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SPECIAL REPORT - SESSION 5

PLANNING OF POWER DISTRIBUTION SYSTEMS

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Session Program and Organization

The session accepted 143 high-level papers (acceptance rate around 60%) divided into four blocks that reflect the S5 traditional topics. General papers are selected to stimulate the discussion in the Main Session with oral presentations; papers with the highest research content are selected for oral presentation in the RIF session. Each oral presentation lasts ten minutes; interactive posters have two minutes presentations followed by a Q&A session.

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

Block 3: Distribution Planning

- Sub block 1: Advanced Planning
- Sub block 2: Smart Grid Planning
- 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 Modeling and Forecasting
- Sub block 2: Network Modeling 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** (September 22, 9:00-12:30 and 14:30 -18:00),
- **PS** (September 23, 9:00-12:30 and 14:30-18:00),
- **RIF** (September 21, 09:00-10:30).

Round Tables are organized by S5 or jointly organized with other Sessions:

- **RT1**: DC Networks (September 21, 09:00-10:30)
- **RT3**: Distribution Planning and E-Mobility (September 21, 11:00-12:30)
- **RT5**: Flexibility and Digital DSO (September 21, 14:30-16:00)
- **RT6**: Hosting Capacity (September 21, 16:30-18:00).

Introduction

The energy transition in distribution systems claims vast infrastructural investments in a highly uncertain scenario, making planning and decision-making a risky exercise in the expected uncertain and volatile scenarios. Thus, forecasts and scenarios development are crucial to transpose country-level decarbonization goals down to the smallest LV network for finding bottlenecks and planning investments. Smart grid technologies are an opportunity to fix the temporary consequences of high demand and renewable generation. Still, DSOs continue to suffer from Regulatory impediments that the Literature and EU directives suggest eliminating. The S5 papers give a contribution to these general topics. Electromobility and heat-pumps impact forecast highly improved with AI combined with geo-referenced and socioeconomic databases and electrical calculations. The energy transition burden on the distribution systems is predicted with accuracy. Many industrial papers propose an excellent combination of practical approach and scientific rigour for dealing with the complexity of new planning. The first attempts to use AI for the automatic planning are a sign of future trends. Microgrids and DC distribution continue to interest, but real-life applications are still few besides the realizations in rural electrification. Local energy communities are the emerging option to foster sector coupling and increase flexibility using P2P markets and blockchain. The resiliency of distribution systems as a development driver is covered by few good papers only. Looking at the received contributions, the planners' interest (and concern) is more on the short-term challenge of enabling the energy transition without rebuilding the system entirely and jeopardizing the quality level. Finally, a panoply of different mathematic approaches to deal with uncertainty and risk, optimally allocate resources and reduce technical and non-technical losses is proposed in the Session. In conclusion, considering the pivotal role of non-wires planning alternatives, two complementary topics are emerging: integration planning and flexibility markets and the TSO/DSO coordination. The research on these two key topics will undoubtedly increase with the progress of energy transition.

Block 1: Risk Assessment and Asset Management

Sub block 1: Risk Assessment and Reliability Assessment

The "Evaluation of Reliability Index for Electric Systems" (ERIS) to ensure efficient grid development based on its reliability is the **Paper 0327** focus. ERIS proposes an integrated approach to support investment decisions by quantifying the benefits of investments on load flow, topology and condition of the grid. By considering the ERIS indexes into the long-term asset analysis of the infrastructure, it is possible to analyse grid reliability and the financial effects of integrated scenarios.

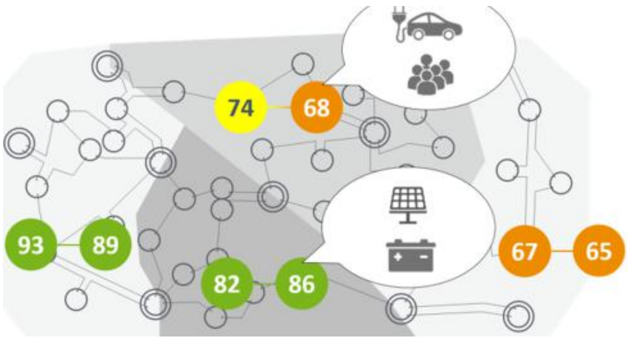


Fig. 1: Identity actions required based on ERIS score, as in Paper 0327.

Paper 0840 deals with a method to localize in different countries the Common Network Asset Indices Methodology (CNAIM), which is a framework to consistently model asset risks and to make risk-based decisions, developed by the English DSOs on RA (OFGEM) request. The localisation work within five Danish DSOs has shown that CNAIM is transferrable to other countries by applying a structured methodology to ensure that all local aspects are checked and taken into account.

Sub block 2: Resiliency

Possible evolutions around 2050 of strong winds, heavy precipitations, wet snow, extreme hot temperature and wildfire are evaluated by **Paper 0468** authors to assess distribution network adaptation needs. The changes in the occurrence and intensity of these events have been studied using climate simulations under RCP8.5 and RCP4.5 IPCC emission scenarios. An increase in flash river flooding is likely to happen as well as extreme hot temperatures and fire risk.

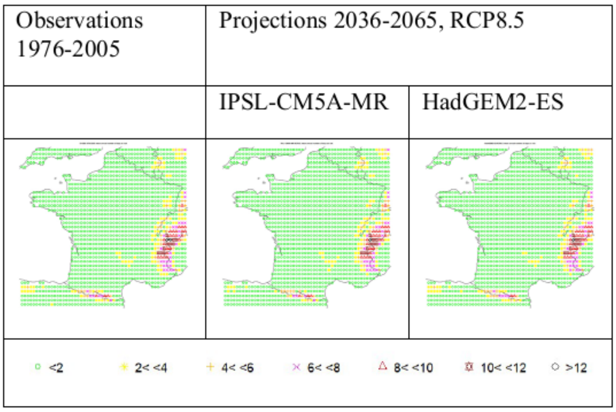


Fig. 2: Mean annual number of days at risk of wet snow for both historical and future periods according to two climate models with emission scenario RCP8.5. as in Paper 0468.

Paper 0829 focuses on developing a method to accurately classify the overhead line section's susceptibility to stormwind damage by combining forest data and DSO interruption data. The categorization results corresponded to expectations and DSO's internal information. The data uncertainty and the small sample size impedes definitive conclusions, but the methodology developed in this paper can be used for further developments.

A framework for evaluating the resilience in a distribution network serving a given geographical area is proposed in **Paper 0978**. The potential impact of different network and non-network measures for improving system resilience is investigated with a probabilistic approach. Results derived by testing the methodology on a case study demonstrate the model effectiveness for planning applications.

Sub block 3: Asset Management and Maintenance Strategies

Paper 0018 analyses the lifetime estimation and lifetime planning of MV cables and cable accessories in the Helsinki network. The loading rate and the material types in use, and own fault statistics are taken into account to estimate the optimal technical lifetime of the MV cable. Anyway, the study proves that the new technical lifetime of the MV cable and cable accessories is also economically viable and supported in the Finnish regulation.

An asset management strategy for reducing the number of Medium Voltage (MV) levels in the Stedin distribution network is described in **Paper 0431**. Progressive load development due to energy transition and increasing voltage problems due to Renewable Energy Sources (RES) necessitate a review of the existing voltage level of MV grids. The first step was to convert the 10 kV network of Rotterdam city centre to 20 kV. Research has been done to scale up the other 10, 13, 23 and 25 kV grids to the 20 kV level.

Paper 0436 proposes a comprehensive analytics method to calculate the probability of failure or the health index of single network equipment and for a group of assets as substations, transformers, etc. Asset health modelling, probability of failure modelling (degradation curve derivation) and asset criticality calculation are combined to formulate an overall risk index of each asset/type of asset of the grid.

The benefits that tan δ measurement can bring and the evaluation software features and its results are discussed in **Paper 0766**. The potential savings that data analysis opens up and draws upon the case study of a German distribution network operator are described to illustrate its economic benefits.

Paper 0801 deals with the digitalization and 3D modelling of the power distribution network through a Mobile Mapping System (MMS) with different technologies like high-resolution cameras, LiDAR (Light Detection and Ranging) and thermographic cameras. The MMS helps utility companies inspect their network faster and more accurately and store all the information on a common platform where all users can access. The expected result is an improvement in the grid inspection and maintenance based on real field information.

The choice of an optimal ageing limit of transformers in flexible power systems by using a maximal energy transfer as a criterion for defining the optimal ageing limit of transformers (both the existing and new ones) is investigated by **Paper 0897**. Results show that the optimal ageing limit for transformers should be equal to the ratio between the remaining insulation life and the remaining calendar life. Moreover, the paper presents the energy transfer through a new transformer as a function of various ageing limits and different durations of a calendar life.

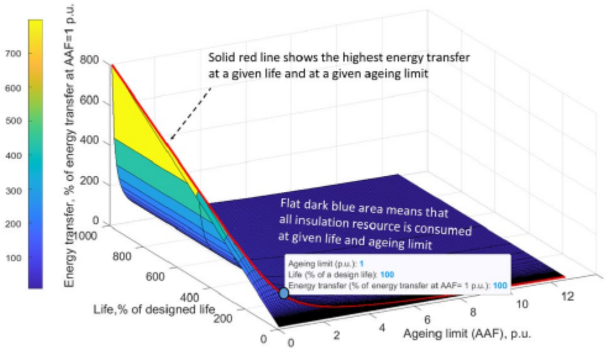


Fig. 3: Dependency: ageing limit - remaining calendar life - maximal energy transfer according to Paper 0897.

A thermographic inspection is an effective way for the energy distributor to carry out preventive maintenance on the power grid, avoid problems in transformers, connections, and protective equipment, thus preventing consumers' lack of power supply.

Paper 1076 presents the Asset Investment Management/Condition Based Risk Management methodology adopted by a Croatian DSO that combines asset information, engineering knowledge and practical experience to define the current and future condition, performance and risk of network assets. It has been applied for prioritizing the investment portfolio of transition from 10 kV to 20 kV. The methodology will be now used for planning the refurbishment of 35 kV overhead lines.

An optimal stochastic Reliability-Centered Maintenance approach in which online and offline monitoring techniques are combined to reduce costs and enhance reliability is proposed by **paper 1131**. The reliability level of the distribution network components is evaluated according to the three-state Markov model, considering the uncertainty of repair time for maintenance actions. The proposed approach has been tested within the Birka Nat distribution system in Sweden.

The potential scope of the discussion

Resiliency is crucial in modern distribution due to a clear trend leading to a greater frequency of extreme events. How can the different dimensions of resiliency be included in planning? Is cost/benefit analysis suitable to guide the decision making if applied to projects for improving resiliency? Can the smart grid and digitalization have a significant role in improving resiliency?
Is it time to include safety as a topic for CIRED?

Table 1: Papers of Block 1 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0018: Estimating the lifetime of medium voltage cables and cable accessories in an urban environment				X
0327: Combining the evaluation of reliability index for electric systems with the long-term analysis of infrastructures				X
0431: Grid planning in the midst of several existing voltage levels				X
0436: Asset management system in DSO using business intelligence tools and advanced analytics				X
0468: Resilience of the French distribution network to climate change: Projected changes for 5 main meteorological hazards around 2050	X			X
0766: Case study: More cost-efficient asset management by prediction the remaining lifetime of medium voltage underground cables				X
0801: Mobile mapping system in a power distribution network				X
0829: Assessing overhead line's susceptibility to stormwind damage using open data				X
0840: Global application of the British CNAIM for asset risk modelling – A case study from Denmark				X
0897: Optimal ageing limit of oil-immersed transformers in flexible power systems				X
0978: Application of resilience triangle model to the electric distribution system				X
1076: Asset management in HEP DSO: from development of methodologies towards application	X			X
1131: A stochastic Markov model for reliability-centered maintenance approach in electrical distribution networks				X

Block 2: Network Development

DSOs have been the most innovative among electricity operators in the last ten years: lower costs and reduced size made previously unavailable functionalities at hand deployed in everyday operation. New materials, components and systems are constantly tested and introduced, expanding DSOs' possibilities in network management.

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

Sub block 1: Innovative Power Distribution

Sub block 1 deals with all kinds of innovation not explicitly connected with "mainstream" topics; it may deal with specific, Country-based projects including multi-source energy systems or be related to the adoption of a specific new component and technical solution.

In **Paper 0219**, a comparison among different bonding techniques for HV and MV cables is presented. The most common practices (Solid Bonding, Single Side Bonding and Cross Bonding) are evaluated regarding investment and operational costs (ampacity, losses, etc.). The strengths and weaknesses of different techniques are detailed depending on the specific component, installation type and size. Finally, some general recommendations are made regarding the best suitable solutions according to operational conditions.

Paper 0134 focuses on the Zero Down Time (ZDT) concept, referring to network architecture and configuration intended to minimize the interruption time by looping pairs of MV feeders coming from the same MV busbar and HV/MV transformer. The protection system uses Line Current Differential between two secondary substations on each feeder. This approach is being developed in the distribution system of the New State Capital City of Indonesia.

Paper 0722 investigates the effects of static and dynamically meshed grid topologies on the short-circuit current situation and power supply reliability of medium voltage grids. As expected, the meshed operation significantly increases the short-circuit currents (but these generally do not exceed the critical limit values). It brings the power supply reliability to almost the same level as in the initial topology in static meshing by applying a loose coupling. A significant expansion cost reduction (up to 63%) is also expected both in the case of static and dynamic meshing.

In **Paper 0180**, a change of paradigm in the KEPCO's approach to the connection of large customers is described: instead of supplying them at MV voltage level, forcing them to manage their transformation, the idea is to ensure a low voltage supply, installing compact substations that can be buried underground. The architectural solution adopted to deliver optimal service quality by using RMU and RING configuration is then described.

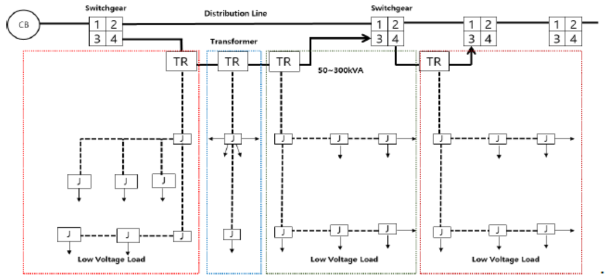


Fig. 4: KEPCO underground distribution network reference scheme according to Paper 0180.

Paper 0392 examines Power-to-Hydrogen solutions as possible measures to relieve the HV grid in case of a massive penetration of PV-based generation. By installing small scale electrolyzers in the proximity of existing PV sites, the possible strain on the HV network can be significantly relieved. The benefits persist with no significant increase of stress on the network scaling up the electrolyzers size, thus showing that the electrolysers' contribution is more dependent on their location than on their power.

In **Paper 0649**, a solar-hydrogen-storage (SHS)-EV charging station with photovoltaic power, battery storage, hydrogen generation and storage system is presented. The system is designed to be operated, minimizing the operation costs, including hydrogen fuel costs and electricity purchase. In detail, the system operation is simulated through MATLAB to verify the renewable energy operation method in terms of cost and payoff period. Results show that compared with the traditional charging system, the cost of this SHS charging station is greatly reduced, the energy reserves are always guaranteed at the expected level, the utilization rate of the hydrogen storage system is high, and the reliability of the system is increased.

In **Paper 1049,** a technical, economic, and feasibility study of a PV-BESS system to support the diffusion of EV charging stations in Brazil is presented. The system includes a PV system, a BESS, and EV fast chargers connected to the power grid; the load can be supplied by the PV system when available or by the grid or BESS when energy prices are high. The system optimization has been performed, finding a return on the initial investment of seven years, besides 10% of ROI and 0.28% of LCOE.

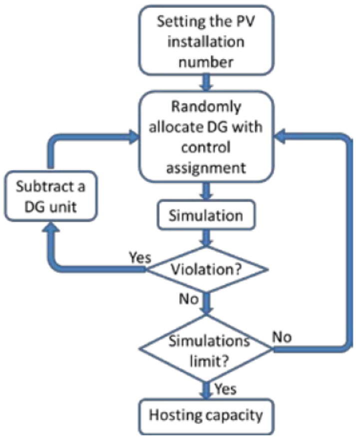


Fig. 5: Flowchart of the algorithm to determine the Hosting Capacity according to Paper 0391.

