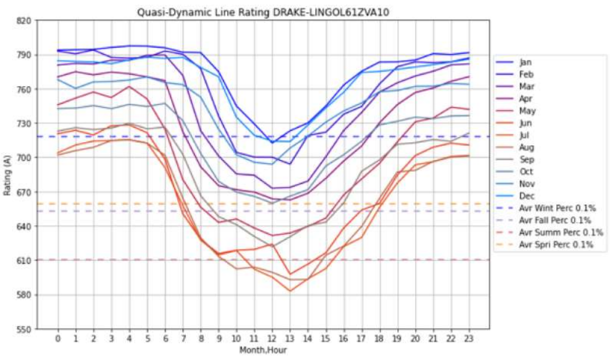

Fig. 67: qDLR with an exceedance probability of 0.1% compared with the respective static seasonal ratings, as in Paper 10209

Generic failure rates for components classes are generally available and can be used to generate a forecast of the number and duration of outages. The authors of **Paper 10382** found that the predictions made with these average failure rates, cannot reliably predict which circuits will feature in the worst performing group. Improvements could be made to this forecast using data that are already held by DNOs, such as the network topology, health indices, and other pieces of information kept. Another possible improvement is envisaged by using a sequential prediction to better predict the effect of a fault on the rest of the network and simulate multiple faults happening in the same area at the same time.

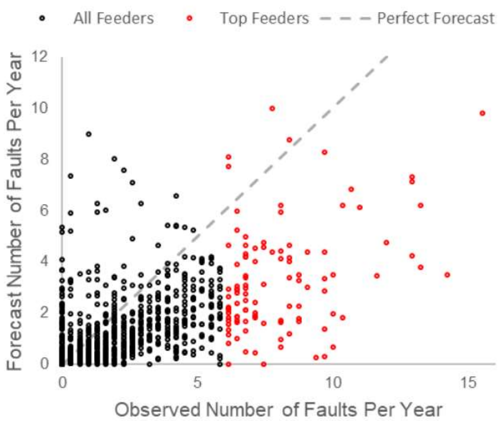

Fig. 68: Comparison between observed and forecasted number of faults according to Paper 10382

In **Paper 10520**, the authors present their vision for a "Unified Grid Modelling" that combines geographical and electrical modelling. The proposed approach could help grid operators to benefit from digitalization without significantly increasing the complexity of their IT environment.

Paper 10827 addresses ampacity rating calculations using Finite Elements Analysis (FEA) compared to data from a Distributed Temperature Sensing (DTS) measurement system on an onshore wind farm export cable in operation. Steady-state and time-dependent rating calculations have been performed, for several operational scenarios and input parameters, and compared to DTS data on the same cable. The results show that conventional steady-state calculations give a very conservative estimate of the current-carrying capacity. Statistical treatment of the intermittent load profile shows that the cable is subjected to the static load limit only during short periods of time.

FASIT is the Norwegian standardised system for collecting, recording, calculating, and reporting of reliability data in the electric power network. It has been in operation since 1995 and has been regularly updated. A major revision and update with an information model based on CIM and utilizing the MADES/ECP communication technology resulted in a new version put into operation from 2019. **Paper 10846** focuses on the areas of use, the applications, and the utilitarian values for the NRA and the TSO in their supervision and control, for the DNOs in using the collected data to improve their own performance, and as a source for input data for various reliability calculations and simulations.

The LV topology recorded by Distribution System Operators is essential for optimal PV/EV deployment or non- technical losses localization but is often incomplete or inaccurate. **Paper 10873** presents a joint experimentation between Odit-e and Endesa to assess the precision of a GIS correction and completion algorithm based on smart meters' voltage measurement. The method does not require any additional secondary substation sensor.

