SPECIAL REPORT FOR SC C6

SC C6 - ACTIVE DISTRIBUTION SYSTEMS AND DISTRIBUTED ENERGY RESOURCES

Special Reporters

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INTRODUCTION

The Study Committee (SC) C6 focus for 2026 examines the technical and operational requirements of increasingly active distribution systems as Distributed Energy Resources (DER) proliferate and a growing share of generation becomes non-dispatchable.

SC C6 also addresses the enabling technologies and innovative practices needed to integrate DER into distribution networks. This Special Report covers a wide spectrum, from rural electrification and demand-side integration to the use of storage and electric vehicles as grid resources.

For the CIGRE Session 2026, SC C6 has identified three Preferential Subjects (PSs) that reflect the sector's emerging challenges and opportunities:

Preferential Subject 1 — Enabling flexibility in distribution networks
- Effects of and grid services provided by energy storage and energy conversion units (for example, hydrogen) in distribution systems.
- The contributions of energy communities, aggregators and virtual power plants to network flexibility.
- Managing risk during network congestion and balancing flexibility procurement with stretching operational limits.

Preferential Subject 2 — Planning and operations for 2030 and beyond in active distribution systems
- How transformational changes (accelerated electrification, new electric loads, and evolving customer behaviour) affect planning objectives and criteria.
- Integration of electric vehicles and other advancing technologies into distribution systems.
- The DSO's role in planning and operating the system to improve network resilience while considering customer affordability.

Preferential Subject 3 — Rural and industrial electrification: standards, practices and technology options
- Microgrid and multi-microgrid deployments, including industrial network applications.

- Off-grid and islanded DER solutions and appropriate resilience measures.
- Approaches for connecting the “last mile” in rural electrification projects.

A total of 120 papers were selected for presentation and discussion at C6 2026 Session: 54 for PS1, 49 for PS2 and 17 for PS3. These papers form a broad evidence base that will inform the Group Discussion Meeting (GDM). Participants should review the presented insights in advance: the GDM will use them to frame questions, stimulate focused dialogue, and drive actionable conclusions that support the practical integration and operation of DER in distribution networks.

HOW DOES THE PARIS CONFERENCE FUNCTION?

Brief guide to the process and your role.

Overview — purpose and how the Conference uses the Special Report

- The SC C6 Special Report frames the Group Discussion Meeting (GDM) by summarising Session scope, main themes and practical questions for discussion.
- Understanding the Paris Conference structure and timing will help you prepare a focused contribution and participate effectively in the SC C6 GDM.

Conference structure and where SC C6 fits

- Session Papers are organised around “Preferential Subjects” (PS) selected in advance by CIGRE’s 16 Study Committees; these subjects formed the basis of the Call for Papers and accepted submissions.
- Each submitted paper underwent two-stage review (abstract, then full paper). The Technical Programme in the Conference Registration Portal lists the selected papers and their topics—use it to identify relevant Session Papers.
- Authors present accepted work in **Poster Sessions; the SC C6 Poster Session is Tuesday 25 August 2026, Hall Ternes (Level 1), 08:30–12:30**. Posters will be displayed on digital screens; poster template and preparation instructions are on the CIGRE 2026 Session website. Authors must upload poster files to ConfTool from 18 May to 29 June 2026 for convener review; a final version (if requested) must be uploaded by 14 August 2026. Authors cannot upload on the day of the Poster Session. If an author cannot attend, arrange a substitute or contact your National Committee.

Group Discussion Meetings (GDMs) — purpose, timing and leadership

- Dedicated GDMs are organised by each Study Committee; four GDMs run concurrently each day (Tuesday–Friday).
- Each GDM is chaired by the Study Committee Chair together with the Special Reporters assigned to the relevant Preferential Subjects.
- The SC C6 GDM will be held on Thursday, 27 August 2026, and is an all-day event. Its purpose is to discuss Session Papers using the SC C6 Special Report as the framing document. The Special Reporters distilled 41 questions for the GDM that reflect common themes across papers and invite broad engagement; these are not directed only at paper authors.
- During the GDM, the Preferential Subjects will be discussed. Rather than doing this by presenting every paper, the delegates get the opportunity to start the discussion by a Contribution. This Contribution may either be prepared beforehand or be spontaneous (see instructions below). The Contributions are short responses to the questions the Special Reporters outlined further on in this Special Report, based on their review of

all the papers. These Contributions are the start of the focused dialogue shaping the GDM.

Preparing for the GDM — what to read and where to find it

- To enable productive exchanges, delegates are strongly encouraged to read the Session Papers they plan to discuss before attending the GDM.
- All selected Session Papers are available to registered delegates for download from their private account in the registration portal before the Session and are accessible via the Conference mobile app during the event.
- Keep informed on C6 session news, the general programme and updates by visiting the Conference website.

How to submit Contributions to the SC C6 GDM — practical steps

- If you wish to respond to one (or more) of the questions in this Special Report, upload tour Contribution(s) through the registration portal (https://registrations.cigre.org/) under "C6 Contributions to Group Discussion Meetings" using your existing account credentials.
- Contribution uploading opens from the start of June 2026. Deadline for upload: 07 August 2026, 18:00 CET. Contributions received by this date will be screened in advance to support effective organisation of the GDM.
- Only duly registered delegates can upload Contributions. Complete your CIGRE Session registration before attempting to upload.

Required Contribution format and guidance

- Each Contribution must include:
  - A PowerPoint presentation of no more than 3 slides.
  - A written Word file of no more than 1,000 words.
- Contributor guide, templates and example pages will be available on the Paris Session 2026 webpage.
- *Important: No commercial names are to be included in presentations or written summaries (this includes TSO/DSO names).*

Review process and feedback

- Special Reporters will review all submitted Contributions.
- Any recommendations or required changes will be communicated to contributors via the registration portal between 07 August and 14 August 2026. Contributors should check their registration account in that period to view feedback.
- Contributors whose submissions are accepted/finalised will be contacted by SC C6 Special Reporters by email between 07 August and 14 August 2026; this correspondence will include final presentation instructions and session details.
- There is a limit to the number of contributions accepted for each Preferential Subject (PS1, PS2 and PS3) within SC C6. It is up to the discretion of the Special Reporters to accept or reject your contribution

On-site contributors' meeting and final checks

- SC C6 Contributors' Meeting: Tuesday 25 August 2026, 08:30–10:30, Hall Ternes (Level 1) — (same venue as the Poster Session.)
- This meeting verifies contributors' attendance and finalises programme timing. No last-minute changes to Contributions will be accepted at the Contributors' Meeting.

Spontaneous (verbal) Contributions and Proceedings

- There may be opportunity for spontaneous verbal Contributions during the GDM; these are verbal only (no slides).
- Those who give a spontaneous verbal Contribution are encouraged to submit a short-written summary for the Proceedings. That summary must be submitted within two

weeks after the SC C6 Session — by Tuesday 10 September 2026 — to be considered for inclusion into the Conference Proceedings.