Paper 0391 deals with the hosting capacity increase that can be achieved in an LV grid through the flexibility that storage systems and smart inverters can ensure. The proposed methodology provides a reliable estimation of the hosting capacity and can be ordinarily used while evaluating a new generation connection. As expected in LV, the most effective measure happens to be Volt-Watt regulation, while Volt-VAR is not always beneficial as it. However, it does not limit generation but may significantly increase losses.

Paper 0490 describes a pilot project where parts of the LV grid of Mainz have been monitored over a period of about 1.5 years. Evidence coming from the collected data shows that an accurate understanding of the grid status may lead to better decisions regarding asset usage and grid reinforcement in the connection process and operation. Finally, the authors state that digitalising the LV grid may lead to automatise some common processes that DSOs are executing daily.

Paper 0583 discusses technical, economic, and other types of Non-Wires Alternatives (NWA) screening criteria and methods that can be applied to streamline the NWA evaluation process. The abovementioned techniques can be applied to assess NWA potential to defer or avoid conventional distribution system investments. Notwithstanding the authors exploring several key types of NWA screening criteria, they foresee the need for more research to refine the processes, methods, and criteria and develop software support tools.

In **Paper 0751**, the LENI Least cost ElectrificatioN decIsion support tool) for the optimisation of LV electrification is presented. The idea behind LENI is to develop a flexible approach for determining the best electrification solution within unelectrified villages: the tool provides the grid design. It performs a techno-economical optimisation of the LV grid and individual solutions such as solar home systems or microgrids. Future LENI developments include a techno-economical arbitration between on-grid and off-grid solutions.

Paper 0996 introduces a simple (naïve) methodology to select characteristics network nodes, in which smart meters should be installed with high priority to achieving effective coverage of the LV network for DSO monitoring purposes. The idea behind the initiative is to assess possible problems with voltage quality while keeping the necessary initial investment low. The simplicity of the method also allows easy automation of the selection process. By applying it in the smart metering project Komorany, it was found that the success rate is quite far from outstanding.

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.

Paper 0715 deals with Smart Grid Architecture Model (SGAM), an already established tool supporting standardization in the Smart Grid technical design. The authors present a methodology that is aimed at including the social perspective in the development of a Smart Grid project: this is increasingly needed as, due to decentralisation and the development of new business models in the energy system, stakeholders are becoming increasingly dependent on each other, and the agreement on interoperable solutions represent an organizational as well as a technical issue.

In **Paper 0573,** the implementation of self-healing concepts to the LV grid is discussed. The extension to the lower voltage levels to operational practices already introduced in MV networks may seem almost natural; however, technological challenges exist. The economic viability of the investment needed to establish a self-healing infrastructure is not immediately clear. The authors argue that possible synergies with other concepts that are being developed (microgrids, EV, Demand Response, etc.) will eventually help to implement the elements (such as telecommunication capabilities) needed to boost self-healing in LV.

Paper 0138 presents the results of the SERVING project. A platform has been developed within this project that aggregates the flexibility of individual loads (night storage heaters, heat pumps, water pumps, etc.) for optimized energy procurement, considering grid constraints. During the pilot project with 50 customers, water pumps and night storage heaters were controlled, but the platform can easily integrate other flexibilities like electric vehicles or heat pumps. Challenges to gather data and control a large mass of flexibilities in rural networks are presented, and the solutions developed.

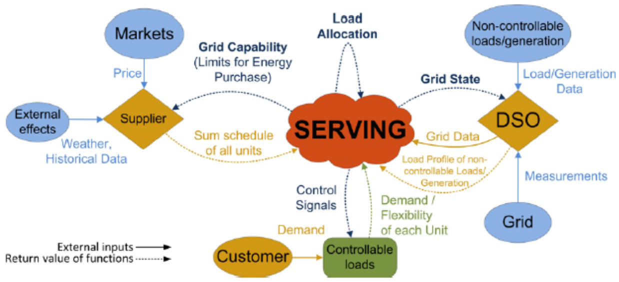


Fig. 6: Functional interactions of the SERVING platform as described in Paper 0138.

Paper 0740 presents an optimization model to derive the load profiles of future active domestic customers. It compares different incentive-based control strategies to meet the challenges of these developments from a grid perspective. The advantages, disadvantages and interactions of different incentive-based grid control strategies are then analyzed. The results show how different incentive strategies have different effects on the load profiles of active customers. In particular, price tariffs that contain power-related elements or thresholds for energy prices seem more effective, from the grid point of view, compared to time-variable price tariffs about voltage quality and grid utilisation.

Paper 1085 describes an agent-based model for simulating participants' offering mechanism in a Local Energy Market (LEM). The market users' behaviours are simulated through a decentralized version of the common genetic algorithm (DGA), implemented on a Real-Time Digital Simulator (RTDS), capable of inspecting the grid dynamics. To test the proposed model, approximately an hour of simulation with three users was performed. As the next steps, the authors want to improve the full Hardware In the Loop (HIL) process to simulate one or more days of operation of the system.

Sub block 3: DC Distribution Systems and Microgrids

There is already enough technical literature about DC distribution systems that have been largely investigated during the last years due to the characteristics of many new loads that intrinsically reminded DC distribution to be supplied. It must be noted that DC systems can also be used in an off-grid solution powered by RES, hence the inclusion, in the same Sub-block 3, of the wider Microgrid topic.

In **Paper 0450**, a technical solution to perform the conversion of portions of LVAC network in DC grid is examined. Authors show that transforming some parts of a conventional LV system into DC-operated ones is more convenient than ordinary reinforcing to reduce voltage violations and mitigate overloading, especially when future developments and learning curves of DC technologies are considered.

Paper 0383 proposes a procedure for designing an electrification project in a remote rural area, relying on distributed resources of energy and information from the studied area supported in the geographic information systems (GIS). Based on information available about the location of users, paths, forests, access roads, land use, contour lines, solar radiation, wind speed, and rivers, the most appropriate radial distribution network is designed. AC, as well as DC installations, are considered and ranked to find the optimal techno-economical solution.

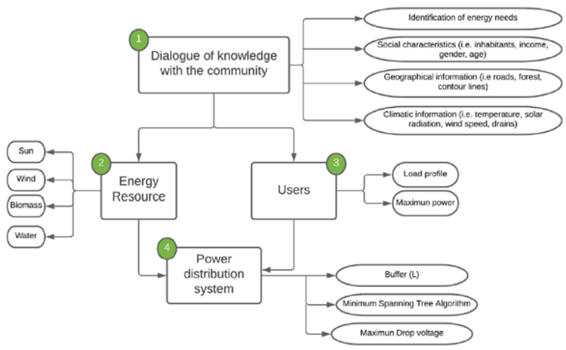


Fig. 7: Methodology for electrification projects in rural areas, as in Paper 0383.

In **Paper 0360**, a methodology to design and operate rural microgrids, particularly suitable for off-grid areas in emerging or developing countries and island communities, is presented. Firstly, three use cases (off-grid microgrid, connected/island-mode microgrid, community microgrid) are introduced. Secondly, a seven-step process to perform the design and implementation of a specific microgrid is described. Finally, some practical applications are detailed. Further investigation will be devoted to finding a suitable business model to support the sustainable industrialization of the proposed solutions.

Paper 0602 presents a new AC/DC microgrid topology as an alternative to the traditional AC network in the context of developing countries' electrification. DC loads are firstly grouped using K-means clustering. Next, a minimum spanning tree (MST) algorithm is applied to the clusters to get the minimum length of DC conductors. Hence, using the shortest path (SP), the closest electrical poles connected to a cluster where the AC/DC converter is placed are found and then balanced by the mixed-integer linear programming (MILP). Finally, the AC lines connecting all poles and clusters are designed with the MST. The optimal cost of the complete AC/DC microgrid is determined for 20 years of operation.

In **Paper 0817**, a comprehensive electrification strategy to grant universal energy access in Zambia in 2030 is presented. Based on an available grid and off-grid solutions, an investment plan is developed, in which different architectures are adopted according to population density and proximity to an existing network. The result is a least-cost study of MV grid extension feeders and areas for off-grid electrification.

Paper 1011 describes the main results of the POSEIDON project. The project aims at defining optimal control strategies of microgrids in the port area, including the management of electric vehicles with public charging stations, energy storage systems installed on boats, flexible loads and Renewable Energy Sources (RES). The planning studies will evaluate, by considering the use of vehicle-to-grid and boat-to-grid paradigms, the positive impact of electric vehicles and boats in terms of better exploitation of RES, energy efficiency and reduction of the polluting emission.

The potential scope of the discussion

Microgrids are already planned as a viable solution for isolated areas electrification due to their modular structure and relative ease of installation. Can we imagine the same microgrid structure as the atomic element to build larger distribution architectures, being able to operate both as a standalone entity and as an inter-connected sub-system?

Table 2: Papers of Block 2 assigned to the Session

Paper No. Title	**MS a.m.**	**MS p.m.**	**RIF**	**PS**
0134: Zero downtime (ZDT) network topology for reliability supply in new capital city of Indonesia				X
0138: Combined market and grid oriented operation of distributed flexibilities				X

– results of a pilot project				
0180: Power flow and economics analysis for RMU-based low-voltage distribution networks operation.				X
0219: Influence of bonding of medium and high voltage cables on annual costs				X
0360: Methodology for rural microgrids development				X
0383: Electrification projects in remote rural areas using geographic information systems				X
0391: Smart inverters and storage systems used to increase PV hosting capacity of LV distribution networks				X
0392: Is power to hydrogen an appropriate approach to mitigate PV-induced strain on 110 kV high-voltage grids?	X			X
0450: Simulation tool for techno-economic analysis of hybrid AC/DC low voltage distribution grids	X			X
0490: Digitalisation of urban grid for better grid planning purposes				X
0573: Would self-healing be economically justifiable on LV networks?	X			X
0583: Screening criteria and methods to aid the integration of non-wires alternatives in distribution planning	X			X
0602: Planning low voltage AC/DC microgrids for un-electrified areas				X
0649: Design and operation of solar-hydrogen-storage integrated electric vehicle charging station in smart city				X
0715: Perspectives on the social embeddedness of the smart grid architecture model in innovation projects				X
0722: Effects of static and dynamically meshed topologies on short-circuit currents and the reliability of medium voltage grids	X			X
0740: Modelling the demand behaviour of active customer and the impact of price incentive based strategies			X	X
0751: LENI: an example of development of least cost electrification approach				X
0817: Geospatial least-cost plan for on and off-grid electrification to achieve universal electricity access in Zambia by 2030	X			X
0996: The proposal for reduction of regularly monitored consumers in smart metering project Komorany				X
1011: Optimal planning of port microgrids to improve energy efficiency by the integration of RES, flexible loads and smart mobility - POSEIDON				X
1049: A proposal for technical and economic sizing of energy storage systems and PV for EV charger-stations with reduced impacts on the distribution network				X
1085: Agent-based approach for decentralized genetic algorithm			X	X

Block 3: Distribution Planning

Sub block 1: Advanced Planning

The Hosting Capacity of distribution networks has been debated for a long time. The expected connection of new distributed generation for the energy transition is attracting new research on the field covering a range that spans from the HC definition to some practical applications.

Paper 0046 defines HC as the amount of PV generation connected to a network that does not cause an overload of lines or equipment. The authors propose a methodology to estimate the HC of any distribution network, and map zones with the highest overload risk can be easily prepared. One significant result is that according to the examined data, transformers are more prone to overloads than the cables feeding a cabinet. **Paper 0029** deals with the case of reverse power flow from LV to MV network. Reverse power flow is not an issue for the distribution transformer. Problems can arise if a negative load happens on an intentionally isolated distribution network energised by a rotating generator during maintenance. In this case, the concept of Hosting Capacity is used to identify the maximum level of PV generation that allows using a backup generator to supply loads. In conclusion, the authors find that for small distribution transformers, where backup generation is most often needed, it will often simply not be possible. For larger distribution transformers, backup generation during the summer months becomes a serious challenge with tens of kW installed capacity.

Distribution planners seek new tools and methodologies capable of considering at the same time different objectives that include reliability and resiliency besides economy and energy efficiency. **Paper 0064** proposes a new algorithm for distribution planning capable of finding the optimal network expansion and breaker and switches position simultaneously. The proposed procedure obtains the Pareto set of the integrated network development plans. It provides a decision-maker to determine the best network development plan by integrating the network expansion and network automation planning in radial distribution networks with distributed generators. The topic is not new (the first contributions of integrated network/automation planning were proposed in 1997-1999), but the authors significantly improved using a novel methodology.

The electrification of energy consumption is one of the success keys for the energy transition. Load demand is expected to grow as well as the power injected by generators connected. Old models based on average data and single point representation of customers' needs are no longer suitable and cannot help planners in the existing context. Furthermore, tools to assess the worth of flexibility, related costs and inherent risk are crucial to modern planning and fulfilment, such as recent EU directives. Indeed, non-network solutions are progressively being considered by distribution and transmission planners for economically addressing acknowledged grid limitations. Gaining popularity due to technological advancements, falling costs, and supportive regulatory orders, regulators in several jurisdictions are now mandating that utilities evaluate the feasibility of DER-based alternatives before conducting any major grid reinforcement. Non-network solutions significantly impact the complexity of the planning process and pose new challenges to associated analytics, tools, and business processes. Many CIRED 2021 papers give significant contributions to the topic of modern distribution planning working in this field. **Paper 0358** brilliantly shows how to bridge the gap between national energy transition goals and distribution planning. It proposes an approach based on geographic and statistical data to distribute national projections for distributed generation and consumption into five distinct distribution grid types. Geographic data analysis is used to categorize areas into these five grid types. National projections are used to determine the needed number of EV chargers for distributing roof-top and large-scale PVs and individual heat pumps.

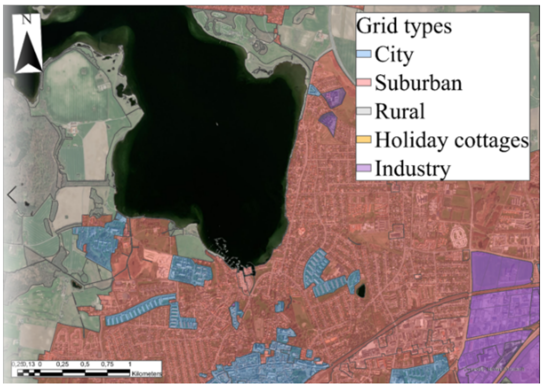


Fig. 8: Example of network classification with GIS in the area of Roskilde Fjord in Denmark (Paper 0358).

Paper 0157 is another example of advanced planning to include non-wires alternatives within distribution planning with a multi-dimensional planning technique. With this technique, planning studies can be as detailed as needed for integrating new technologies, visualizing their effect on current and future distribution systems. The multiple dimensions generated can be compared economically to obtain the best investment plan for the next years based on the load growth forecast, the technologies used to relieve the power system and the circuit model used for the planning study. The method proposed is a graphical framework for describing the relationship, progression, and dependencies between the power system state through time and the alternatives needed to solve the violations found during the analysis period.

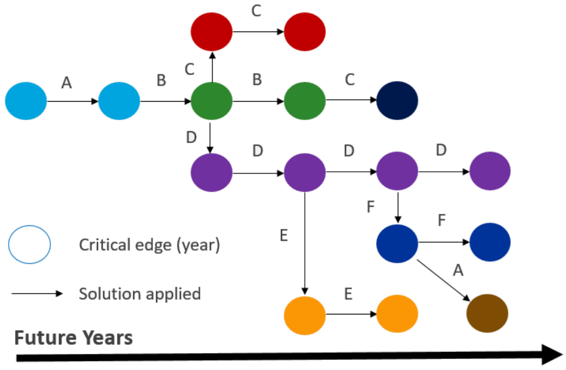


Fig. 9: Example of graphical representation relationship, progression, and dependencies between the power system state through time (Paper 0157).