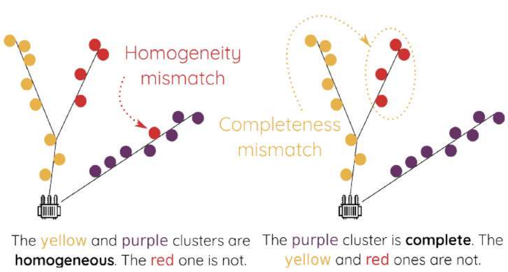

Fig. 69: Homogeneity versus completeness clustering criteria according to Paper 10873

Estimation of peak currents in LV feeders requires accurate data identifying customer service connections and the phases of each single-phase customer. **Paper 11305** presents the SMITN project focused on correlation and machine-learning clustering techniques using smart meter voltage data to determine connection phases. Results show the impact of time-resolution and measurement duration on the accuracy of phase detections.

Sub block 3: Load Flow and Short-Circuit Calculations

In Sub block 3 the improvement of performances of load flow and short-circuit calculations algorithms exploiting graph theory, probabilistic approaches, multiconductor network methodologies as well as dispersed generation modeling are addressed.

Paper 10348 investigates the possible power flow improvement on real distribution networks using a graph-based algorithm. 18 input networks in IEC CIM standard have been first converted into a network graph. Under this representation, it was possible to compute typical graph centrality indexes to characterize networks: degree, closeness and betweenness centrality. The use of non-relational databases and knowledge graphs to describe grid elements and their relationships is crucial to ensure interoperability between different energy carriers. At the same time, graph algorithms enable new possibilities to solve multi-energy applications in an efficient and innovative way.

Paper 10397 presents a machine learning approach in order to monitor congestion within distribution grids making use of smart meter data. The proposed algorithm performs as expected by correctly predicting the impact on the voltage when unobserved cases of stochastic distribution grid exchanges are introduced. At the same time the methodology is promising for monitoring the limitations of the grid hosting capacity by mapping the congestion occurring at each particular scenario.

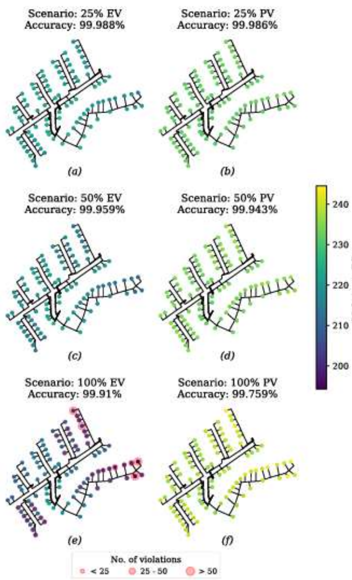

Fig. 70: Predicted congestion using the ML approach for different (left) EV and (right) PV penetration levels as in Paper 10397

Power Grid Model, a high- performance Python/C++ library for distribution grid calculations, is presented in **Paper 10468**. It elaborates the design choices for mathematical modelling and software implementation. The benchmark test case shows that the model is significantly faster than existing solutions on the market.

Usually, networks are planned with deterministic approaches according to defined worst-case scenarios. This leads to incorrect assumptions being made, especially for new consumer groups whose exact load behavior is not yet known, and this can lead to faulty network expansion. In **Paper 10371** a new planning approach is presented, which combines a case-based probabilistic load flow by using grouped time series and classification of the substations. The authors shows that the critical cases are also mapped by this approach.

Paper 10607 presents a multi-conductor methodology for modelling electric power systems which can be adopted for the analysis of distribution networks. This is crucial to address the intrinsic asymmetry and high percentage of single-phase users connected in the low voltage network. The proposed approach allows for a complete generalization of the network model, providing a detailed set of results which can be used for monitoring and controlling the distribution system.

The Hosting Capacity estimation, by applying a time-series-based methodology using real consumption, PV production and EV charging data, is presented in **Paper 11054**. The background voltage from PV/EV integration at the MV level is modelled in the time domain. An 11 kV MV network with 57 underlying 400 volts LV networks is assessed. Results show the importance of using real data for modelling EV charging in order to get a correct coincidence factor of charging.