Deadlines, restrictions and important reminders

- Contribution uploading opens from the start of June 2026.
- Deadline for upload: 07 August 2026, 18:00 CET. No new Contributions will be accepted after this deadline.
- Only registered delegates can upload; complete your CIGRE Session registration before attempting to upload.
- Posters: initial upload window 18 May–29 June for convener review; convener-requested final versions by 14 August; no uploads allowed on the poster day.

Scope of contributions

- Submitted Contributions should address the 41 questions prepared by the Special Reporters and align with the SC C6 Special Report themes. Contributions need not be limited to authors of Session Papers—practical experience and perspectives from any delegate are welcome

The Contributions received will revolve around the list of question posed by the respective Special Reporters. The summary of the papers and the ensuing list of questions / thoughts to consider, are posed in the section that follows:

PREFERENTIAL SUBJECT 1 – Enabling flexibility in distribution networks

Special Reporters: Barbara Herndler (Austria), Josh Snodgrass (USA), Gilles Lancel (France)

PS1 received 54 papers for review with authors providing inputs into this preferential subject.

The papers have been grouped into the following subtopics:

1. **Flexibility-oriented distribution system operation and market integration**

Focus: Operational flexibility, congestion management, DER coordination, demand response, EV flexibility, flexibility markets, and active network operation.
Papers: 10913, 10976, 11128, 11137, 11747, 12470, 12633, 11561, 10717, 10807, 11385, 11539, 11542, 11740, 11759, 11978, 12019, 11937, 12021, 12018, 11311, 12367, 11139, 12626

2. **Distributed energy resources, hosting capacity and grid impact assessment**

Focus: PV/DER integration impacts, hosting capacity enhancement, network reinforcement, power quality, and emerging grid architectures.
Papers: 10314, 10334, 11414, 11535, 11745, 12567, 10697, 10975, 11217, 11691, 11708, 11939, 12053, 12365, 12633

3. **Digital platforms, data and AI for smart energy systems**

Focus: Digital platforms, AI/data-driven methods, advanced monitoring, system visibility, and planning analytics.
Papers: 10608, 11755, 12521, 10109, 10170, 11136, 11390, 12110, 12141, 12409, 12601, 12637, 11940, 11129, 11533

Subtopic 1.1: Flexibility-oriented distribution system operation and market integration

The papers in this subtopic investigate the growing role of flexibility as a key enabler for operating future active distribution networks with high penetrations of distributed energy resources (DERs), electrified demand, and variable renewable generation. Topics include demand-side flexibility, battery energy storage systems (BESSs), renewable energy communities, EV charging management, and virtual power plant aggregation frameworks. Several studies examine market-based flexibility mechanisms, interoperability between stakeholders, and advanced operational strategies to mitigate congestion, reduce network reinforcement needs, and improve grid utilisation. Collectively, the contributions emphasise the transition from passive network operation toward dynamic, flexibility-driven distribution system management supported by digitalisation, optimisation, and active customer participation.

The transition to a One Grid solution as outlined by CIGRE, is one that is still in its infancy, but these papers outline frameworks and solutions to enhance the coordination between DSOs and TSOs. They also offer market-based solutions that will increase the flexibility between these organizations, so that cohesive solutions are made. These frameworks will be critical as we move towards 2030 and beyond.

Statistics: A total of 24 papers from 22 countries (European dominant)

<u>Summaries</u>

10913 Flex Ready® - The French solution for tertiary flexibility

This paper addresses a key barrier to scaling demand-side flexibility, namely the lack of interoperability between building control systems and electricity market actors. It demonstrates that fragmented data exchange frameworks significantly limit the deployment of flexibility despite the growing availability of controllable loads in buildings. By proposing a standardised, technology-agnostic data exchange model and communication interface, the work shows how interoperability can unlock both implicit and explicit flexibility, reduce integration costs, and avoid vendor lock-in. The results highlight clear benefits across stakeholders, including improved market access for aggregators, more effective price signal translation by suppliers, and enhanced visibility and controllability for system operators.

10976 Cost study of DER flexibility installation and distribution system reinforcement to mitigate grid congestion

This paper evaluates the cost-effectiveness of conventional grid reinforcement versus the use of distributed energy resource flexibility, specifically BESS, to mitigate congestion driven by high PV penetration in distribution networks. Based on detailed case studies and Monte Carlo simulations incorporating PV generation uncertainty, the results show that BESS can provide a cost-advantageous alternative in scenarios requiring extensive and costly grid upgrades, particularly for long distribution lines and moderate PV capacities (e.g. 500 kW). However, for larger PV installations, the required storage capacity increases significantly, reducing economic viability compared to reinforcement. The analysis further highlights that sizing BESS based on average rather than extreme PV generation improves cost efficiency.

11128 Enabling Demand-Side Flexibility in Residential Communities using Low-Carbon Technologies

This paper investigates a hybrid photovoltaic-thermal and ground-source heat pump (PVT-GSHP) system for residential communities in Wales, United Kingdom, as a flexibility solution for distribution networks with increasing electrified heating demand. A dynamic simulation framework was developed for a community of four terraced houses and compared a conventional GSHP system with an integrated PVT-GSHP configuration under representative winter and summer operating conditions. Results showed that the integrated system reduced grid electricity imports, lowered peak demand and improved heat pump efficiency through thermal preheating of the shared ground loop. During summer periods, the system achieved periods of net electricity export, while winter operation still demonstrated meaningful peak shaving benefits. Estimated household electricity cost savings reached approximately £17 in winter and £111 in summer. The work demonstrates the potential of integrated thermal-electric systems to provide demand-side flexibility, reduce stress on LV networks and support active distribution system operation.

11137 Renewable Energy Communities and flexibility services: intersecting or parallel paths?

This paper investigates the interaction between Renewable Energy Communities (RECs) and flexibility services in distribution networks, focusing on regulatory frameworks, technical impacts, and operational opportunities. A case study based on a real Italian distribution network compares scenarios with increased distributed photovoltaic generation against shared REC photovoltaic plants under different penetration levels and with or without demand-side engagement. Results show that distributed generation scenarios reduced network losses, while shared REC plants could increase losses depending on the electrical distance between generation and loads. Demand-side engagement improved network performance in all cases by reducing losses, voltage issues, and line loading through load shifting toward periods of PV generation. The paper also discusses the potential role of RECs in providing flexibility services to local and global markets, while highlighting barriers including ICT requirements, lack of standardisation, and the need for advanced technical expertise.