Paper 0611 is an example applied to the long-term planning of active distribution networks (ADN). The authors propose a step-by-step methodology that aims at tackling the problem of efficiency in long term planning based on the ADN concept. Therefore, ADN planning (ADNP) extends the complexity of conventional planning with additional operational considerations, such as switching regulation taps of distribution transformers, the curtailment of distributed generation (DG) or active and passive feed-in management, as well as the operation of demand response. The methodology builds on the ADN concept as a strong candidate to defer network investments common practice in usual business scenarios. Its application to the case study of a medium-size Spanish city highlights the economic advantages already on a horizon of 10 years. Assuming a moderate engagement of 15% of the loads connected to the network into demand response mechanisms results in a 7% reduction of operational costs and 14% reduction for conventional expansion investments than the expansion strategy without DR.

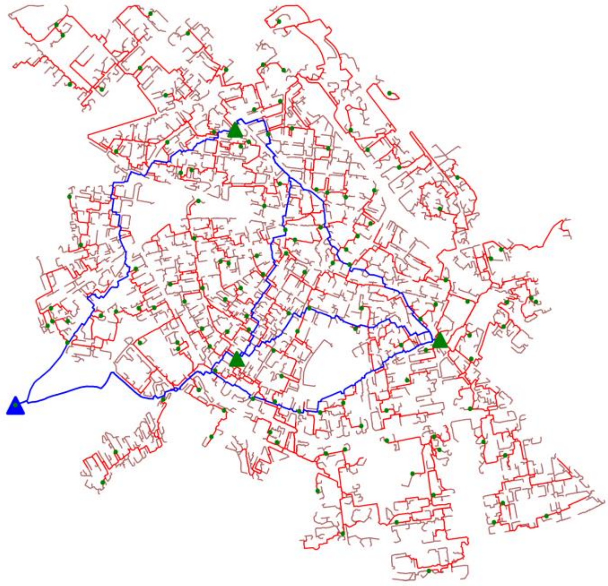


Fig. 10: Albacete: HV, MV and LV network model (Paper 611).

Paper 0719 contributes to flexibility in distribution planning by showing the Enedis approach to the problem. Enedis has issued a request for proposals of flexibility services with an online tool that would enable actors to bid with any kind of services. The tool enables the actors to evaluate the performance of their services, and Enedis to assess the collective value of each bided service. Enedis awards the flexibility contract yielding the greatest collective savings based on the score, the hidden point value, and the bid price. The network solution has an optimal balance between costs and benefits for the collective value in the studied case. Flexibility service providers, on the contrary, must aggregate a large amount of consumption curtailment services to beat the efficiency of the investment. Thus, in this case, flexibility is not a good option. However, the methodology and the online tool developed can sustain pedagogy on local flexibility and help actors improve their proposals to the DSO.

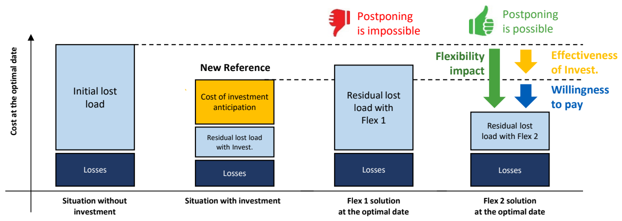


Fig. 11: The cost balances with investment or with different flexibility services (Paper 719).

Paper 0757 demonstrates the potential benefits of integrating demand forecasting, flexibility service providers and system network models. Western Power Distribution (WPD) proposes developing an automated tool as part of a project termed the Electricity Flexibility and Forecasting System (EFFS). EFFS interfaces with the market platforms to request flexibility requirements, receive the available flexibility and returning the final selection of services. Thus, the optimisation process is distinguished into two stages: procurement and selection. An optimisation algorithm takes place for the optimum selection of services based on a ranking system where for each service, a total score is calculated. Finally, a validation process is launched. The EFFS optimisation algorithm runs power system analysis and contingency analysis to determine network constraints and select optimal flexibility services to resolve the constraints. The EFFS tool has the potential to be further developed into a fully automated end-to-end system that could be used as a real-time system tool. It could be utilised to identify future network constraints in a distribution network or to process flexibility services and select the optimum solution.

Primary Substation	Primary Transformer Loading (in %)	Remaining Constraint (MW)
Eggbuckland	83.2	0.74
Longbridge	<75	None

Fig. 12: Example of network constraints reduction after selecting flexibility in services in the UK test case proposed by Paper 0757.

Paper 0956 deals with a platform focused on flexibility for integrating RES. The EU platform METIS II is capable of increasing the resolution on electrical transmission and distribution grids with the detailed representation of European distribution networks using archetypes and climatic zones. Concerning the EUCO3232.5, both load shifting and EV charging flexibility are activated to reduce distribution network generation curtailment and load shedding. Thus, flexible distribution network assets help to integrate more renewables without having to invest further in infrastructure. Heat pumps and hot water demand have a limited contribution to reducing renewable generation curtailment because of seasonality. Anyway, besides many restrictions, the flexibility helps reduce the generation curtailment by 37% and load shedding by 100% in some of the examined networks.

Scenario	Load shedding (TWh)	Generation curtailment (TWh)	Load shifting (TWh)	EV load shifting (TWh)
No flexibility	12.5	71.0	--	--
Flexibility	10.1	68.3	3.0	1.6

Fig. 13: Impact of flexibility on reducing load shedding and generation curtailment in the EU (Paper 0956).

Paper 1040 proposes a DSO portfolio composition method to secure flexibility in the cooperative operation with an aggregator. The proposed method simultaneously reduces the computation time and satisfies the technical constraints. Since the DSO does not control individual DERs, neutrality in the cooperative operation with the aggregator is guaranteed. In the portfolio composition process, the DSO provides for each zone the flexibility type required for the target epoch. The aggregator provides the amount of available flexibility and the unit price for each zone, which the DSO considers to compose the flexibility portfolio of the distribution system. This approach can reduce the complexity of the portfolio construction.

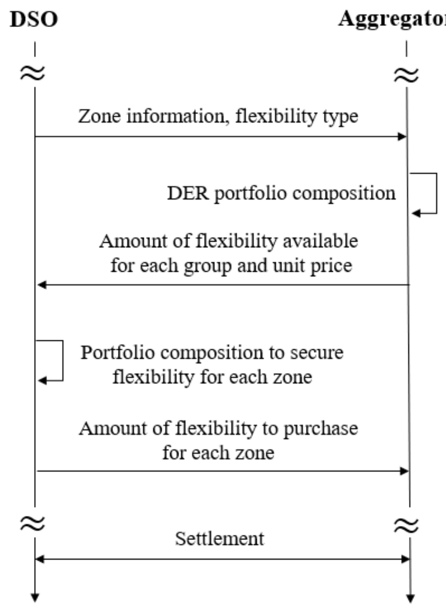


Fig. 14: Flowchart of the cooperative approach between DSO and Aggregator for the flexibility portfolio (Paper 1040).

Paper 0867 analyses the worth of flexibility from the reliability point of view. Flexibility with respect to the reliability of supply means that the distribution utility agrees with the end-customer. The customer takes the risk of long interruptions but receives monetary compensation for them. The economic value of flexibility can be significantly high in sparsely populated rural areas with challenges in supply reliability (risk of major storms) and depopulation. By selecting the best few per cent of all customers to the flexibility agreement, a relatively high share of network investments can be reconsidered from the perspective of scheduling, placement and technological choices of the network renewal. However, the results support a preliminary estimate that flexibility targets (customer nodes) have to be defined by the utility. Otherwise, if customer nodes are selected randomly, network areas committed to flexibility are not uniform enough to take them effectively into account in the long-term development of the network infrastructure.

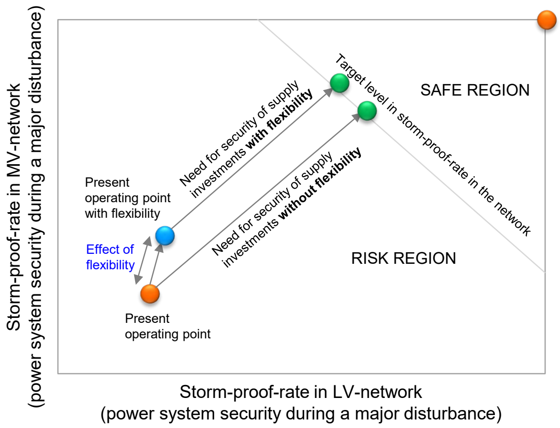


Fig. 15: Two alternative paths from the present operating point to the level where the network has to be renovated to satisfy the requirements of the law (Paper 0867).

Flexibility is not infinite and, if used by DSO for distribution network operation and planning, there will be less flexibility for the TSO. TSO/DSO integration is crucial. A compromise must be found between the investment cost minimisation and the maximisation of distribution flexibility for transmission services. **Paper 0976** gives an original contribution on this crucial point with an algorithm that supports cooperative (but decoupled) planning for both distribution and transmission systems. The planning strategy for distribution networks can explore several planning options to minimise the operational/investment costs and maximise local flexibility for the provision of services to the upstream transmission network. The complex procedure explores different options regarding the required regulation reserve for transmission services and optimises the distribution planning. The cooperation between system operators is expected to be simple and efficient since the identified distribution planning options can be negotiated with a limited exchange of standard and non-sensitive information. The proposed algorithm avoids solving a fully coupled joint optimization problem while still considering the interactions among different voltage levels.

Paper 0543 is an original contribution that shows a different approach to planning based on the extensive inclusion of communities and open data sharing. Distributed open data is key to planning how the electricity distribution network develops to accommodate different visions of local stakeholders. The paper describes a real application in the UK that trials open data, visualisation tools and common languages for mutually sharing disparate data sets associated with distribution future energy scenarios (DFES). One example of specific feedback came from the local industry about plans to switch fuel in glass furnaces. This resulted in a special sensitivity on the load impacts of large industrial fuel-switching strategies being carried out and included in the following year's DFES publication (DFES 2020).

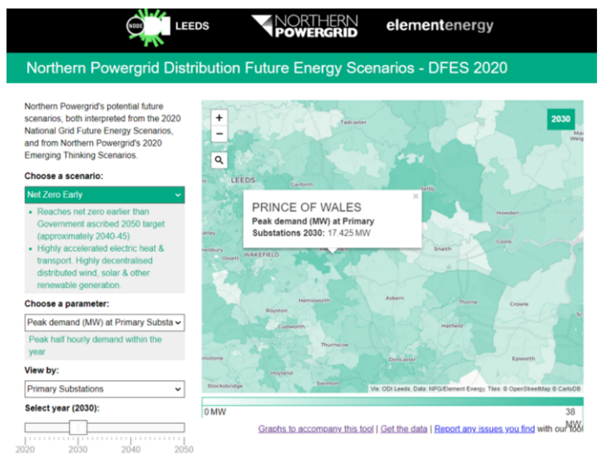


Fig. 16: Primary substation DFES view (Paper 543)

Paper 0483 is another high-level contribution that aims at giving distribution planners data to produce significant load patterns. In particular, the authors focused on the forecast of temperature because of climate change. The paper is particularly relevant for countries with power demand highly linked to temperature. The current practice for forecasting is based on historical data. **Paper 0483** first examines the adequacy of indicators based on historical data and suggests a methodology to anticipate future low and high temperatures better. The authors show that the current methodology underestimates the risk in the next decade linked to warm temperature levels. The study has shown that the estimation of very low and very high percentiles of the temperature distribution over a historical past 30-year period may not fully represent what could be expected in the following decade. The proposed approach to produce temperature time series seems to improve the anticipation of near-future conditions.

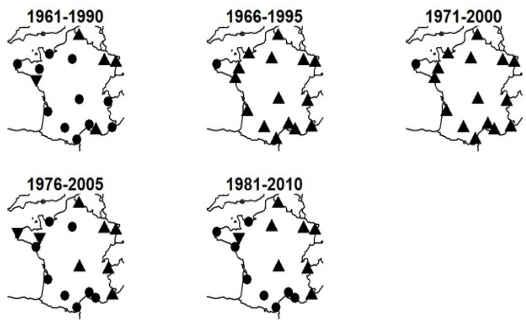


Fig. 17: Comparison of the frequency of higher temperatures than the 99.7% percentile estimated over 30 years in the following decade to that of each of the three decades of the considered 30-year period. An upward triangle means a higher frequency, a downward triangle a lower frequency, and a circle no significant change (Paper 0483).

Paper 0190 is an interesting example of long-term planning that uses network and non-network options for finding the optimal expansion plan. The uncertainty due to the variability of production and consumption pro-files and producers' arrival (date, technology, installed power, location) is considered. Since scenarios are randomly produced and optimized, the optimization is based on stochastic planning. More precisely, the optimization problem is a stochastic, multi-objective optimisation problem, with expensive-to-evaluate objective functions solved with the Bayesian optimization technique. The paper's main result is that the proposed technique can dramatically reduce computing time compared to Monte Carlo. The procedure is suitable for the application in real-world problems with many contrasting objectives and planning parameters.

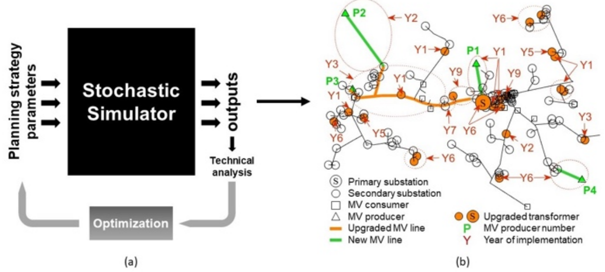


Fig. 18: (a) Illustration of the optimisation process of the input parameters of a stochastic simulator and (b) example of resulting network planning decisions for a given scenario and set of network planning parameters (Paper 0190)

Paper 141 presents a very good prototype that leverages customer times series to provide the grid planner with the information necessary. Furthermore, an analysis of how flexibility could be leveraged to alleviate the capacity needs is also available.

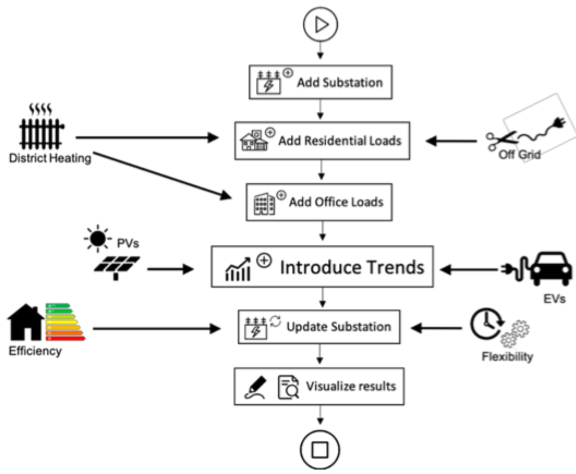


Fig. 19: Conceptual design of the tool proposed by Paper 0141.

Paper 0257 proposes an innovative holistic approach to planning that improves the traditional planning and development process. The proposed method is capable of identifying grid hotspots in future supply tasks. Providing and combining real grid and asset data with forecast scenarios into a multi-scenario analysis empowers grid planners to focus on hotspots. The resulting complexity of such a multivariate method is controlled by using the concept of hierarchical KPI navigation and aggregation carrying the planner to the most relevant grid issues. The tool will be applied to the entire Westnetz MV (E.ON) grid. Automatic optimization tools are still missing in the model, and their development will increase the model worth.