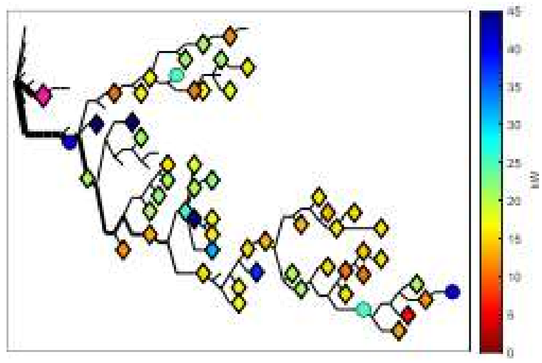

Fig. 71: PV Hosting Capacity map for each LV transformer considering the background voltage as in Paper 11054

Sub block 4: Energy Losses

Energy losses are always a priority in the distribution business and generally deserve a specific treatment within DSOs' organizations. Both technical and non-technical losses may represent the focus of advanced analytics, often based on big data and/or leveraging on Artificial Intelligence.

Sub block 4 deals with methodology to optimize technical losses, to discriminate between technical and non-technical ones and/or the detection process leading to the discovery of frauds or energy theft, either leveraging exclusively on own metering data or incorporating information from publicly available sources.

Paper 10424 describes a procedure to detect and locate technical (TL) and non-technical losses (NTL) in distribution networks where only a few consumers are equipped with smart meter. The proposed algorithm is implemented in Isfahan city electricity distribution company, serving about 1 million and 200 thousand consumers, 20 thousand of which are equipped with smart meters, through a web-based monitoring dashboard called SEPAD system. The algorithm accesses billing data, operating and automation data, AMI data, and GIS data to estimate load and voltage in all network branches and consumers, and - consequently - losses by TL and NTL at the level of transformer distribution, consumers, and medium voltage feeders. Results show that the load is estimated with less than 5% error, a value that can be adequate for assessing TL and NTL.

Paper 10836 addresses the problem of the reduction of reliability of data in low voltage networks due to unquantified non-technical losses (NTL). The authors focus on a methodology to determine if the losses are due to a customer or an external element unrelated to the customer. The hybrid methodology presented in the paper is based on implementing dynamic linear models with a Recursive Least Squares (RLS) Estimator and introduces an indicator to detect potential NTL and to identify if they come from changes in the customers' behavior or if they are due to external factors related to the distribution network. The proposed hybrid approach has been specifically developed for small DSO motivated to identify direct connections or meter tampering, assess them and evaluate their real capacity to integrate DER into their existing infrastructure.

Paper 10301 presents a hybrid fraud detection system in which both smart meter and grid data are used. The methodology focuses on non-technical losses, namely on meter tampering, and adopts clustering and correlation tools, such as the Matthews Correlation Coefficient, to flag potential fraudsters based on strategies defined by the DSO. The algorithm has been tested on several synthetic grids and was found to be effective in detecting meter tampering conditions, resulting in a significant improvement compared to conventional techniques. Next steps imply testing the system with real-world data and optimizing the economic viability of the process.

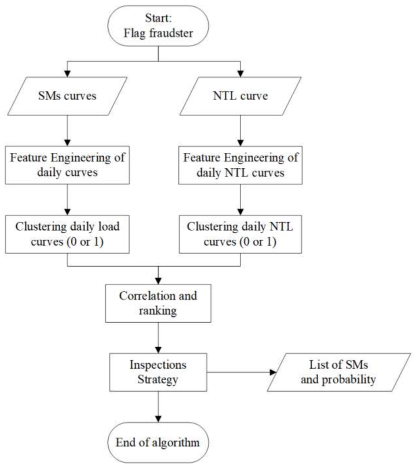

Fig. 72: Fraud detection system flowchart as exposed in Paper 10301

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 modify them according to predefined guidelines. However, to get the full benefits of this evolution, we must consider the expected, and possibly the unexpected, flexibility patterns. How can we represent the adaptive strategies a Smart Grid can pursue to make optimal use of them in planning, avoiding unnecessary oversizing of equipment? How can be obtained reliable profile of EV consumption? What is the expected level of confidence?