11561 A Continuous-Time Hierarchical Aggregation Framework of Distributed Energy Resource

This paper proposes a continuous-time hierarchical aggregation framework for DERs in virtual power plants (VPPs). The framework addresses challenges such as limited temporal resolution and high computational complexity by transforming traditional discrete-time models into continuous-time models using Bézier curves. At the DER cluster level, flexibility regions are aggregated through approximated Minkowski sums using affine transformations, while at the VPP level a robust optimization approach determines the overall feasible flexibility region. The proposed method preserves linearity, captures sub-hourly flexibility, reduces communication and computation burdens, and guarantees feasible disaggregation back to individual DERs. Numerical tests on a hierarchical power system demonstrate the framework's practicality and computational efficiency for real-world grid operation and flexibility management.

11747 Flexibility Needs Assessment in the Distribution System with Significant Generation from Photovoltaic Power Plants

This paper investigates flexibility solutions for integrating large numbers of PV power plants into a constrained 110/10 kV distribution network in Bosnia and Herzegovina that is already experiencing voltage violations and network overloads. While demand-side management and dynamic tariffs were initially considered, the current lack of smart-grid infrastructure and regulatory readiness makes these options insufficient for accommodating future PV growth. The study therefore identifies BESS as the key flexibility solution for balancing generation and demand, stabilising voltages, and reducing congestion. Using power-flow simulations and iterative sizing methods, the paper evaluates the storage capacity required to integrate planned PV power plants while maintaining grid constraints. The proposed PV-BESS hybrid approach enables safer and more flexible renewable integration, reduces curtailment needs, and offers long-term operational and economic benefits for both grid operators and investors.

12470 Road to flexibility - How to integrate LV and MV flexsumers in Distribution Grids - Examples from Germany and Italy

This paper highlights the growing importance of flexibility in European MV and LV distribution grids as increasing electrification, DER integration, and volatile customer behaviour create congestion, voltage issues, and connection bottlenecks. Based on collaboration between four European DSOs the paper demonstrates how flexibility can improve grid utilization, defer costly reinforcements, reduce congestion risks, and accelerate customer connections through tools such as flexible connection agreements, flexibility markets, forecasting, and enhanced grid observability. It proposes a practical roadmap for DSOs that combines digitalisation, advanced grid management, interoperable IT/OT architectures, and market-based flexibility mechanisms to enable a transition from static, reinforcement-driven grid planning toward dynamic, data-driven, and flexibility-centred distribution system operation.

12633 A User-Centric Flexibility Dispatch Framework: Mitigating EV- Induced Feeder Overloads via Differentiated Incentives

This paper presents a data-driven demand-response framework for managing EV charging demand and reducing distribution network overloads caused by fast-charging infrastructure. EV users are classified into four behavioural groups using survey data and factor analysis, and these profiles are integrated into a utility-based charging choice and pricing model. The proposed framework uses differentiated incentives and charging guidance to shift charging demand away from overloaded areas while maintaining user satisfaction. A Shenzhen case study shows that the method successfully relieves overloads and reduces incentive costs by about 19% compared to uniform pricing approaches.

Paper 10717: This paper presents dynamic operating limits for DER export/import levels based upon real time grid operating conditions. These limits improve grid utilization and reduce conflicts between distribution operators and wholesale markets, preventing the need of DSOs to override market decisions. Overall, dynamic limits promote flexibility for the grid.

Paper 10807: This paper presents a framework for a unified transmission and distribution modelling for a virtual power plan. It integrates production cost modelling with detailed transmission and distribution models, while reflecting time series responses for DER behaviour. The paper highlights a case study of grid in the United States, that shows targeted VPP dispatch can relieve transmission congestion, while maintain distribution performance. Which concludes that VVP can provide value to a one grid platform.

Paper 11385: This paper examines the need to support a one grid approach, by proposing a TSO-DSO coordination model. The TSO would then issue instructions that the DSO could implement via an intermediated dispatch mechanism. This would enhance the flexibility of DERs and allow for greater participation in frequency control and congestion management. It also approaches the regulatory steps and has recommendations for gradual implementation.

Paper 11539: This paper proposes a hierarchical control structure using synchrophasor measurement and wide-area control. It outlines the support for central orchestration of data and applications, zonal real-time control, and edge control interfacing to the managed DERs. This allows the DSO to provide services, such as black start, island stability, and resynchronization to the transmission system. The paper also examines results from Hardware-in-the-Loop testing and results from a demonstration project in Scotland.

Paper 11542: This paper examines the regulatory approaches to enhance DERs in India. It outlines the current challenges faced by Distribution Companies (DISCOMs) including limited visibility, forecasting, and grid instability. The paper proposes a roadmap for creation of a DSO role to encourage rooftop solar, including provisions of net meters, prompt inspections, and commissioning. The DSO is seen as critical to ensure the management of the distribution system in real time and to guarantee the security and supply to the consumes of energy in India.

Paper 11740: This paper proses a grid-aware flexibility framework to manage congestion from rising DERs and electrification. Utilizing day-ahead optimization (via Linear programming) with real-time safeguarding using an Additive Increase Multiplicative Decrease (AIMD) algorithms that can adjust dynamically with the inputs of AMI data. The paper than shows several demonstrations of the algorithm, showing that it can fix real time solutions involving a variety of DERs, EVs, and BESS. This architecture can also be expanded beyond the grid edge to support optimization strategies within Virtual Power Plants.

Paper 11759: The paper introduces the Community DSO concept, where a coordinator manages flexibility within local energy communities on low-voltage networks to reduce congestion. By coordinating distributed assets (BESS, DERs, EVs), it aligns actions with local grid constraints, outperforming uncoordinated responses to time-of-use tariffs. Simulation results show statistically significant peak demand reductions, even with modest participation. The approach can lower reinforcement costs, enable decarbonization, and deliver economic benefits.

Paper 11978: This paper highlights a project's results, which primary objectives were to demonstrate a decentralized, cost-effective approach to manage network capacity in a growing two-sided market. Using smart inverter standards, the project shows customers can shift consumption and exports to support the grid, flatten demand peaks, and improve market participation. Early results highlight benefits like reduced congestion and better wholesale market outcomes, while ongoing efforts focus on scaling, improving forecasting, and transitioning to full market deployment.

Paper 11989: The paper proposes a Smart Grid Architecture Model-based architecture for Local Flexibility Markets to improve integration of distributed energy resources. It addresses interoperability challenges by using Common Information Modelling (CIM). The framework structures market processes, data exchange, and system components. It supports efficient congestion management and reliable Local Flexibility Market operation, providing a practical, interoperable foundation for future flexibility-driven distribution systems.

Paper 12019: The paper reviews projects on improving TSO–DSO coordination to manage growing DER integration and grid complexity. It finds that clear roles, advanced information and communication technology (ICT) tools, and standardized data exchange are essential. DSOs are evolving into active system managers, requiring close coordination with TSOs across planning and operations. Market mechanisms and regulatory frameworks must be harmonized to enable scalable flexibility. Overall, coordinated technical, market, and regulatory solutions are key to enhancing grid reliability, reducing congestion, and supporting a flexible one grid solution.