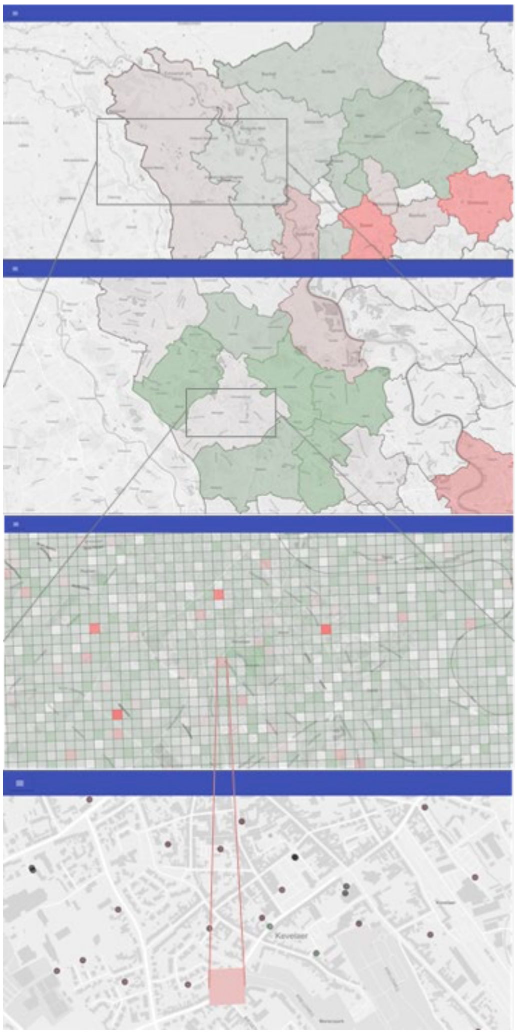
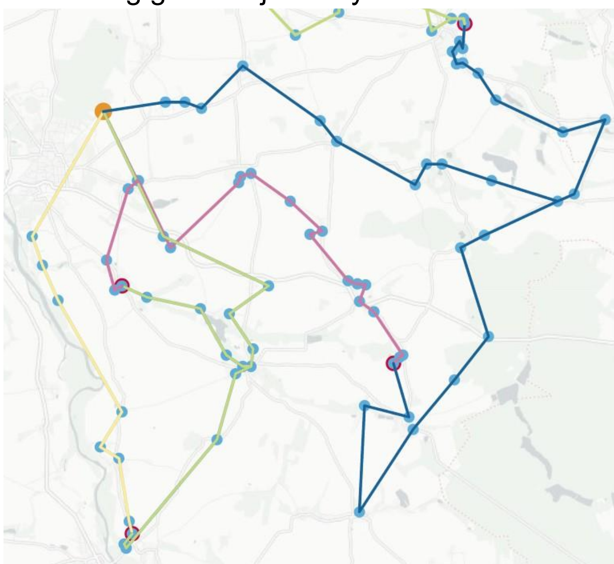
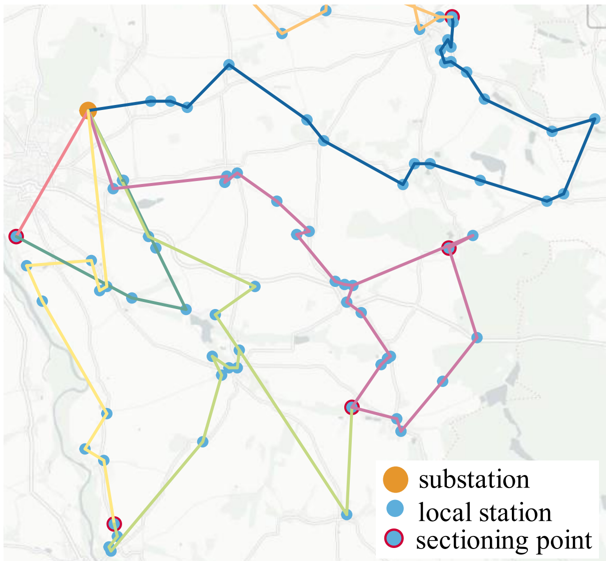


Fig. 20: Hierarchical Scenario Management as in Paper 0257.

Paper 0565 presents an ant algorithm that optimises the costs of a medium-voltage power network structure while complying with the electrical specifications for several given scenarios. The increasingly used holistic planning approach requires several criteria to be considered at the same time. Therefore, the given technology is extended for an application in multi-criteria optimisation. The criteria selected for this paper are cost minimisation, reliability maximisation, and minimisation of the number of sectioning points to increase network operation efficiency. Thus, optimisation provides a variety of solutions to choose from depending on individual preferences. The paper has been tested with a greenfield optimization. The use of multi-objective programming is very promising, but the algorithm does not explicitly consider uncertainty and the role of flexibility as a planning option. Anyway, the authors show that by using multi-objective-oriented algorithms, the decision making is more transparent, and planners can find a compromise among several contrasting goals objectively.



(a)



(b)

Fig. 21: Impact of different criteria in distribution planning: a) cost criterion and b) reliability criterion (Paper 0565).

Paper 0395 also describes a planning methodology for supporting the technical/economic analyses to choose interventions on the distribution network. The genetic algorithm exploits AI techniques for the multi-objective optimization of the grid configuration, aiming to optimize costs, quality of service and load KPIs simultaneously. The use of GA and AI for distribution planning is not original, but the algorithm developed is a very good step towards considering flexibility services offered by distributed energy resources as an alternative to traditional infrastructure solutions.

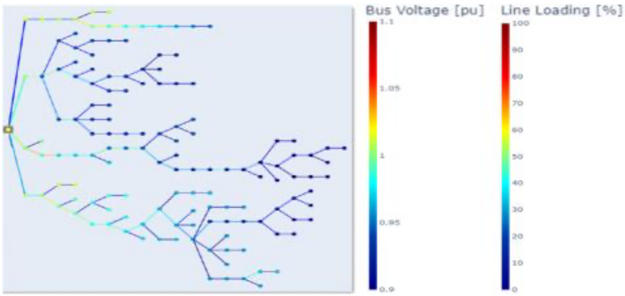


Fig. 22: Example of network optimization from Paper 0395.

Paper 0685 is a very good contribution to improving a typical automated network planning process, such as the cost estimation of new underground cable routes. The traditional approach of calculating these costs based on rough average cost assumptions fails to consider each individual case's specific geographical and geological conditions. It can therefore compromise the quality of network planning, especially when applied to heterogeneous supply areas. The proposed algorithm enables an individualized cost estimation for each possible new underground cable route using the least-cost path algorithm on a calculated cost raster, covering the whole supply area and including all relevant geological and geographical information. To this scope, the entire supply area has been divided into 334 million raster cells of 25 m2 each (5x5 meters). A new underground cable route cost is calculated for each cell, using as inputs mostly publicly available geodata from different sources. The developed algorithm enables an individualized estimation for any arbitrary route considering all relevant geographical and geological conditions. The accuracy of the model in the vast majority of the "normal" cable routes lies within +/-25% accuracy, providing reliable input for the MV network's automated planning and a useful tool for the daily business of operative asset management and engineering.

In the early phase of planning, an optimization algorithm can trace the least cost path between two points, avoiding using the most expensive pixels. The same approach is also used for more automated planning of MV distribution planning.

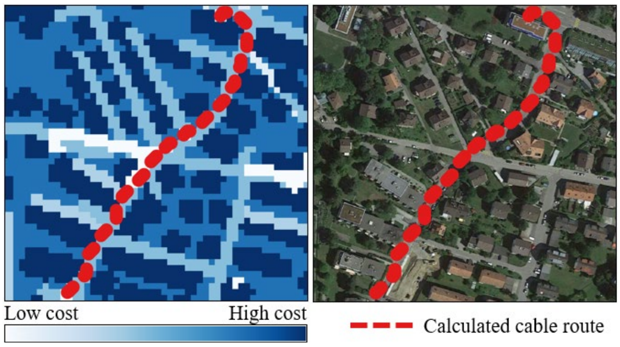


Fig. 23: Optimal route calculated in an urban area (Paper 0685).

Papers 0322 highlights the need for new tools and methodologies capable of assessing the impact of new loads. The paper uses the data from AMR to build a better load pattern that can be used to assess voltage regulation, and power flows in MV and LV networks. Furthermore, EV demand is included in the model with the complete electrification of heating demand in Denmark. The number of feeders and transformers expected not to meet the load, and the voltage criteria are significant. The voltage criterion is the most critical for 0.4 kV radials. The paper demonstrates the positive impact of flexibility that can reduce the harmful impact of new loads and electric vehicles.

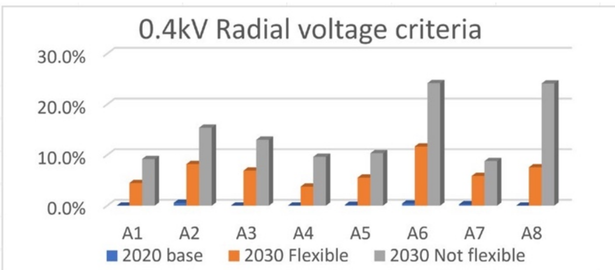


Fig. 24: The percentage of LV radials that do not meet voltage criteria according to Paper 0322.

Paper 0472 investigates the role of operating points in urban LV planning. Peak load and peak generation are considered assuming different scenarios for heat pumps, EV charging points, and PV generation. The peak load operating point is relevant for equipment dimensioning in the examined test case. The peak generation operating point is particularly relevant in networks strongly penetrated by detached and semi-detached houses in suburban areas. The paper considers innovative planning actions such as regulated distribution transformers (RDT), energy storage systems (ESS), and static or dynamic load and DG management systems. The voltage regulating measures are recommended the transformer substitution.

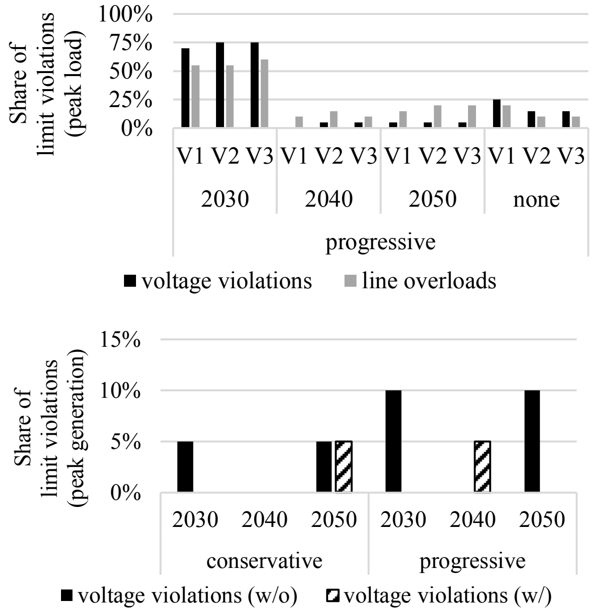


Fig. 25: Expected voltage violations for LV networks in different operating points (Paper 0472).

Paper 0552 proposes an online interface for distribution planning of LV unbalanced distribution networks. A stochastic load simulator generates accurate and tailored load profiles at a resolution down to one minute for a neighbourhood. New and upcoming load and source technologies, such as electric vehicles and photovoltaic panels, can be forecasted. The control strategy of demand with an accurate representation of tariffs can be used to plan, delay, or avoid grid reinforcements. If a user already has power time series (such as smart meter data), they can be used directly for power flow optimization and assess the worth of flexibility control.

Fig. 26: Example of undergoing node voltage drop and line overloading from Paper 0552.

The uncertainty associated with loading demand, generation, and even network elements can affect the results of distribution planning and make decision-making a too much risky activity. **Paper 0823** gives an original way to fix this issue regarding the French case by assessing the impact of models and related uncertainties. The method uses a Global Sensitivity Analysis to characterize the impact of any model on the decision criteria. Several modelling hypotheses are considered in the paper, and their impact on a French low voltage network is assessed. The dependence of the decision criteria on the models considered in the LV grid planning process is the main paper result. The methodology can assess the impact of models and related uncertainty when flexibility is used to operate LV distribution networks.

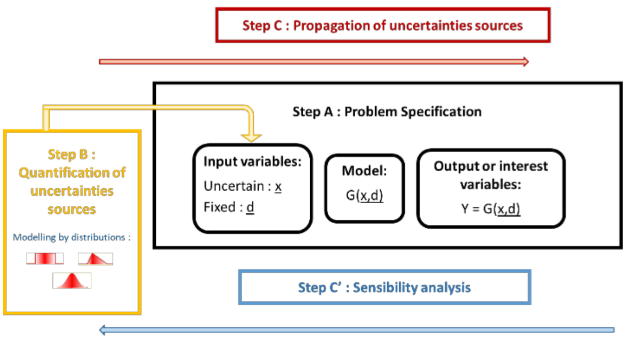


Fig. 27: The General Global Sensitivity approach used by Paper 0823.

Paper 1071 is another interesting contribution, including flexibility from loads with higher nominal powers and stochastic behaviour, such as electric vehicles and heat pumps. Conventional concepts of network planning typically do not consider the potential flexibility of newly introduced loads, which can lead to unnecessary network investments and oversized networks. For this reason, a methodology, which considers the possible flexibility potential of loads and uses a probabilistic approach to network planning is introduced and applied on a model of a real LV network. The proposed methodology utilises the Monte Carlo method for performing load flow analysis. The simulation platform developed integrates GIS data, Powerfactory and Matlab, and enables analysing a system with stochastic consumption and production. The potential impact of flexibility services provided by prosumers on distribution network operation is assessed. As part of the methodology, weekly quasi-dynamic Monte Carlo simulations are performed, thus including the unpredictability of consumption and location of individual loads in the planning process. Simulations showed that modernization would enable better utilisation of infrastructure and the reduction or postponement of investments.

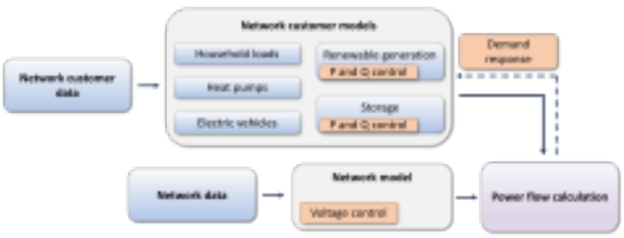


Fig. 28: The block diagram of the platform used in Paper 1071 for studying flexibility impact on LV networks.

Paper 0347 describes the process developed by authors for analyzing distribution in a German distribution network with suitable algorithms capable of detecting ageing and electrical usage issues. The combined results of a long-term infrastructure analysis and electrical analysis deliver various evaluation opportunities. Vulnerabilities regarding reliability on the medium-voltage level are revealed, and, for the low-voltage level, critical assets are discovered with a grid overview. A sound basis for short-term measures and the development of "optimized" medium- and long-term measures (including optimising the grid structure reflecting the dependencies between medium- and low-voltage levels) is proposed.

Paper 0406 proposes a methodology for expansion planning of systems with increasing participation of renewable generation, linking a long-term expansion planning model to a day-ahead operation model. The last enables adjustments in the expansion plan considering the uncertainty of the intermittent generation and the hourly operational constraints of thermal generation. The methodology was applied to an expansion plan of the Brazilian system, where the increase of wind generation would imply problems in the daily operation of the final years. The results show the importance of considering the daily operation constraints of distributed energy resources in long-term expansion planning.

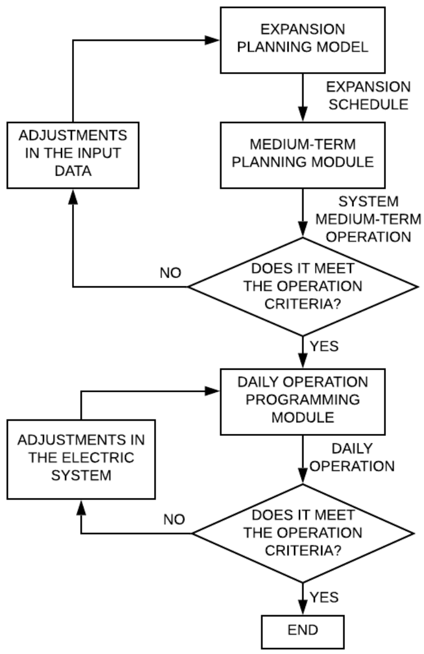


Fig. 29: Flowchart of the methodology proposed by Paper 0406.

Paper 0752 deals with developing synthetic network models for studying HV and MV distribution networks and their mutual interaction during faults in the presence of decentralised generation. Therefore, detailed mapping of the high-voltage level is crucial, but no holistic, publicly available grid data set is accessible for high voltage networks. Existing models are often simplified or, in real grid data, focusing on limited network sections with a lack of representativity. Synthetic grids can offer an alternative to this problem. Modelling synthetic grids aims to generate fictitious test systems but capable of representing characteristics of actual power grids. An approach to model current and future synthetic high voltage grids based on open data is developed. In addition, an existing method for modelling synthetic grids of the medium voltage level is integrated into the model to obtain linked synthetic MV and LV distribution networks.