Table 4: Papers of Block 3 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
10107: Large Scale Detection Of Voltage Level Violations In LV-grids Using Smart Meters				X
10161: Development Of A Model To Optimize The Energy Efficiency Of Residential Building And Their Impact On The Low Voltage Grid				X
10209: Quasi-Dynamic Line Rating Spatial and Temporal Analysis for Network Planning				X
10295: Voltage Demand Relationship Modelling for Future Energy Scenarios				X

10301: Non-technical Losses Identification in Distribution Grids: A Hybrid Approach		24		X
10327: Use Of Linky Smart Meter Data To Enhance The Diversity Factor Assessment In Real Networks				X
10348: Graph Computing Techniques for Power Flow Resolution Considering Real Distribution Networks		23		X
10371: Case-Based Probabilistic Load-Flow Calculation Considering The Correlative Interdependence Of Loads				X
10382: Determining the Accuracy of Average Fault Rates in Assessing the Risks of Individual Circuits		22		X
10397: Voltage Congestion Monitoring Through Machine Learning				X
10424: A Novel Approach on Monitoring Technical and Non-technical Losses in Distribution Networks				X
10453: Comparison of RMS and EMT Models of an Inverter-Based Generator with Fast-Frequency Response				X
10468: Power Grid Model: a High-Performance Distribution Grid Calculation Library				X
10475: Modelling and Validation of Latent Heat Storage Systems for Demand Response Applications		19		
10496: Data-driven Assessment of Aggregated EV Charging Potential for Flexibility Procurement				X
10501: Evaluation Of Dynamic Active Distribution Network Equivalents With Grid Forming Converters In The Context Of System Stability Studies				X
10517: Comprehensive Building Clustering as an Abstraction Method for Planning of Power Distribution Systems				X
10520: Bridging The Gap From Geographical To Electrical Modeling				X
10607: A Multiconductor Approach To Study Power Flows In Asymmetric And Unbalanced Electric Distribution Networks				X
10651: Data Driven Photovoltaic Regionalization Approach for Distribution System Operator Supply Areas				X
10737: Analysis Of The Renewable Energy Sources Generation Simultaneity In Croatia And The Impact On The Network Management				X
10746: Validation of Gaussian Mixture LV Load Models using Measurements				X
10765: Low Carbon Customers: Analysis of Loading of Domestic Electric Vehicle and Heat Pump Transformers in Ireland				X
10790: The Impact of COVID-19 on Electricity Demand in Portugal				X
10800: Autocalibration of a Bottom-up Methodology for Long Term Electricity Consumption Forecasting				X
10821: Deployment Of Forecasting Tools In Diverse Demonstration Areas To Improve Energy Scheduling Of Microgrids				X
10827: Experiences With Ampacity Rating Calculations For Wind Farm Export Cable				X
10835: A Prediction Tool To Evaluate EV Charging Demand Based On Socio-Demographic Indicators				X
10836: Data-driven Techniques to Improve the Reliability of Low Voltage Electricity Networks Through Dynamical Evaluation of Non-technical Losses				X
10846: FASIT, The Norwegian Reliability Data Collection System – Experiences And Utilitarian Values				X
10873: Low-Voltage Topology Identification from Incomplete Smart Meters Data: Spain Experiment				X
11054: Hosting Capacity Using Real Time-Series for PV, EV, Load and Background Voltage				X
11101: Post-Covid Customer Service Behavior Forecasting Using Machine Learning Techniques				X

11123: Anticipating Aggregated Demand From Charging EV In Collective Car Park With A Multi-Agent System		20		X
11183: Electric Vehicle Charging Measurements in the Nordic Environment – Charging Profile Dependence on Ambient Temperature				X
11188: Forecasting For Electricity Grid Planning: Current Challenges And Future Improvements				X
11241: Meteorological Benchmark Forecasts for Energy Management Systems				X
11305: Phase Identification using Smart Meter Data				X
11427: Support Vector Machine For Classification Of Households' Heating Type Using Load Curves				X
11481: The Impact Of Forecasting Accuracy On The Economic Performance of Flexibility Provision		21		X