Paper 11937 (Jordan). Field-based assessment of how the deployment of public EV charging stations affects a real MV feeder in Jordan. Three-step analysis: feeder baseline, uncoordinated charging, then evaluation of the recently introduced time-of-use tariff. Uncoordinated charging noticeably increases losses and degrades voltage at the end of the feeder; the TOU signal already shifts a significant share of charging away from the evening peak.

Paper 12021 (Austria). Part of the MEDUSA project on megawatt charging for heavy-duty vehicles. Traffic analysis along the Austrian motorway network combined with synthetic MV grid models, used to assess the impact of MCS-class chargers (above 1 MW per connection) clustered at rest stops. Even moderate growth scenarios produce thermal overloads and large voltage deviations: the charging hubs should be treated as a new category of MV-connected load.

Paper 12018 (Austria). Economic counterpart of the previous paper. A heavy-duty truck (600 kWh battery, 100 kW MV-connected charger) is simulated over 10 years with historical day-ahead prices. Smart unidirectional charging already produces large savings vs conventional, with slightly better SoH at the end of the period. V2G adds further savings, but the additional benefit depends strongly on price volatility (very high in 2022). The paper also looks at the new Austrian network tariff law.

Paper 11311 (Iran). IoT-based architecture that combines battery swapping with V2G (vehicle-to-grid) and integrates it into a demand response program. A battery swapping station decouples vehicle availability from battery charging. Multi-objective optimization (electricity cost, V2G revenue, peak load, battery degradation), tested in simulation with 100 EVs over one week. Reported peak load reduction around 22 %, with a moderate increase in customer profit.

Paper 12367 (Slovenia / France). FlexCHESS architecture combining V2G, OCPP (Open Charge Point Protocol) 2.0.1 smart charging, and second-life batteries used as power buffer at ultra-high power charging hubs. The second-life battery absorbs the peak charging power so that the local grid connection does not need to be reinforced, a "silicon-based" approach as opposed to the "copper-based" reinforcement.

Paper 11139 (Italy). Structured methodology for the electrification of the public ferry fleets on the three major Italian lakes (Maggiore, Garda, Como). Eight-step approach from vessel classification and operational profile analysis up to grid connection sizing and cost analysis. Full electrification is feasible for ferries and motor-vessels (not yet for high-speed hydrofoils and catamarans). 12 charging hubs identified across the three lakes (750 kW to 3 MW per hub), 64 vessels to electrify (27 retrofits + 37 new builds). Break-even point in 2055, five years after the end of the planned electrification.

Paper 12626 (Finland) This paper investigates the harmonic impacts of electric vehicle (EV) fast charging on low-voltage (LV) distribution networks, focusing on power quality and hosting capacity. Using a measurement-based approach, harmonic spectra (magnitude and phase angle up to the 50th order) from 20 kW DC fast-charging tests are reconstructed into time-domain waveforms and applied to a detailed Finnish 20 kV/0.4 kV feeder model. The study demonstrates that harmonic behaviour is strongly influenced by charger phase-angle alignment, which can lead to reinforcement or cancellation effects at the point of common coupling. Results show that while current distortion may temporarily exceed limits during transient conditions, voltage distortion generally remains within EN 50160 bounds. Neutral current increases significantly due to triplen harmonics under multi-charger operation. The validated modelling approach provides a practical tool for distribution system operators, indicating that up to six chargers can operate simultaneously without sustained compliance violations

Questions

> ***Q 1.01:*** *How can DSOs integrate and operate distributed flexibility (EVs, storage, heat pumps, RECs, and DERs) in both planning and real-time operation, and how does this reshape the role of customers, aggregators, and market mechanisms (e.g., pricing vs aggregation)?*
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> ***Q 1.02:*** *Under which technical and economic conditions is flexibility more cost-effective than conventional grid reinforcement, and how should DSOs evaluate these trade-offs under uncertainty (e.g., extreme events vs average operation)?*
>
> ***Q 1.03:*** *What are the main technical, regulatory, and operational barriers limiting large-scale flexibility deployment in MV and LV networks, and which of these are most critical for enabling dynamic operating limits and flexibility-based operation?*

Q 1.04: *How should coordination between TSOs, DSOs, and DER operators be structured across real-time, day-ahead, and long-term horizons, and what are the risks of conflicting control signals or loss of operational authority (e.g., dynamic limits vs override mechanisms)?*

Q 1.05: *How should DSOs adapt planning and connection processes for emerging high-power MV-connected loads (e.g., megawatt EV charging, ferries), and what is the role of smart charging, V2G, and storage buffering in managing these impacts?*

Q 1.06: *How can interoperability frameworks, data exchange standards, and aggregation models enable scalable local and system-wide flexibility markets, and what role do digital architectures play in enabling coordination between heterogeneous DERs?*

Subtopic 1.2: Distributed energy resources, hosting capacity and grid impact assessment

The papers in this subtopic focus on the technical and infrastructural challenges associated with integrating large shares of DERs, particularly photovoltaic systems and electric vehicle charging infrastructure, into modern distribution networks. The contributions explore hosting capacity enhancement, thermal and fault-level constraints, power quality impacts, renewable variability, and the role of emerging grid architectures such as medium-voltage DC systems. Several studies assess the effectiveness of network reinforcement measures, advanced operational concepts, and PV-BESS integration strategies for reducing congestion, improving system stability, and enabling higher renewable penetration. Together, the papers illustrate how distribution networks must evolve both operationally and physically to support increasingly decentralized and electrified energy systems.

Electrification and deployment of DERs still are some the largest challenges faced by DSOs today. Understanding their impacts as resources, but as flexible resources is a challenge that must be met. Electric transportation is also hitting critical mass in some countries while, still getting its footing in others. All these items are important as we look forward to 2030 and beyond. These papers provide glimpse of what is to come for our ever-evolving grid.

Statistics: A total of 15 papers from 14 countries

Summaries

10314 Weighing benefits and risks of thermal rating amid uncertainty in asset parameters and load patterns in times of congestion: computational method and key observations

This paper addresses how Dutch DSOs can safely increase the utilisation of already congested medium-voltage grids by applying dynamic and cyclic cable ratings instead of conservative static limits. The authors propose a probabilistic, population-based thermal risk assessment method that combines Monte Carlo simulations, thermal cable modelling, and stochastic load and soil parameters to evaluate the risks of higher cable loading under uncertainty. Their findings show that individual yearly load profiles are too variable to reliably determine cyclic ratings, making population-level statistical analysis more suitable for practical grid planning and operation.