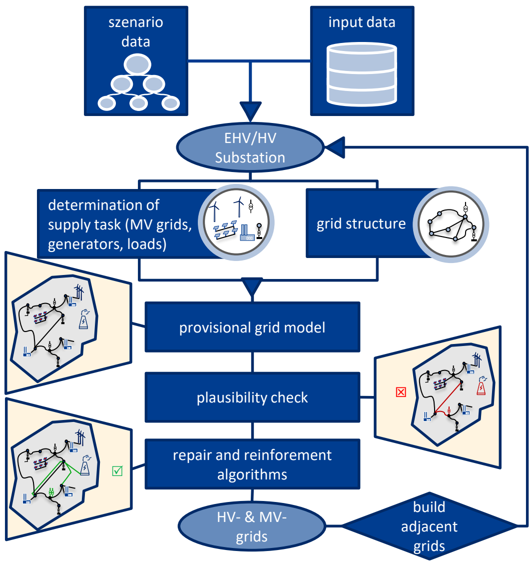


Fig. 30: The process to find the HV synthetic networks as in Paper 0752.

The energy transition will impact HV sub-transmission grids, namely 150 kV, concerning underground cables with a long life. Assets have a long service life, and therefore the correct choice of requirements for new cables is crucial for grid operators. The ampacity of HV cables put into service in the present impacts the target grid planned. **Paper 0777** presents a structured analysis procedure to establish the requirements for new HV cables for planning a target grid in Zurich. A reference power flow scenario with estimations on population growth and development of EV was established as starting point. According to the municipal structure plan of Zurich, the allowable build space for the future and, therefore, the maximum expected load is determined. Domestic, commercial and EV loads have been estimated for 2050 and distributed to the substations in the city. They were combined with corresponding load profiles to generate 24h load profiles. With the cable requirements obtained by load flow calculations, the Zurich 150kV target grid is being developed.

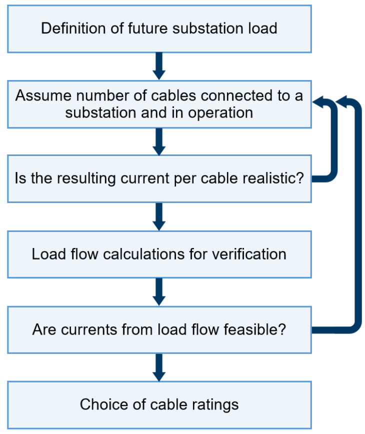


Fig. 31: The process to find the cable requirements used in Paper 0777.

One of the most innovative planning methods proposed in CIRED 2021 is the one in **Paper 0350** that combines traditional distribution planning with AI and Machine Learning (Q-learning approach). The effectiveness and feasibility of the proposed model are proved in practical applications with the aid of simple examples. The Q-learning model obtained several excellent alternatives, and the adjusted Q-learning model even obtained an identical scheme to that of the mechanistic model. The process of using ML in distribution planning is still at the beginning, but it is quite easy to see the benefit of a new approach in computing time and transparency of results.

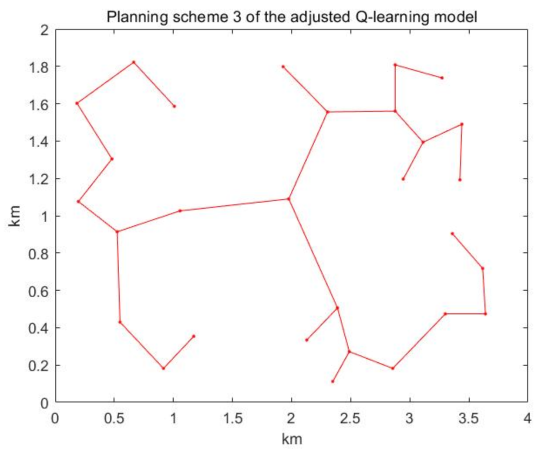


Fig. 32: Example of optimal distribution network discovered by a non-mechanistic algorithm (Paper 0350).

Sub block 2: Smart Grid Planning

The papers in the Sub block deal with the use of the smart grid in planning without the flexibility offered by service providers.

Paper 1059 proposes a new model for the operational planning of Smart Grid with DG generation interfaced with power electronics and study the instability of inverters connected to high impedance networks. The proposed method can evaluate the stability of a nonlinear and time-varying system. Therefore, it can be useful in evaluating the stability of nonlinear power electronic components at different grid connection points under changing conditions.

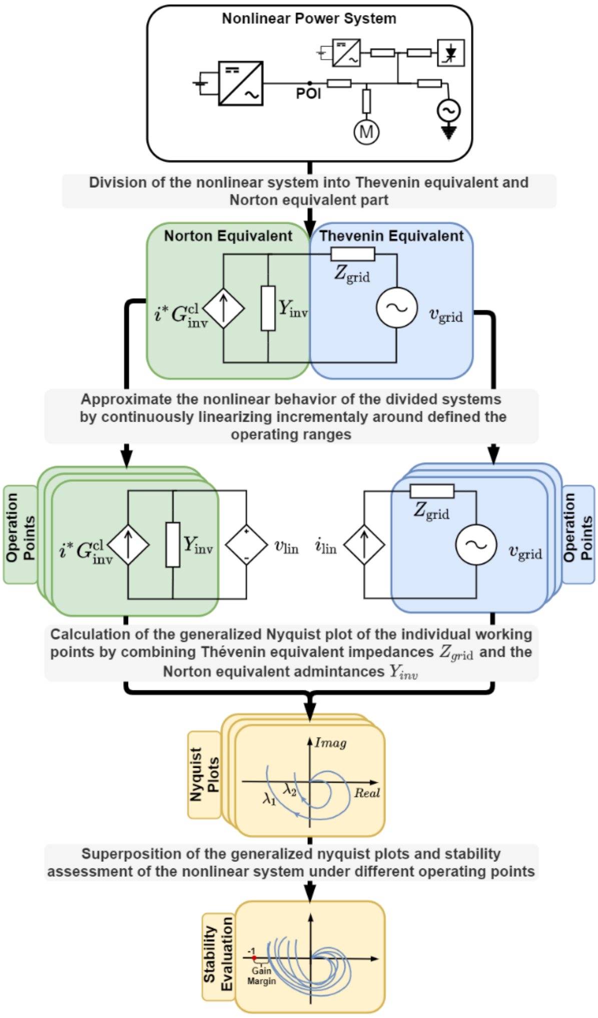


Fig. 33: The method proposed by Paper 0159 to evaluate the stability of non-linear and time-varying systems.

Paper 0518 is an interesting application of machine learning to solve dynamic network reconfiguration and avoid the generation curtailment of PV power plants. The impact on planning is evident since the non-network solutions used can avoid or postpone network investments without penalising the power producers. Dynamic network reconfiguration (DNR) controls the network topology by controlling sectionalizing and tie switches to reduce PV curtailment as changing the power flow in the network and the joule losses. The problem is modelled as a Markov decision process (MDP) and uses a deep Q-network (DQN) to solve it. DQN algorithm is a data-driven approach for MDP, so it does not require topology information, and this is an important benefit from machine learning.

Paper 1126 presents a process that allows a semi-automated analysis of cross-system KPIs of given Use Cases (UC) managed within a UC Management Repository based on the IEC 62559 and SGAM standard. The examples demonstrate how the SGAM framework can utilize existing domain knowledge as a Reference Designation System to compute quality indicators. Finally, a concrete example was given based on the i-Score methodology. However, the presented example shows that existing UCs can be analysed with minimum effort. Complementing single metrics on Smart Grid architectures, the SGAM KPI-Dashboard can be applied as an expert system to support the decision-maker by analyzing and comparing different options.

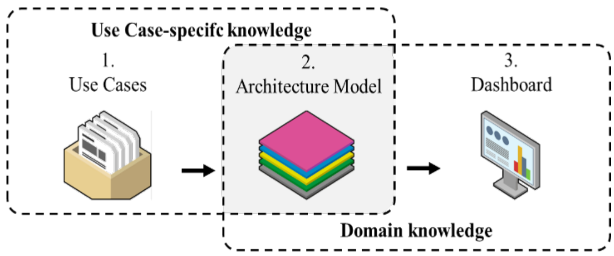


Fig. 34: The overall process proposed by Paper 1126.

Paper 0353 proposes the use of autonomous *web-of-cell* (AWoC)*,* a new connection scheme that aims to connect RES and energy storage to the grid. The "gathering and dispersing" multi-state control operation mode of AWoC based on coupling point and tie-line control is proposed innovatively. The AWoC division can provide a reference for Micro-Grid planning. Thanks to its flexibility and expansibility, AWoC can provide a new idea for developing power systems under the trend imposed by the energy transition.

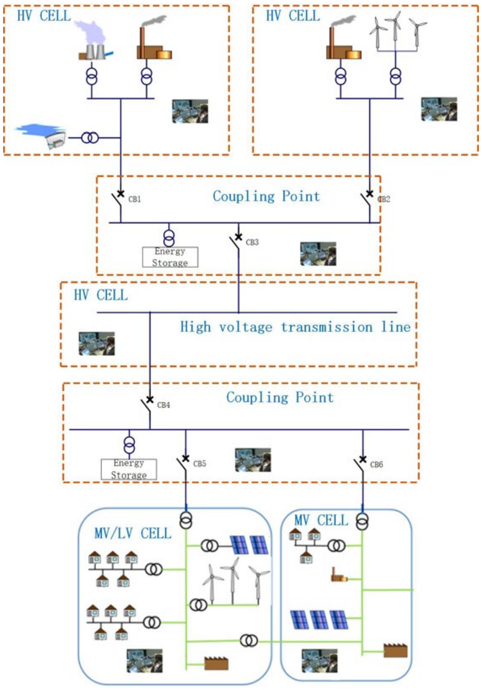


Fig. 35: Concept diagram of AWoC as proposed by Paper 0353.

Paper 0975 addresses the topic of sector coupling in local energy communities to increase the level of self-consumption. A residential subnetwork with installed photovoltaic systems and central storage connected to a low voltage network is considered a reference. An electrolyser, a fuel cell and a hydrogen pressure storage are added to the model, determining the global solution of the multi-period optimal power flow problem. Different households and photovoltaic power supply scenarios are analysed. Two cases (photovoltaic, battery storage vs. photovoltaic, battery storage, polymer electrolyte fuel cell) are analysed, and seasonal influences are considered for an optimization horizon of an entire year. One result is that the H2 storage reduces the maximum voltages, and it improves the design and operation of the system. Future works should extend the analysis to multi-energy systems excessing heat of the polymer electrolyte fuel cell to be integrated into the system and taking additional loads such as heat pumps and electric vehicles into account.

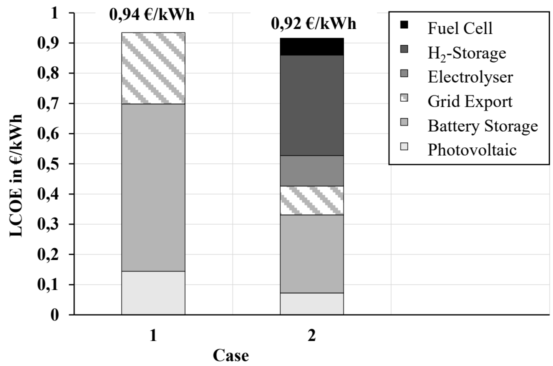


Fig. 36: LCOE in the multi-energy local energy community simulated in Paper 0975.

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

Papers in this subblock deal with allocating distributed resources and their use to solve specific network problems. A typical example dealt with by **Paper 0167** is the use of SVC in MV distribution networks. This paper proposes a strategy to optimize the performance of distribution networks through the optimal coordination among Stationary Shunt Capacitors (SSCs), Dispersed Energy Sources (DESs) and Static VAR Compensator modules (SVCs). Several objectives are merged in one multi-objective function with the weighted sum method. A theoretical process is used to calculate the weights adequately. The original contribution is the use of Grey Wolf Optimization that is a relatively new optimization algorithm. Various regular loadings are further combined to investigate the influences of varying loading conditions. The reactive power compensation using SVCs leads to major quality improvements of the nodal voltage with variations of loads.

Paper 0170 proposed another optimization algorithm to find the optimal allocation of capacitor banks (CB), distributed generation (DG), and automatic voltage regulators (AVR). The paper uses the hybrid statistical Rough Set theory and Grasshopper Optimization algorithm to optimise the distribution system optimal planning and automation. Multi-objective functions of power loss minimization and cost minimization are proposed for the optimal allocation and control of CBs, DGs, and AVRs simultaneously.

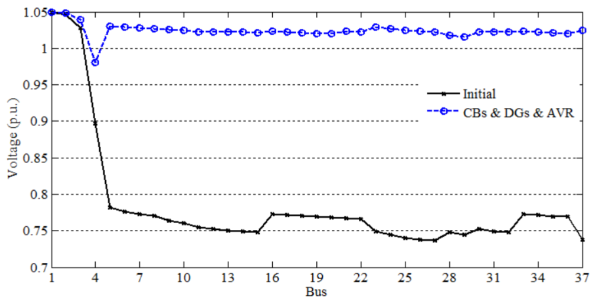


Fig. 37: The voltage profile of the TALA distribution network in Egypt with and without the optimization process (Paper 0170).

Paper 0280 proposes the optimal siting and sizing of distributed generation for resilience enhancement in power distribution systems against volcanic eruptions focusing on the lahar occurrence. The proposed methodology includes the concept of vulnerability curves to determine the unavailability of the distribution system elements. The Monte-Carlo simulation method (MCS) and a stochastic optimization problem (SOP) characterize the volcanic lahars and optimally allocate DG. The results reveal that DG is critical for the resilience enhancement of a PDS against lahars formed by a volcanic eruption. Preliminary results refer to the distribution network in Cotopaxi-Ecuador, which is vulnerable to lahars in the case of Cotopaxi volcano eruptions.

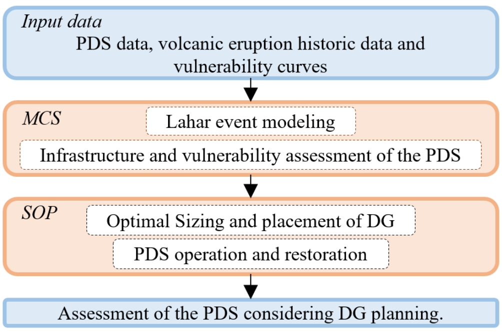


Fig. 38: The proposed methodological framework for resilience enhancement against lahars (Paper 0280).

Paper 0333 proposes the optimal allocation of switches in a distribution network to optimize the post-fault reconfiguration. The switch placement problem determines the optimal configuration of manual and remote-controlled switches (MSs and RCSs) and field circuit breakers (FCBs). The objective is to minimise the installation and operation costs of switches together with the reliability-oriented costs, which include the distribution company's lost revenue due to the undelivered energy and the regulatory incentives (or penalties) associated with service reliability indices. The paper demonstrates that it is essential to consider the placement of FCBs concurrent with that of MSs and RCSs. Modelling the malfunctioning in RCSs and FCBs is crucial in switch optimisation models. Finally, the selection of the reliability index and incentive rates in reward-penalty schemes are essential in imposing an effective incentive reliability regulation.

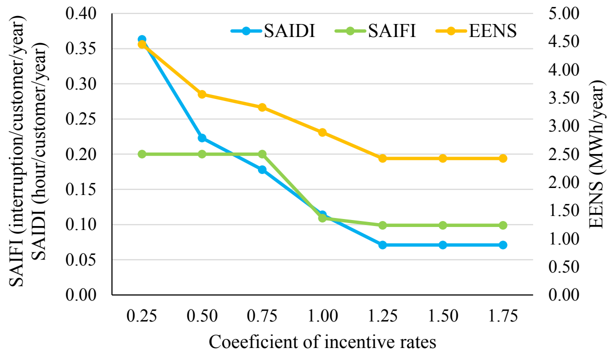


Fig. 39: Sensitivity analysis with reference to reliability incentive rates (Paper 0333).