10334 MVDC Feasibility Assessment in High-Renewable Distribution Networks: A German 110 kV/20kV Case Study

The contribution highlights the growing challenge of accommodating high electrification demand and increasing RES penetration in sub-transmission and distribution networks, leading to congestion and significant RES curtailment. Through Optimal Power Flow-based comparisons of AC and Medium Voltage DC (MVDC) expansion options, the study demonstrates that while MVDC introduces slightly higher losses due to converter stations, it uniquely enables the reliable supply of large emerging loads (e.g. data centres, EV charging) and substantially reduces RES curtailment. Based on the results, MVDC emerges as a promising solution for future network planning, particularly in scenarios characterised by high loading and high-RES integration**.**

11414 From Consumers to Prosumers: A Techno-Economic Analysis of Residential PV-BESS Deployment in Sweden

This paper presents a techno-economic analysis of residential PV and BESS in Sweden, based on laboratory measurements and full-year modelling for four representative single-family house archetypes with different heating systems and EV integration. Twelve PV and PV+BESS configurations were tested using a condensed 4-day "Frankenstein" laboratory time series to characterise converter efficiencies and EMS operation. The validated models were then used for annual simulations considering Swedish electricity spot prices and peak power tariffs. Results show that PV installation reduced annual operational costs by an average of 47% compared to a reference case without PV or BESS, while adding battery storage provided an additional average reduction of 11 percentage points mainly through increased self-consumption and reduced grid imports. However, the impact on peak power tariffs was limited, and PV-only systems generally achieved shorter simple payback times than PV+BESS systems under current market conditions.

11535 Simulation Analysis and Prospect of Charging Pile Access to Distribution Network Considering Power Quality Governance

This paper investigates the impact of large-scale electric vehicle charging infrastructure on distribution network power quality and explores the use of charging piles as active power quality regulation resources. The study analyses AC and DC charging station integration, harmonic generation mechanisms, and coordinated control strategies based on grid-forming and Vehicle-to-Grid (V2G) concepts. A VSG control framework combined with Odd-order Repetitive Control (ORC) is proposed to suppress harmonics and provide reactive power support. Simulation results for a 20 kW V2G charging station demonstrate significant improvements in grid current quality and voltage waveform distortion, reducing current total harmonic distortion from 18.15% to 4.90%. The study concludes that charging piles can evolve from passive harmonic sources into multifunctional power quality regulation units, supporting the reliable and flexible integration of large-scale EV charging in future distribution networks.

11745 Impact of Photovoltaic Power Plant Topology and Geographical Dispersion on Output Variability in Distribution Networks – a Case Study

This paper analyses how the geographical dispersion and capacity distribution of PVPPs affect short-term power variability and balancing costs in distribution networks. Using one year of real 15-minute operational data from 97 PV power plants a Bosnia and Herzegovinian distribution system, the study shows that aggregating a larger number of smaller, geographically dispersed PV power plans significantly reduces output variability through a smoothing effect. In contrast, concentrated areas with fewer large PV power plants experience higher fluctuations, imbalance volumes, and balancing costs, particularly during partly cloudy conditions. The results demonstrate that decentralised and spatially distributed PV deployment improves forecast reliability, lowers reserve and balancing requirements, and supports more stable and cost-effective integration of high shares of solar energy into distribution networks.

12567 Upgrading the short-circuit withstand capability of distribution networks to increase DG hosting capacity

This paper presents a methodology for upgrading the short-circuit current capability of HV/MV substations and MV distribution networks to increase renewable energy hosting capacity. Using a real

150/20 kV substation in Greece, the study combines site surveys, network modelling, and short-circuit simulations to assess existing fault levels and estimate the additional PV capacity enabled by increasing the substation short-circuit limit from 7.2 kA to 10 kA. The results show that the upgrade could enable around 110 MW of additional PV capacity. Furthermore, the paper also introduces a simulation-based approach for identifying required MV network reinforcements while considering actual protection system operation and reclosing sequences. This allows targeted and cost-efficient upgrades, requiring only limited conductor and sectionaliser replacements while maintaining safe network operation.

Paper 10697: This paper outlines the current adoption rates of electric vehicles (EVs) in South Africa, while exploring use cases that support grid reliability through managed charging and ancillary services. EV adoption remains low in South Africa but is projected to grow over the next decade. This growth can be a challenged and opportunity for the South African grid, as EVs can provide flexibility benefits to the grid through a variety of methods as the paper presents.

Paper 10975: This paper outlines the ability of Battery Energy Storage systems and flexible loads like data centres to utilize excess PV generation. Providing much needed flexibility to the grid during these events. It demonstrates that DERs can reduce congestion but could cause voltage drips in the process. Results show that applying fixed power factor control can mitigate these issues while maintaining the flexibility needed to support the grid.

Paper 11217: This paper compares geospatial, statistical, and agent-based modelling for estimating EV charging demand. The paper reviews these methods against real-world data, which was collected throughout major Russian cities over a 2.5-year period. It shows that each type of modelling has its strengths and weaknesses. Depending on the end use of the study it outlines the best approaches to modelling.

Paper 11691: This paper explores the EV integration into Oman's distribution networks. It highlights the risks of unmanaged charging, such as overloading, voltage violations, and increased losses. While also demonstrating smart charging, demand-side management can be viable solutions for grid flexibility. It also shows that Vehicle-to-Grid (V2G) can improve resiliency. Finally, a roadmap for empowering Oman's DSOs to adapt to the transition of EVs is also presented.

Paper 11708: This paper approaches the subject of Consume Energy Resources (CERs) in the United Kingdom. CERs include smart consumer devices such as solar PV, home batteries, EV, and heat pumps. Their rapid growth has posed challenges for the TSO, because CERs increase demand and respond dynamically to price signals and weather changes. It ultimately provides recommendation and solutions to increase CER participating in the market, while ensuring grid-stability.

Paper 11939: This paper highlights the critical challenge of integrating DER into low voltage networks. A hybrid methodology of combining conventional power flow simulations with K-Means clustering was employed to access the following scenarios, a base case (no DERs), PV only, PV with battery energy storage system (BESS), and BESS. The paper highlights the findings of these studies and shows cases the K-clustering analysis strengths.

Paper 12053: The paper evaluates frequency stability in high-renewable power systems using EMT simulations, focusing on grid-forming (GFM) inverters. Results show GFM inverters improve stability by reducing rate of change of frequency through fast active power injection. However, frequency improvement is limited unless sufficient GFM capacity is installed. Stability depends more on absolute GFM capacity than its share of generation. High renewable scenarios can still lead to collapse without adequate GFM capability, highlighting the need for sufficient power capacity and support in future grid planning.

Paper 12365: The paper examines Dynamic Operating Envelopes (DOEs) for managing congestion from increasing DER adoption. A model-free DOE approach using AMI data and machine learning outperforms methods, significantly lowers curtailment and better addresses voltage constraints. Results from Australian networks show increased hosting capacity and efficiency. Though limited trader offs do occur with equity and fairness remaining a challenge.