The optimal allocation of energy storage is a topic that gained the attention of many researchers in recent years. **Paper 0459** deals with the algorithm differently and proposes a physic-guided algorithm instead of more traditional approaches that need better network observability and a large amount of data. The novel method for the distribution network voltage prediction based on Physic-guided machine learning modelling is the algorithm's core. The accurate model of the distribution network gives the power flow boundaries estimation. The estimated power flow boundaries allow finding the optimal size and control energy storage system.

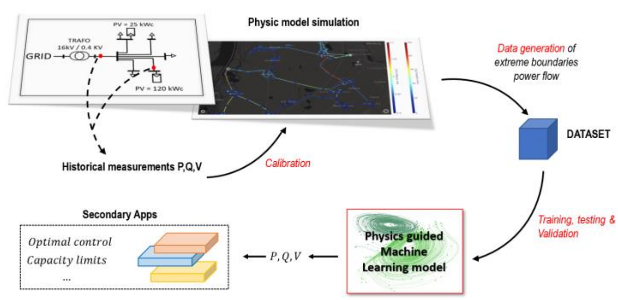


Fig. 40: Physic-guided machine learning modelling concept (Paper 0457).

Paper 0940 evaluates the techno-economic benefits of advanced PV forecasts for predictive congestion management at the distribution level. The effectiveness of predictive congestion management at the distribution level strongly depends on the congestion forecast accuracy, thus in PV dominated grid sections, especially on the PV forecast accuracy. Furthermore, the paper gives insights into the evaluation chain of PV-forecasting applications for distribution system operation. One important message is that the accuracy of (PV) forecasts must also be evaluated on the application effect. Four different performance indicators are proposed: PV forecast accuracy, congestion forecast accuracy, DER energy curtailment, and DER energy curtailment costs.

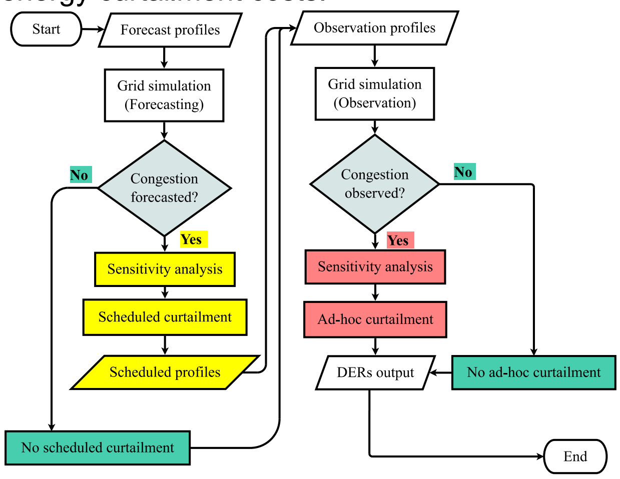


Fig. 41: Flowchart of the predictive congestion management method for one-time step (Paper 0940).

Paper 0562 addresses the topic of finding the optimal phase for the connection of LV loads that could be adapted to the connection of PV and EV charging points. A recommendation algorithm is proposed that is based on the improvement in neutral current minimization.

Sub block 4: EV Accommodation Planning

This Sub-block focuses on specific planning problems related to the connection to the distribution grid of specific user typologies: electric vehicles and charging stations. Topics span from mobility analyses to load forecast to the optimal location of charging infrastructure to hosting capacity evaluation to integrated connection solution.

Paper 0783 proposes a procedure to characterize charging stations based on relevant parts of their neighbourhood, defined as “service areas”. The procedure starts from the zoning plan of a German city to generate location-dependent features for several charging stations that allow a categorisation by the most dominant land use designation types in the neighbourhood. This categorisation is, in most cases, sufficient for analysing location-based influences as distinct user behaviour and power consumption patterns can be found for different categories.

Paper 1136 focuses on a specific charging process, i.e. work-based EV charging. The paper presents the results of a study about expanding EV charging at a 750-acre industrial/commercial site with over 5.500 employees, 6.000 parking spaces, approximately 10 MW of peak power consumption and 4 MW of CHP generation. A load flow analysis has been performed on the 11 kV distribution, and the impact of increased load from EV charging on the thermal limits of the main transformer has been investigated. Results show significant differences in EV charging capacity between peak winter and peak summer due to the lower availability of CHP during summer. Recommendations are also provided on how best to equip future distribution systems for increased EV charging.

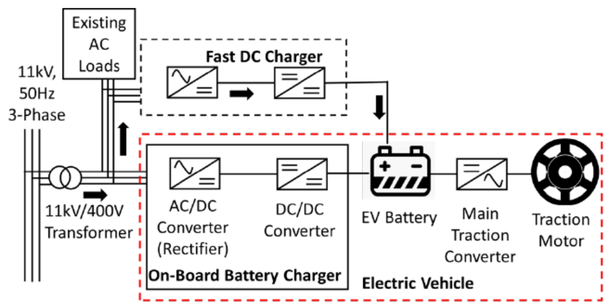


Fig. 42: EV charging scheme with DC fast charger as in Paper 1136.

To simulate the mobility behaviour of both private and commercial electric vehicles, **Paper 1043** proposes two different stochastic models; each one of the two relies on available public databases containing mobility behaviours of individual private drivers and commercial vehicles. The models provide a simulation of realistic mobility profiles and the extraction of respective charging schedules; the results of the two simulations are then compared to obtain the desired coincidence factor. Results show that the proposed models can represent private and commercial mobility, respectively. The resulting coincidence factors show differences depending on the settlement structure; in particular, metropolitan regions show a lower coincidence factor than other areas.

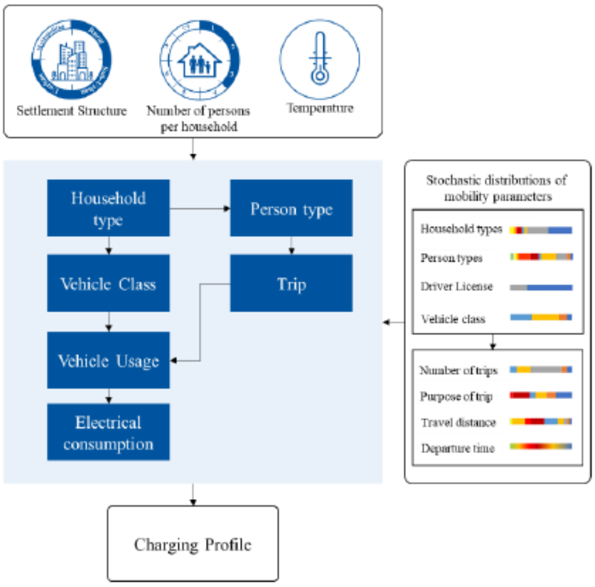


Fig. 43: Process of the simulation of individual charging profiles for private vehicles as in Paper 1043.

Paper 0161 examines the impact on electrical networks of the connections of service areas in motorways to develop EVs, coming from a joint evaluation between French main DSO Enedis and French TSO RTE. The first evaluations focus on light vehicles. In the future, analysis on lorries and coaches' needs will be developed; national roads will also be considered.

Paper 0107 analyzes the different effects in network planning arising from developing a comprehensive model for the EV charging process compared to adopting a simplified one. Different assumptions were implemented in the two case studies, with specific reference to charging losses and the charging method for the battery. Results show that simplified models lead to a higher load than the comprehensive ones, suitable for worst-case scenario planning. In contrast, the application of comprehensive models in a specific planning exercise leads to a significant reduction of the estimated cost for grid enhancement.

In **Paper 0123**, a probabilistic model is presented to estimate the primary substation load from the diffusion of electric vehicles. Authors analyze the differences between substations with mainly residential and working place/service type customers, determining charging peaks and energy patterns; the estimation is based on specific Helsinki data. Results show that residential charging load is more significant even if primary substations have relatively high service customers.

Paper 0226 presents a detailed analysis of the impact of EV charging points on a real MV distribution network located in Northern Italy. The study considers different deployment scenarios and alternative charging strategies; such operating conditions are then simulated to identify the most impacted parts of the network. The most critical components happen to be the MV/LV transformers due to the high nominal power of fast charging points.

Paper 0301 deals with estimating the load related to the charging process of vehicles for public transportation in 15 cities in Sweden. The study shows that the peak charging load is significant, eventually even bigger than the existing peak demand. Passenger cars and lorries account for most of it; the demand from electric busses is much less. To manage the network avoiding overloading conditions, a curtailment strategy has been defined. The hosting capacity of the grid for electric vehicle charging is then calculated based on the acceptable amount of curtailment in terms of hours per year to establish the need for new primary infrastructure.

Paper 0470 introduces a methodology to determine the load increase in a distribution system due to the charging stations for EVs. The process described begins with the appropriate distribution of charging points in the different voltage levels depending on the characteristics of the existing grid. The demand factor for each charging point is then determined. Finally, the demand factors are used to calculate the load demand in an exemplary LV distribution system.

Paper 1140 describes the results of Project PACE, delivered by SP Energy Networks, a UK Distribution Network Operator (DNO), together with the Scottish Government and local authorities. Project PACE is a pilot project demonstrating the benefits of DNO-led site selection and delivery of electric vehicle (EV) charging infrastructure for local communities. The project explores the strategic role a DNO can play in planning and delivering a public EV charging network. By a sophisticated site selection exercise, where optimum sites were identified, problematic sites were eliminated, and legal, planning and land rights agreements were agreed on upfront, optimum sites were identified, allowing significant time savings in the end-to-end delivery of the EV charging hubs.

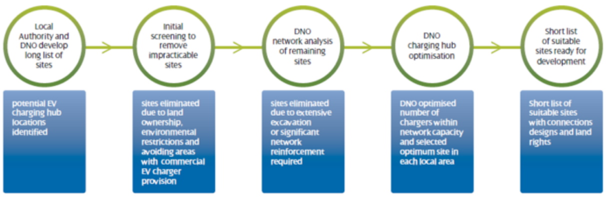


Fig. 44: The public charging infrastructure site selection process according to Paper 1140.

Paper 0832 introduces a methodology to identify potential locations for public charging infrastructure based on publicly available data. Information is derived from OpenStreetMap, and the quality of data is improved by neural networks, through which missing information is also predicted. The methodology allows determining location, capacity and individual suitability of georeferenced car parks. A simulation was conducted, based on a study case in Germany, in which approximately 400.000 car parks were extracted from OpenStreetMap and evaluated in terms of car park capacity and suitability.

In **Paper 0724,** the 'Take Charge' project is described, an initiative by Western Power Distribution to design and test a highly innovative standardized, pre-constructed and pre-packaged 33/11 kV compact connection solution to support large scale, high power, rapid EV charging at motorway service areas. In particular, the paper focuses on the methodology developed to identify a suitable site for the project trials and the process used to calculate the required electrical capacity for the new solution.

In **Paper 0025**, a model for estimating the EV hosting capacity of a given MV/LV network considering weather conditions (namely, temperature) is presented. A deterministic approach was developed and applied in a real MV/LV distribution grid in northern Sweden to support network planning activities. Results show that considering temperature impact by introducing a K coefficient leads to an approximate 30% reduction in hosting capacity during colder months due to the fast discharge of the battery.

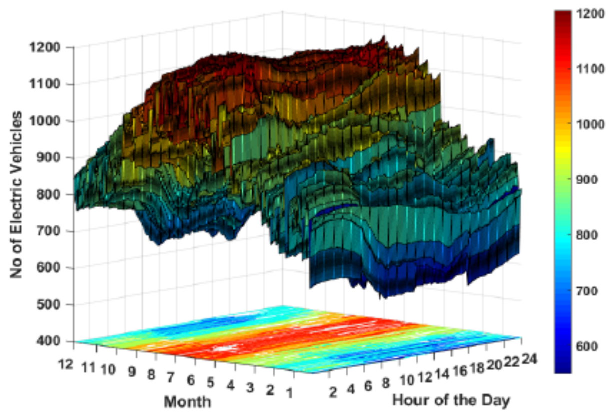


Fig. 45: Hosting capacity of EVs for 24 hours and 12 months according to Paper 0025.

Paper 1110 presents a model that estimates the investments needed to upgrade primary and secondary substations, reinforce MV and LV grids and connect new charging points, both normal and fast. The process starts from input data such EV as annual adoption curve, load peak values registered at DSO installations (primary and secondary substations) and a predefined set of parameterizable assumptions. Results show that EVs' full adoption and integration require an upgrade or reinforcement of around 20% of the entire MV and LV grid, representing around 18% of the required investment. The remaining share of 82% is associated with the new connections for charging points. A sensitivity analysis has also been performed, resulting in an estimated investment ranging from 19% higher or 5% lower. It must be noticed that smart charging technologies if used to support grid management and operation in real-time, may help to reduce such impact.

The potential scope of the discussion

The transition from deterministic worst-case analyses to probabilistic network planning has just started.

Yet, it already seems that an accurate evaluation of network criticalities requires 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
0025: Estimation of electric vehicle hosting capacity of a distribution network based on ambient temperature				X
0029: Risk of negative net consumption during backup-generator operation of LV distribution with solar PV				X
0046: Likelihood of overload due to connected solar PV				X
0064: Integrated approach for expansion and reliability planning of radial distribution networks with island operation of distributed generators				X
0107: Impact of different electric vehicle charging models on distribution grid planning				X
0123: Prediction of primary substation demands with EV charging in urban city environment: Case study Helsinki				X
0141: A time series based tool for capacity and flexibility forecasting in the power grid				X
0157: Multi-dimensional method for assessing non-wires alternatives within distribution system planning	X			X
0161: Characterisation of long-term demand on French motorways for long-distance mobility of EVs and evaluation of the impact on French distribution networks				X
0167: Optimum coordination of SVC modules in mv distribution systems (a real case study)				X
0170: Optimal planning and automation of distribution systems using a hybrid statistical rough set theory, and grasshopper optimization algorithm				X
0190: A Bayesian approach for the optimal integration of renewable energy sources in distribution networks over multi-year horizons			X	X
0226: Evaluation of the future impact of electric vehicles on the distribution network of Brescia				X
0257: Integrated network development and planning - from forecasting to grid screening and concepts				X
0280: Optimal placement and sizing of distributed generation (DG) in a radial distribution system for resilience enhancement against volcanic eruptions				X
0301: Risk of overloading and hosting capacity under charging load for nordic cities				X
0322: Grid planning MV/LV by combining smart meter data with greenhouse gas reduction changers as EV, PV and heat pump conversion				X
0333: Optimal distribution network switch planning considering malfunction of switches				X

0347: “Integrated electrical and long-term analysis” for the medium and low voltage grids of KWH Netz				X
0350: Study on non-mechanistic modelling in distribution network structure planning			X	X
0353: Research on patterns and planning method of autonomous web-of-cell				X
0358: A robust approach for determining future projections for the distribution grid based on national projections				X
0395: Development of an advanced planning tool for supporting the choice of optimal investments aimed at optimizing the infrastructure of power distribution systems in future scenarios				X
0406: Expansion planning considering daily operation programming of distributed energy resources				X
0459: A physic-informed machine learning approach for distribution network modeling: Application on optimal storage sizing and control				X
0470: Demand factor identification of electric vehicle charging points for distribution system planning				X
0472: Relevant operating points for future grid planning of urban low-voltage grids				X
0483: Climate change and the lowest and highest temperatures to be expected in the next decade				X
0518: DQN based dynamic distribution network reconfiguration for energy loss minimization considering DGS	X			X
0543: Using open data in planning the net zero distribution network				X
0552: Grid Scope – an online platform for better distribution system planning	X			X
0565: Multi-criteria optimization in automated medium-voltage network planning				X
0611: Achieving active distribution networks through operational and architectural aspects analysis: A methodology for long term planning				X
0685: Automated cost estimation for new underground MV cable routes through geoanalysis				X
0719: Flexibility as a cost-effective solution to postpone grid investment: request guidelines and ranking of proposals		X		X
0724: Site selection and assessment of required system capacity for rapid EV charging at motorway service areas (take charge project)				X
0752: Modelling of synthetic high voltage networks based on open data and integration into a modular synthetic distribution grid generator				X
0757: Utilising forecasting time series data and flexibility services to manage distribution networks				X
0777: Establishing HV cable requirements to develop an urban 150kV target grid				X
0783: Analysis of the service area of public charging stations for electric vehicles in urban areas				X
0793: Flexible planning of integrated energy systems under long term uncertainties				X
0823: Sensitivity of LV grid planning to load modelling		X		X
0832: Georeferenced determination of the potential of public charging infrastructure				X
0867: Value of customer flexibility regarding reliability of supply in the rural area electricity distribution		X		X
0940: Techno-economic assessment of PV forecast accuracy for a predictive				X

congestion management at the distribution level				
0956: Quantitative assessment of the role of flexibility measures in the integration of renewables using the upgraded METIS platform		X		X
0975: Multi-period optimal power flow in low voltage grids for a high degree of self-sufficiency		X		X
0976: Planning of distribution networks considering flexibility of local resources: how to deal with transmission system services		X		X
1040: Techno-economic approach of appropriate flexibility portfolio for distribution system operators (DSO)				X
1043: Simulation of private and commercial e-mobility charging behavior to reassess diversity factors for distribution grid planning				X
1059: New method for evaluating the stable operation of inverters in the planning phase using impedance-based stability criterion				X
1071: Evaluation of potential impact of load flexibility on LV network's operation as a part of distribution network planning		X		X
1110: Modelling the impact of electric vehicle in power distribution grids from a DSO perspective				X
1126: IEC 62559-2 use case template-based smart grid architecture analytics				X
1136: Expanding EV charging capacity in distribution networks: a case study for charging EVs at work				X
1140: DNO-led site selection for public electric vehicle charging infrastructure				X

Block 4: Methods and Tools

Sub block 1: Load/Generation Modeling and Forecasting

Paper 0033 presents a method to determine the individual demand of the average residential user using probability distribution functions to solve an LV network with Monte Carlo method scenarios. The statistical user demand characterization allows establishing LV distribution network power scenarios, considering various DG penetration levels, and carrying out electric current calculus, network node voltages, electric losses, and obtaining results with a statistical distribution.

An aggregate load model is presented in **paper 0084**, considering the peculiar characteristics of 210 European regions hourly along one year from the perspective of the high, medium, and low voltage levels. The proposed load model is used to understand better the influence of regional characteristics on voltage recovery during a short-circuit event, as well as the static point of voltage collapse. The conducted study demonstrates that regional differences in the composition of demand highly impact local voltage stability

Paper 0126 presents a stochastic modelling approach based on Markov chain Monte Carlo simulation to model the aggregated EV load profile and calculate the overloading probability of the distribution transformers. Historical data of seven different charging stations have been used to develop the model. The DSOs could use the proposed methodology for planning their network development.

The charging behaviour at public charging stations regarding temporal and location-based dependencies is examined in **Paper 0082**. Load profiles for typical days of the week and characteristic land uses have been created for public AC charging stations. The application of these load profiles is suitable to estimate the impact of a larger number of charging stations on medium and high voltage grids. Moreover, the distribution of plug-in events can provide input data for stochastic models valid at the LV level.

Three different charging location types were analysed with regards to charging flexibility and simultaneity factors in **Paper 0247**. According to the simulation results, due to the high level of flexibility, the use of charging management systems seems to be more effective for locations of the types “Courier and Parcel Service” and “Employees Parking Area” than “Shopping Centre” one.

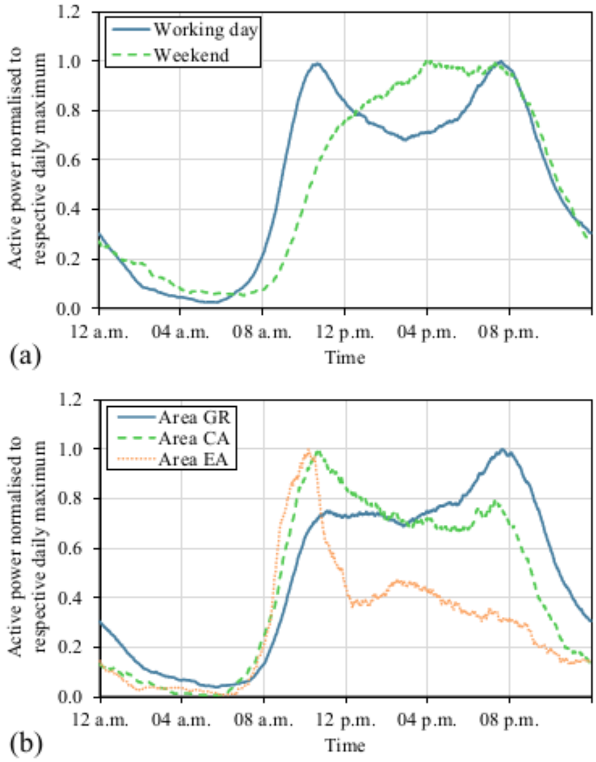


Fig. 46: Average daily load profile for a charging station concerning (a) the day of the week, (b) dominating land use type, according to Paper 0082.

Paper 0326 proposes a method to analyze the smart meter data collected for each customer and the attribute information to calculate representative profiles. Then machine learning is performed to generate a regression tree that allows estimating the maximum power in the connection point. This makes it possible to design LV distribution with higher accuracy than the conventional method.

A method to model households and commercial loads on the level of individual buildings is presented in **Paper 0428**. Geo-referencing, building footprints, points of interest, and land uses for the area under investigation are combined to georeferenced socioeconomic data. Then consumers are allocated to individual buildings, and load time series are assigned. The calculated loads are aggregated to match the supply area of a German distribution grid operator to compare the modelled data with the measured load time series.

Paper 0454 proposes demand and generation forecasting models for distribution systems, each employing a different artificial neural networks architecture. The models have been developed on real data of an Austrian distribution system. The adaptability of the models to the changes in demand during the Covid-19 lockdown is investigated.

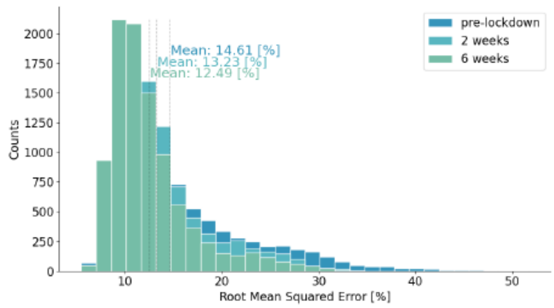


Fig. 47: Evolution of forecasting errors during the lockdown, according to Paper 0454.

An approach to model the forthcoming electrical flexibility and energy demand of electric vehicles and to analyze future grid loads and the potential of different types of load management is the **Paper 0508** focus. The basis of this approach is the detail of load and driving profiles. The energy demand is derived from historical user data. The plausibility of the generated load profiles is demonstrated in a real application.

The widespread deployment of DER provides challenges in both real-time operational and long-term planning situations, some of which can be mitigated using time-series data collection and forecasting. In the **Paper 0528** investigation, three artificial intelligence forecasting methods, AutoRegressive Integrated Moving Average (ARIMA), Holt-Winters Exponential Smoothing (HWES) and Box-Jenkins Adjusted ARIMA (BOXJ), are evaluated for their relative effectiveness in real-time and long-term situations using various datasets from UK electricity industry innovation projects.

Paper 0510 deals with EV charging infrastructure modelling. The model is based on mobility behaviour and predicts charging processes. For scenarios with more than 20 charging points, parameters of the grid load (e.g. simultaneity factor, load profile) are predicted to be used in the planning process of charging infrastructure in cities and suburbs.

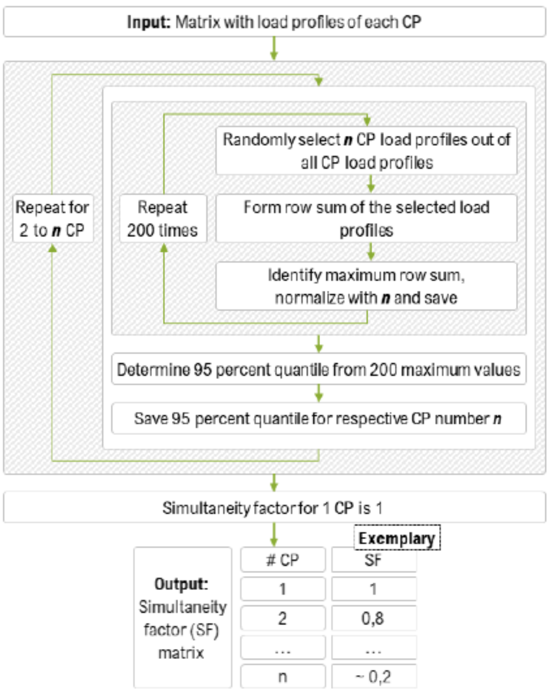


Fig. 48: Determination of simultaneity factor of grid load including EV contribution, according to Paper 510.

The research conducted in **Paper 0520** shows significant errors for power forecasts on the distribution level. The study also quantifies the effect of various influencing variables on forecast accuracy. The forecast horizon and aggregation level dependence on the forecast quality is evident, and forecast errors could be significant. If neglected, they can lead to an underestimation of the probability of critical situations.

Paper 0532 applies interval optimization to schedule a multi-carrier system while considering the uncertainty of photovoltaic (PV) energy generation, represented by a predicted interval obtained from a non-parametric distribution. At the same time, the quantile function is estimated to predict the distribution. The proposed method is applied to the data set of an industrial site. The simulation results show that the forecasting is reliable to obtain predicted intervals for a PV system.

The assessment of the changes in electricity consumption when a residential customer switches to a heat pump and the evaluation of the relevant impact on the distribution grid is the **Paper 0556** goal. A data-driven approach was adopted. The hourly load measurements of 5.000 customers for three years from a suburban area and of 14.000 customers for six years in a rural area were used for the study.

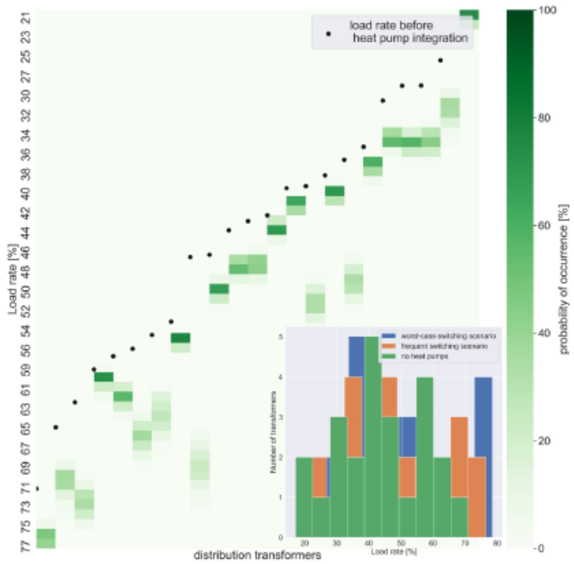


Fig. 49: Load rate at suburban distribution transformers, as in Paper 0556.

Paper 0581 presents a method for decoupling the injected power by photovoltaic systems in an LV network from the total load measured at the transformer. This makes use of solar irradiance information and provides the injection profile and the actual power consumption in a given feeder/phase. Based on uncorrelated series, this method allows forecasting these decoupled profiles and using them for network planning and management.

Paper 0631 considers deep neural networks with convolutional and recurrent layers to investigate the inclusion of various data types as inputs to a load forecasting model by evaluating 24-hour ahead predictions of electricity demand. Using two case studies in Durham, UK, this paper evaluates the benefits of including temporal and meteorological data and proposes a novel approach to incorporating social media data into a load forecasting model.

A methodology based on spatial regression associated with transport modelling to obtain databases and heat maps with flow information of EVs and their State Of Charge (SOC) is presented in **paper 0621**. With the results obtained, the streets with the highest flow of the lowest SOC can be superimposed to determine places with greater attractiveness and the need to install public charging stations.

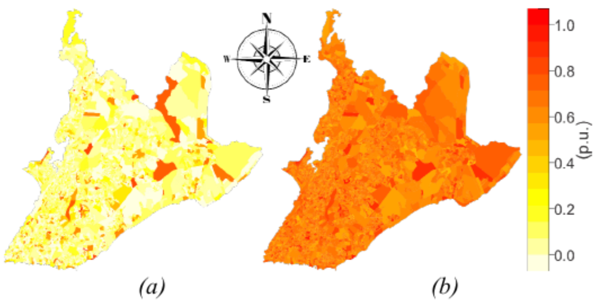


Fig. 50: Spatial distribution for global penetration EV iEv40: (a) 7%; (b) 65%, according to Paper 0621.

A domestic electricity demand forecasting model based on detailed physical model simulations has been presented in **Paper 0636**. In this study, key factors that influence household electricity consumption in the UK have been investigated. The simulation model maps occupant activities to appliance use. The study results are used to analyse the impact of energy efficiency schemes and demand response on the grid and the planning and operation of district-level low-voltage grid considering the flexibility offered by the houses.

The authors of **Paper 0690** implemented an automated algorithm that enables an individualized forecast for undeveloped areas, considering the current load and customer density of each building zone as indicators for its future development. The new automated approach increases the forecast's accuracy, providing reliable input for the automated planning of the medium voltage network and a useful tool for the daily business of operative asset management and engineering.

Paper 0848 presents a generic agent architecture aiming at holistic modelling of human activity based on cognitive ergonomics work. This architecture, applied to residential energy consumption simulations, allowed the generation of coherent load curves at both individual and aggregated levels. This model was extended to simulate EV use and charging profiles for each EV present in a given population. This EV model still lacks validation with a good data set, but its ability to reproduce aggregated data from an emergent bottom-up perspective has been verified.

A model for forecasting disruptive events, such as the COVID-19, is described in **Paper 0895**. As there is no historical data, the authors propose a novel source of information: media monitoring, complemented by observation of other countries' load evolution. The complete model uses a customized collaborative technique (Multi-Task Learning) designed for lack-of-data problems. Test results show that this approach successfully captures consumer's perceptions before their actions, anticipating the impact of abrupt moves and offering precise and reliable forecasts.

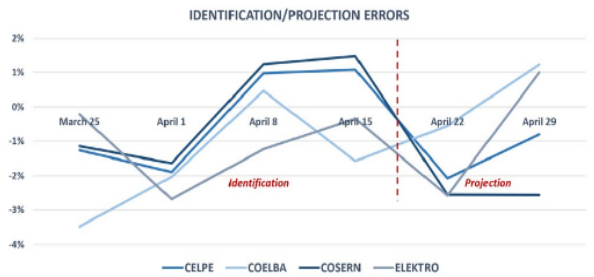


Fig. 51: Brazilian COVID19 Response, errors % with reference to the model described in Paper 0895.

Paper 0968 deals with Enedis methods to update the French estimation method of thermosensitivity for the mass market using the smart meters and “dynamic” load profiling. Accurate estimations will greatly affect forecasts, network planning and markets. France enforces a capacity market as an incentive for electricity production investments since 2017. Its purpose is to reduce the risk of failures during peak loads.

Within **Paper 0971**, the authors present an econometric analysis to improve the understanding of the development of distributed power sources (DPS) over time and across the different French territories. Four different segments were defined and studied, focusing on solar and wind energies and distinguishing them overpower and voltage ranges. With such forecasting models, Enedis had the opportunity to improve regional planning of DPS connection activities.

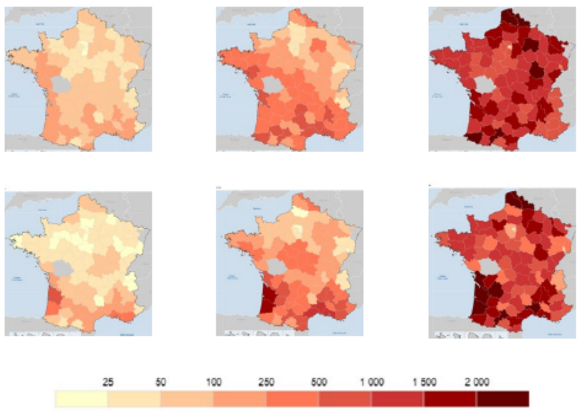


Fig. 52: Power capacity evolution from 2020 (left) to 2050 in a standard scenario (centre) and very favourable scenario (right) for low-voltage PV (top row) and large PV (bottom row) as in Paper 0971.