Paper 12633(China) This paper proposes a user-centric flexibility dispatch framework to mitigate EV-induced overloads in distribution networks by leveraging differentiated incentives. High penetration of fast charging leads to spatial and temporal demand concentration, challenging conventional grid reinforcement approaches. The study introduces a closed-loop system that integrates real-time grid and user data, segments EV users based on behavioural characteristics, and applies tailored pricing signals to encourage load shifting in time and location. A case study in Shenzhen demonstrates that the approach effectively alleviates feeder overloads while reducing incentive costs by approximately 19% compared to uniform pricing, thereby enhancing operational efficiency and grid flexibility.

Questions

> ***Q 1.07:*** *What are the key technical constraints limiting renewable and DER hosting capacity in distribution networks (e.g. voltage limits, congestion, fault levels, power quality, and stability), and how do these constraints evolve with increasing PV, EVs, and inverter-based resources?*
>
> ***Q 1.08****: What is the relative role of conventional reinforcement, advanced operational methods (e.g. dynamic thermal ratings, DOEs), and structural innovations (e.g. MVDC, PV-BESS hybrid systems) in increasing distribution network hosting capacity cost-effectively?*
>
> ***Q 1.09:*** *Which modelling and simulation approaches are best suited to represent high-DER distribution systems, including stochastic generation, EV behaviour, storage control, and dynamic pricing signals, for both planning and operational decision-making?*
>
> ***Q 1.10****: Electrical Vehicles are starting to hit critical mass in some countries, while others are still in the early stages of adaptation. Consumer sentiment around demand response/flexibility programs are also met with more scepticism today, rather from lack of education or compensation. What are the keys of success for a flexibility program involving EVs and how do we increase consumer adaptation. How do DSOs effectively model these programs in their near- and long-term planning models?*
>
> **Q 1.11*****:*** *Dynamic Operating Envelopes are seen by many as a key solution to increasing hosting capacity across the DSO networks. Though there remain many questions from regulators about their equitable and fairness to the consumers that deploy DERs, what are the key takeaways to improve the fairness and equity of dynamic operating envelopes*

Subtopic 1.3: Digital platforms, data and AI for smart energy systems

The papers in this subtopic examine the role of digitalisation, data platforms, and intelligent analytics in enabling the planning and operation of future energy systems. The contributions include the development of national and regional energy data platforms, geospatial planning tools, and AI-based methods for distributed energy resource modelling and parameter identification. Key themes include improving system visibility, integrating fragmented datasets, enhancing forecasting and monitoring capabilities, and supporting data-driven decision-making for network operators and policymakers. Furthermore, the papers demonstrate how advanced digital infrastructures and intelligent analytical methods are becoming essential foundations for managing increasingly complex, decentralised, and multi-energy power systems.

With the advancement of new grid edge technologies like IBR (inverter-based resources) based DERs, AMI 2.0, and Soft Open Points, comes the need of advanced control and modelling techniques. These devices also need to integrate effectively within the DSO framework of day-to-day operations. These papers outline some of the most advance control systems out there to effectively increase the flexibility and operating practices needed for a one-grid solution.

Statistics: A total of 15 papers from 13 countries

Summaries

10608 National Registry of Solar Rooftop

This contribution presents the development of a National Solar Rooftop PV (SRTPV) Registry in India as a key enabler for integrating rapidly growing distributed solar capacity into power system operations. While rooftop PV deployment is accelerating, the lack of centralized visibility currently limits forecasting, grid management, and policy oversight. The proposed registry addresses this gap through a scalable, real-time digital platform providing granular, multi-level insights (DISCOM, feeder, transformer) and advanced analytics for system operators and regulators. The paper highlights significant benefits in terms of improved forecasting, grid stability, compliance monitoring, and facilitation of prosumer participation.

11755 An Integrated Geospatial Data Platform for Energy Planning and Analysis in South Wales

This paper presents a geospatial multi-energy data platform for South Wales, UK, designed to support integrated regional energy planning for net-zero transition pathways. The platform combines datasets on electricity and gas networks, energy demand, low-carbon technology uptake, transport infrastructure, power plants, and building stock into a unified GIS-based environment. By harmonising fragmented and incompatible datasets, the platform enables coordinated analysis of cross-sector energy interactions, flexibility options, and infrastructure constraints. Demonstrated through regional and site-level case studies, the platform supports network planning, decarbonisation strategies, and flexibility optimisation while improving data accessibility and collaboration between stakeholders.

12521 Parameter identification of closed-wave characteristics of distributed power supply based on convolutional neural network optimization algorithm and measured data

This paper proposes an improved convolutional neural network (CNN) optimisation algorithm for accurately identifying the low-voltage ride-through and wave-blocking characteristics of Class B distributed photovoltaic power sources. Using measured transient data from a hardware-in-the-loop test platform, the method enhances CNN performance through adaptive edge-filling and hybrid multi-convolution structures, improving both feature extraction and computational efficiency. The optimized algorithm identifies key parameters such as wave-blocking thresholds and active power recovery rates with significantly lower errors than classical methods. Simulation results show strong agreement with measured data and compliance with national standards, demonstrating that the proposed approach enables more accurate modelling and reliable integration of Class B distributed energy resources in power systems with high renewable penetration.

Paper 10109: This paper presents factory acceptance results of a Soft Open Point (SOP). These are power electronic devices that replace traditional mechanical switches that are Normally Open. This allows for bi-directional power flow, while maintaining the characteristics of a radial distribution network. Testing confirms key capabilities including grid-following/forming operations. Deployment of SOP can improve hosting capacity, reliability, and operational flexibility.

Paper 10170: This paper proposes a multi-objective Home Energy Management System (HEMS) to manage household DERs and support grid stability. Using model predictive control, it optimizes cost, peak demand and voltage for homes with DERs. Simulation results show reduced electricity costs, improved resiliency, and elimination of voltage violations. Overall, it demonstrates how coordinated residential energy systems can provide grid flexibility, while delivering economic benefits to prosumers.

Paper 11136: This paper presents distribution equipment described as Soft Open Points (SOPs). These are inverter-based equipment that would replace the mechanical open points on distribution lines, allowing for reactive power exchange between feeders. Although the feeder would still maintain the characteristics of a radial network. This would improve feeders with high penetration of DERs and allow for more flexibility in distribution networks.

Paper 11390: This paper presents a Power Management System (PMS) utilizing a Supervisory Control Theory (SCT) for Hybrid Power Plants (HPP). These types of plants combine traditional synchronous generators and energy storage systems. This allows them to behave as dispatchable and controllable resources. The proposed PMS is validated using a detailed case study using electromagnetic transient simulations of an HPP composing of multiple synchronous generators, PV, wind plants, a BESS and local loads. Results show accurate active power regulation, effective voltage support, and enhanced flexibility of renewable energy.