Smart-meters data and, more generally, IoT devices are now widely deployed and can enable techno-explicit models for long term forecasting, which are the focus of **Paper 0994**. Indeed, these models allow for studying sensitivity under a single parameter change. Furthermore, they are explainable and can account for the effects of rapid transitions of any type. This is especially useful to assess politics and public funding.

Paper 1045 presents the solutions on renewable energy forecasting proposed by the Horizon2020 Project Smart4RES. They are based on the latest progress in meteorology and original use of data science (combination of multiple data sources, data-driven approaches for trading and grid management). Solutions such as flexibility forecast of distributed resources and data markets are oriented towards value for power system stakeholders.

Sub block 2: Network Modeling and Representation

Paper 0039 gives a detailed analysis of the radiation terms in the heating balance for overhead conductors. The terms in the radiation balance determine the rating of an overhead line for use in dynamic line rating schemes. These radiation terms are often not considered since there is a relatively big uncertainty. The available knowledge and the different uncertainties are summarized, for radiation from the environment reaching the conductor, for thermal emission from the conductor and heating of the conductor due to direct and indicated solar irradiation.

The analysis of the behaviour of an Active Distribution Network and the analysis of the properties of common equivalent model types and procedures for their parameterization using operational measurement data is carried out in **Paper 0452**. In determining equivalent models, the properties and conditions for the parameterization of the quasi-stationary nonlinearity are discussed in the most common equivalent model types in literature, the black-box models based on artificial neural networks (ANN) and the grey-box models based on parametric models.

Paper 0560 presents a method to find the corresponding LV substation, phase and feeder of a given Energy Box using only its voltage and active power series, along with measurements from a sensor at the substation. The method has been applied to two real Portuguese LV networks, for which a preliminary analysis of the energy balance is also shown.

A methodology for assessing the share between the flexibility used by the LV system and the residual flexibility available for other uses is presented in **paper 1093**. It has been assumed that the LV networks are equipped with an energy management system to assess the flexibility needed and available. The energy management system is a multi-agent system capable of handling the small resources' flexibility with a master-client scheme that mimics a possible aggregator-client link. An exemplary Italian LV distribution network is used to test the procedure.

In **Paper 0952**, a comparison of the needed network reinforcements of a distribution grid considering the static seasonal and the dynamic current ratings for overhead lines was carried out. For this purpose, the different current ratings for the lines of a real high-voltage distribution grid have been calculated in network planning. Synergies between the static seasonal and the dynamic current ratings and dynamic curtailment, and an economic evaluation of the different combinations have been presented.

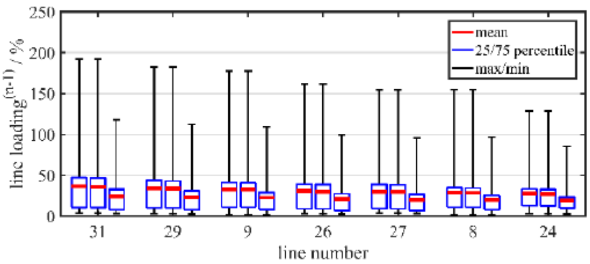


Fig. 53: Comparison of the line loading in (n-1)-state using the nominal (left), static seasonal (middle) and dynamic (right) current ratings as in Paper 0952.

Sub block 3: Load Flow and Short-Circuit Calculations

Sub block 3 deals with the real core of network planning: electrical calculation performed to determine the load conditions and all other relevant parameters of the state estimation, such as load factors, voltages, currents, etc. Two main focuses may be outlined for the papers presented: the Smart Meter data use and the deepening of the knowledge of LV grids.

Paper 0412 proposes a methodology to combine two different ways to analyze distribution systems: a system study software, OpenDSS, and a real-time simulation environment, named RTDS. OpenDSS covers a wider range of study subject areas in more detail, while RTDS allows more detailed attention to the smaller portion of the study subject area. The connections between the two environments were established through various inter-process communication methods, namely COM interface and TCP socket communication. The effectiveness of the proposed method was tested on two example circuit simulations, the first one representing a trivial circuit for the purpose of proof of concept, the other being the IEEE 13 Node Test Feeder System. The maximum error was less than 0.2%, showing the method achieved acceptable performance.

In **Paper 0127**, a calculation approach to calculate peak powers and diversity factors in unbalanced three-phase four-wire LV grids is presented. Worst-case scenarios are investigated for under- and overvoltage, loading of lines and utilization of MV/LV transformer, and maximum voltage unbalances. In the case of under- and overvoltage, additional power flow calculations were needed. The results, that have been validated against probabilistic simulations, show that the assumption of a balanced power flow may lead to significant errors, the adoption of new approaches like the one exposed may increase accuracy in grid planning processes.

Paper 0626 benefits from smart meter data to deal with the typical distribution problem of LV feeder mapping, implying the knowledge of the connectivity model, i.e. the whole set of connections between consumers and their corresponding transformer feeder. The paper proposes Feeder Mapping (FM) algorithms developed to resolve the connectivity model based on AMI time series data. Algorithms that exploit energy conservation, such as Mixed Integer Linear Programming, Genetic Algorithms and the Colony of Ants, have been developed and evaluated. A Load-Flow model using the derived connectivity models and based on the Backward-Forward Sweep is proposed, integrating the Fortescue transform for handling load imbalance. Results proved very accurate through a limited number of iterations with the load on each line, the losses through the neutral wire and the voltage drop in each node.

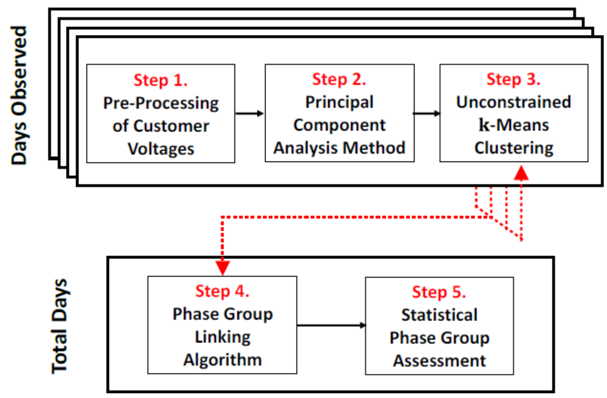


Fig. 54: Methodology proposed in Paper 0568.

Paper 0568 describes a methodology to automatically detect the customer phase grouping in a given PV-rich LV feeder without the need for prior knowledge. The approach is based on time-series voltage magnitude data extracted from single-phase smart meters and relies on the Principal Component Analysis (PCA) method and an unconstrained kk-means clustering technique. The approach has been tested on a realistic Australian LV feeder hosting 29 single-phase customers, with PV penetrations ranging from 0 to 100%. Results show the effectiveness and accuracy of the proposed phase grouping approach in allocating the customers to their correct phase group without or with PV (even with 100% of PV penetration). It must be noted that the time series of smart meter data needed to perform the grouping proved to be limited both in terms of history and in terms of hours per day.

Paper 0499 summarizes the results of several research projects performed in Salzburg Netz, describing a GIS-based system for analyzing low voltage grids using real-time data provided by measurements in secondary substations, Smart Meters and digital switching records. The system allows better integration of technologies, like charging stations, heat pumps and PV systems, in the LV grid. By managing in an integrated manner all measurements provided through different sources, state estimation is provided, filtering the collected data and excluding irrelevant ones, such as the load and voltage data of unsupplied customers. The resulting information is used to supplement traditional grid calculations to rank more accurately priorities and pain points in voltage quality and load criticalities.

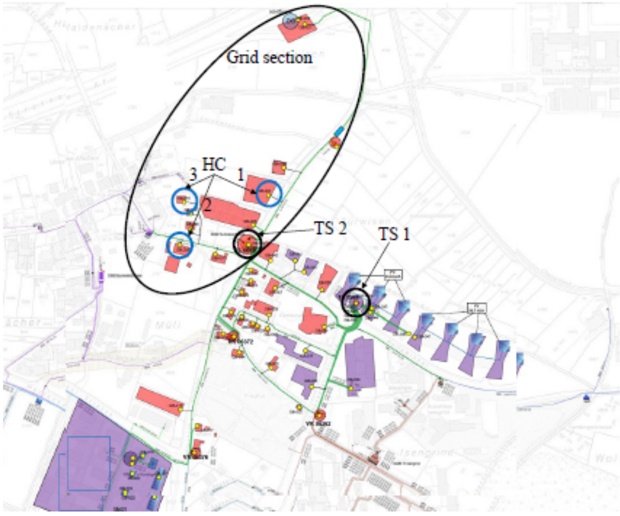


Fig. 55: The Smart Grid real LAB described in Paper 0423.

Paper 0423 presents a monitoring concept developed by ewz, the distribution operator of Zurich, to observe and possibly control the state of the low voltage grid. Starting from voltage and current measurements in a low voltage network of the city, temporal aggregation on the accuracy of the approximation of the measured data was first analyzed. Then the accuracy of power flow calculations was evaluated through a comparison with real measurement data. Finally, the optimal location of measurement equipment and the data resolution needed to determine the state of the grid were defined effectively. The analysis showed that: a 15 min resolution is sufficient for monitoring applications; a 1 min resolution is a reasonable compromise for control applications; the results from the power flow calculations were close to real measurements.

In **Paper 1036**, the results of power flow simulations and actual measurement data from a well-monitored suburban distribution grid area of EKZ, the Electric Utility of the Canton of Zurich, are analyzed to determine how varying measured variables and sensor locations impact the result accuracy. Results show that satisfactory power flow calculation accuracies can be achieved with a smart meter coverage of around 80 % of residential customers. It is also shown that an effective algorithm for load profile synthesis is key to achieve high-quality results with incomplete measurement coverage. Voltage and power at the transformer stations proved to be the most important single measurement for power flow calculation accuracy.

Sub block 4: Energy Losses

Facing a consumption reduction due to COVID impact on the world economy, it seems that efficiency in network operation through losses reduction has somehow lost its priority within DSOs. Most papers included in Sub block 4, devoted to losses, mainly relate to Non-Technical ones, introducing algorithms to evaluate, identify and reduce them.

Paper 0041 presents a methodology for detecting Non-Technical Losses (NTL) of electrical energy in power utilities using machine learning classifiers. It enhances data-oriented analysis and high hit ratio along with less cost and workforce requirements. This approach implies three steps: firstly, a non-supervised clustering of consumption profiles based on a hybrid algorithm using Self-Organizing Maps (SOM) and Discrete Cosine Transform (DCT) is performed. Secondly, further classification is operated based on location, infrastructure, and consumption profile. The final steps include supervised classifiers to detect NTL in the customers. The proposed t approach was trained and tested with real data from Ceará-Brazil (149.000 customers). Results show, among others, an average overall performance of 85% in the detection process of NTL.

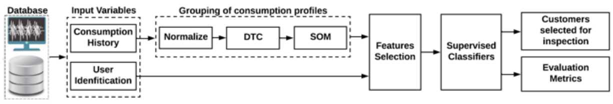


Fig. 56: Structure of methodology proposed in Paper 0041.

Paper 0659 presents a data mining methodology to identify correlations and patterns associated with living conditions in rural areas, considering meteorological and power consumption data in the irrigation period. Results obtained in a case study, where situations of NTL were simulated, show great recognition capacity after the application of data mining and reduction of the considered variables. Discrepancies of 10% or higher are detected for all considered rural customers, showing that irrigation activities have a relatively high potential in NTL.

Paper 0564, by the same authors, also presents a methodology to detect NTL in rural consumers with irrigation-based crops using fuzzy logic, artificial neural network and deep learning. According to reference data, consumption forecasting is performed in four clusters: Satellite images, Weather data, Crop data and Historical power consumption data. According to the forecasted consumption, the methodology suggests proper indicators of NTL and efficiency that will assist utility company decision making. Based on data from three harvests of rice crops in southern Brazil from 2011 to 2014, results achieved showed a percentage less than 10%, which was ranked as a tolerable risk according to the limits defined.

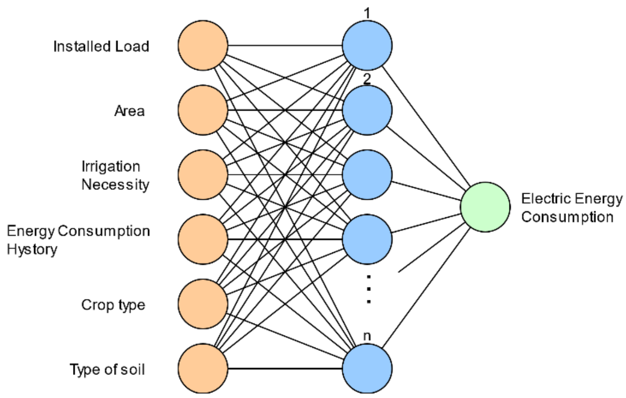


Fig. 57: Artificial neural network developed in Paper 0564.

The potential scope of the 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 4 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0033: Demand statistical characterization of low voltage users in Argentinian distribution networks for distributed generation studies purposes				X
0039: Uncertainties in radiation modelling for overhead lines and their impact on ampacity				X
0041: NTL detection: A intelligent system using a non-supervised clustering of consumption profiles				X
0082: Time-dependent and location-based analysis of power consumption at public charging stations in urban areas				X
0084: Modelling the aggregate load behaviour of European regions and its influence on dynamic and static voltage stability				X
0126: A stochastic modelling of electrical vehicle load and its impacts on a		X		X

Swedish distribution network				
0127: Calculation of peak load and diversity factors in unbalanced low voltage grids				X
0247: Standardization of electric vehicles' charging behavior via load-simulation of charging parks				X
0326: Forecasting method of newly-connected customer's load curve on LV distribution by means of regression tree utilizing smart meter data				X
0412: Co-simulation of OpenDSS and RTDS to realise the real-time simulation of large distribution networks		X		X
0423: Verification of a low-voltage monitoring concept using high-resolution measurements in the distribution grid of Zurich				X
0428: Spatial modelling of electrical loads in distribution grids based on socioeconomic data				X
0452: Challenges in deriving equivalent models of active distribution grids from operational data		X		X
0454: Very short to medium-term demand and generation forecast: A study case in Austria				X
0499: Digital (low voltage) grid - using new technologies to optimise planning and operational processes				X
0508: Modelling of location and time dependent charging profiles of electric vehicles based on historic user behaviour				X
0510: Load prediction tool for EV charging infrastructure				X
0520: Accuracy of load and generation forecasts for the operational planning of power distribution systems		X		X
0528: A comparison of artificial intelligence time-series data analysis techniques for load demand forecasting			X	X
0532: Interval optimization to schedule multi-energy systems considering PV power generation uncertainty				X
0556: Grid impact of heat pump integration in the residential sector				X
0560: Meter mapping & energy balance				X
0564: Methodology to identify non-technical losses in rural grids using artificial neural networks and deep learning				X
0568: Using smart meter data for phase grouping in PV-rich LV feeders				X
0581: Injection visibility & forecast				X
0621: Load estimation to the planning for electric vehicle public charging stations in urban zones using spatial analysis and traffic simulations				X
0626: Feeder mapping and load flow algorithms for LV distribution grids				X
0631: Short-term load forecasting using artificial neural networks and social media data				X
0636: A bottom-up approach for district-level domestic energy demand forecasting				X
0659: Data mining applied to features selectivity for a non-technical loss detection model in rural distribution grids				X
0690: Automated load forecast through geoanalysis				X
0848: Multi-agent simulation of human activity for residential electrical load and demand forecasting and its application to electric mobility			X	X
0895: COVID-19 Demand response outlook: predicting the unknown		X		X

0952: Weather-dependent current ratings of overhead lines in the probabilistic high voltage distribution grid planning				X
0968: Thermosensibility estimation of mass market with smart meters in France				X
0971: Improving renewable integration at local scale: an econometric approach				X
0994: A techno-explicit model implementation for long term electrical load curve prospective				X
1036: Assessing the accuracy of distribution grid analysis for various combinations of grid measurements				X
1045: Smart4RES: Next generation solutions for renewable energy forecasting and applications with focus on distribution grids				X
1093: Synthetic models of LV networks for the estimation of aggregated DER flexibility		X		X