Paper 12110: This paper presents the need for interoperability frameworks for integrating DERs, AMI, and smart grid applications. It highlights the use of Smart Grid Architecture Model; IEC Stands and standardized data exchange profiles. Results show that while these international standards are a starting point, localized improvements are still necessary for providing true interoperability.

Paper 12141: This paper examines the strategic role of Advance Metering Infrastructure as a key enabler in the transition towards decentralized, digitalized, and sustainable power systems. It identifies trends, regulatory frameworks, across the world. Highlighting key directions such as 2009/72/EC and 2019/944/EU. It then uses this information to address key challenges that the Latin America markets have in comparison to the more established AMI areas.

Paper 12409: This paper presents a memetic algorithm to minimize reinforcement costs, due to electrification. Unlike other methods this one combines a reinforcement-oriented objective aligned with discrete equipment ratings, topology-adaptive coincidence factors, which are recalculated for each configuration. Results of this algorithm on a municipal network shows improvements over traditional optimization planning method.

Paper 12601: This paper presents utilizing enhancing Active Distribution Network (ADN) by integrating a microgrid and optimizing it's use by Multiperiod Optimal Power Flow (MPOPF). Using this methodology to optimizes day-ahead operation by coordinating PV, batteries, EVs, flexible loads, and grid devices to provide ancillary services such as voltage control and flexibility. Test simulations on a real Brazilian distribution network, shows improvements on voltage profiles, reduced losses, and lower costs. Furthermore, the digital twin model demonstrates successful real-time operation, islanding, and fault response, highlighting the role of DERs and microgrids in enhancing grid reliability, resilience, and operational efficiency.

Paper 12637: This paper examines the transition from centralized power systems to decentralized grids using the Internet of Energy (IoE) concept. It proposes an intelligent voltage regulator (IVR) as an "energy router" to coordinate bidirectional power and information flows. The IVR enables adaptive control of voltage and power, improving stability, reliability, and power quality in networks with high DER penetration. Validations through modelling, simulation, and pilot deployment. The IVR reduces losses and enhances system performance.

Paper 11940 (Jordan). AI-based ramp rate control applied to a 6 MW PV system connected to the Jordanian distribution network. The Jordanian regulator imposes a 12 V limit on the voltage drop during PV ramp events. The fixed 20 % per minute rule helps but does not adapt to changing load and weather. The proposed AI controller, trained on a month of one-minute data, adjusts the ramp rate dynamically and keeps the voltage drop within limits across all tested conditions.

Paper 11129 (UK / Spain). Deep reinforcement learning agent that maximizes CO_2 savings from regenerative braking energy in the Madrid metro. The agent decides in real time whether to inject the energy back to the grid or store it for later, depending on the grid carbon intensity. Trained on real measurement data combined with grid emission factors, the agent recovers a significant fraction of an offline upper bound within a few training hours.

Paper 11533 (China). Deep Q-Network agent that jointly optimizes a steel rolling mill production schedule and its response to time-varying electricity prices and renewable availability. Compared to a genetic algorithm baseline, the DRL approach reduces electricity costs by about 53%, lowers CO_2 emissions by about 48%, and increases renewable utilization by about 4%.

<u>Questions?</u>

> ***Q 1.12:*** *Soft Open Points (SOPs) are being discussed as cost-effective alternatives to traditional grid reinforcements. What are some of the most cost-effective business cases that SOP provide the alternative to? How should the DSO determine appropriate placement of SOPs to maximize their value? Once SOPs are placed how do DSO appropriately incorporate them into their day-to-day operations?*
>
> ***Q 1.13:*** *AMI 1.0 provided a foundational knowledge base of consumer load profiles and troves of data that still is being researched today to increase interoperability. While collection of this data and usage is great for engineering purposes, there was a lot of feedback from regulators about the cost and implementation of the promised use cases. How does AMI 2.0 solve these issues and what use cases that did not pan out as effectively for AMI 1.0 will see the biggest benefit for both the DSO and consumers moving forward? Does AMI 2.0 solve the interoperability issues for control systems that AMI 1.0 did not?*
>
> ***Q 1.14:*** *Hybrid Power Plants paired with additional operating mechanisms of Microgrids can provide great value for ancillary services to the grid. Local controllers and algorithms to support this fast response time are always improving. What steps are being taken by DSOs to support deployment of these devices and*

ensuring that provide the flexibility to support the one grid approach? How do we ensure that their responses will not affect the local operating conditions for the DSO?

Q 1.15: *As grid edge control devices start to coordinate with other grid edge devices without a centralized control; what steps are necessary for a DSO to ensure that false feedback rather it be unintentional or intentional doesn't create runaway conditions that could lower the flexibility and resiliency of the grid?*

Q 1.16: *Several papers in this report (12379, 11129, 11940, 11533) report that reinforcement learning outperforms classical optimization under uncertainty. Have you started using RL agents in operation in your network, and if not, what is preventing it: explainability, safety, regulatory approval, lack of training data?*

PREFERENTIAL SUBJECT 2 – Planning and operations for 2030 and beyond in active distribution systems

Special Reporters: Barbara Herndler (Austria), Josh Snodgrass (USA), Gilles Lancel (France)

PS2 received 49 papers for review with authors providing inputs into this preferential subject.

The papers have been grouped into the following subtopics:

1. **Hosting capacity, voltage constraints and network limits under DER Growth**

Focus: Physical limits of distribution networks under PV/DER integration, including voltage unbalance, hosting capacity, and constraint-driven operation.
Papers: 10337, 10979, 11140, 11148, 11270, 11693, 12365, 12066, 12626

2. **Digitalisation, data models and observability of distribution networks**

Focus: Smart metering, CIM models, state estimation, data-driven observability, and digital infrastructure enabling DSOs.
Papers: 10620, 11076, 12140, 12434

3. **Planning, investment prioritisation & decision support for DSOs**

Focus: Long-term planning, strategic investment decisions, cost-benefit analysis, and prioritization frameworks under uncertainty.
Papers: 10680, 10681, 10721, 11816, 10912, 10613, 10777

4. **Advanced operation, control, and reliability**

Papers: 10977, 11164, 11563, 12294, 12451, 12465, 10190, 10688, 10978, 11127, 11815, 12507, 12509, 11138, 12303, 10716, 12601, 12637

5. **Storage and multi-energy systems in Distribution networks**

Papers: 10606, 11391, 12090, 12221, 12379, 12577, 11768, 11805, 11891, 11220, 12575

The following sub-topics have been considered under preferential subject 2:

Subtopic 2.1: Hosting capacity, voltage constraints & network limits under DER growth

This subtopic focuses on the physical and operational limits of distribution networks arising from increasing penetration of distributed energy resources, particularly PV systems. The papers examine key constraint mechanisms such as voltage rise, voltage unbalance, flicker, and thermal or hosting capacity limits, and how these factors shape the ability of networks to accommodate additional generation. Methodologies range from detailed power flow and field measurement studies to large-scale hosting capacity mapping and optimization approaches. Together, the works highlight both the challenges and mitigation options for integrating high levels of DER while maintaining power quality and network compliance.

Statistics: A total of 18 papers from 12 countries

Summaries:

10337 Flicker from PV Systems

This paper reviews the issue of flicker caused by PV systems, particularly due to cloud-induced variations in PV output power. It explains the mechanisms of flicker generation, the effects of cloud movement and shading, flicker transfer through distribution networks, and findings from international studies and Australian utility experience. The analysis shows that cloud movement produces relatively slow and gradual PV output changes, significantly reducing flicker severity through ramp-rate effects and low flicker transfer from LV to upstream MV/HV networks. The paper concludes that flicker from PV systems is not a significant practical issue. Numerous international studies and utility reports found no meaningful flicker problems associated with PV installations, despite millions of systems being deployed worldwide.

10979 Derivation and Enhancement of Hosting Capacity Considering Three-Phase Voltage Unbalance in Distribution System

This paper investigates the impact of three-phase voltage unbalance on PV hosting capacity in Japan’s 6.6 kV distribution systems, where increasing PV penetration is causing voltage constraints even below thermal limits. Using field measurements and detailed three-phase unbalanced power flow simulations of an actual feeder, the study demonstrates that reverse power flow from PV installations significantly increases voltage unbalance, particularly at feeder ends. The authors develop a detailed feeder-level simulation model incorporating transformer connection phases and sensor measurements to derive PV hosting capacity considering voltage unbalance constraints. In addition, the paper proposes adjusting the connection phases of single-phase transformers according to actual power flow conditions, showing that voltage unbalance can be mitigated and PV hosting capacity increased without curtailing installed PV capacity.

11140 Definition of hosting capacity maps in MV distribution networks

This paper presents a hybrid methodology for large-scale hosting capacity (HC) assessment in active distribution networks with high PV penetration. The approach combines GIS-based territorial analysis, probabilistic power-flow simulations, and machine learning to estimate the capability of medium-voltage networks to integrate additional distributed energy resources. Morphological and land-use indicators are extracted from geospatial data to characterise network archetypes and support scalable HC estimation. The methodology is validated on 110 real MV networks in Italy under 2030–2050 growth scenarios. Three main archetypes, urban, transition, and rural, are identified, showing distinct hosting-capacity behaviours over time. Results indicate that rural networks are more prone to future saturation, while urban networks maintain relatively stable hosting margins. A Random Forest classifier achieved 77.3% accuracy in predicting network criticality using only morphological indicators, demonstrating the potential of AI-based screening tools to support DSO planning, prioritise detailed simulations, and enable high-granularity hosting-capacity mapping.

11148 Electricity Self-Sufficiency Improvement at a Holiday Park Resort under Local Grid Constraints

This paper presents a techno-economic and emissions assessment framework for integrating on-site renewable generation and BESSs at large holiday resorts operating under distribution network constraints. Using a real-world resort in Wales, UK, the study evaluates how DNO-imposed import, export and installed generation limits influence feasible low-carbon system designs. A mixed-integer linear programming optimisation framework is applied to coordinate solar PV, wind generation and BESS operation, with scenarios compared using technical, economic and emissions KPIs. Results show that increasing renewable generation provides the greatest improvements in self-sufficiency and emissions reduction, while BESSs mainly reduce curtailment and exports under export-constrained conditions. The study highlights the trade-offs between maximising self-sufficiency and achieving balanced techno-economic performance, demonstrating that network constraints significantly restrict the accessible design space and emphasising the importance of integrated planning approaches for large energy-intensive sites.

11270 Utilizing distributed generation of PV technology as an additional solution to constrained medium voltage networks

This paper investigates how increasing PV penetration in South African medium-voltage distribution networks can be used to improve network hosting capacity through optimal placement of distributed generation (DG). Using Particle Swarm Optimization (PSO) integrated into power system analysis software, the study develops a tool to determine the optimal size and location of PV systems while respecting voltage, thermal, rapid voltage change, and fault-level constraints. Simulation results across different feeder scenarios show that strategically placed PV systems can significantly improve voltage profiles and relieve network constraints, with network capacity improvements reaching over 90% in some cases. The research also introduces an objective function linking network capacity improvement to PV generation (%/MW), providing a practical metric for DG planning.

11693 Photovoltaic Renewable Energy Systems for Power Quality Improvement of Electrical Networks

This paper investigates the impact of renewable distributed generation (DG) and reactive power control on the performance of electrical distribution networks. Using a simulated medium- and low-voltage distribution system, the study compares three operating scenarios: without DGs, with DGs but no automatic control, and with DGs using a voltage-reactive power Q(U) control strategy. The results show that integrating DG units such as PV and wind turbines significantly improves voltage profiles and reduces active and reactive power losses, while the proposed automatic Q(U) control further enhances network performance by regulating reactive power injection and absorption. Compared to the base case without DGs, energy losses were reduced by 27% with DG integration alone and by up to 43% when combined with automatic reactive power control, demonstrating the effectiveness of DG-based voltage regulation for improving distribution network efficiency and stability.

Paper 12365 (Australia). Comparison of two approaches to dynamic operating envelopes (DOE) on 52 LV networks across 3 MV feeders in Queensland. The traditional Scheduled Operating Envelope (SOE) is built from conservative seasonal assumptions; the proposed model-free DOE uses AMI data and a machine-learning grey-box model to estimate the network state without explicit impedance model. Under baseline conditions with optimal allocation, the MF-DOE curtails 0.2% of the energy that could be exported against 3.9% for the SOE; under a 100% solar uptake scenario, 1.9% against 5.1%. The voltage prediction accuracy drops below 1 V RMSE above 20% AMI coverage.

Paper 12066 (Thailand). Voltage regulation study on a residential area of northern Bangkok with 218 PV-equipped households. Smart meter data from January 2024 and a power system analysis model are used to evaluate autonomous Q(U) smart inverter control. Reactive power absorption during peak PV generation, reactive power injection during low-voltage periods: voltage fluctuations are significantly reduced, and the profile remains within acceptable bounds without operator intervention. The effectiveness depends on the installer correctly configuring the inverter, which is not always the case.

Paper 12626 (Finland). Measurement-based study of the harmonic emission of 20 kW DC fast chargers. The harmonic spectrum is measured up to the 50th order in the lab and injected into a detailed 20/0.4 kV Finnish feeder model. THDi (Total Harmonic current Distortion) between 6 and 12% for one charger. With several chargers operating in parallel, the 5th and 7th harmonics dominate and neutral current grows because of triplen components. Up to 6 chargers at the same node respect EN 50160 and IEEE 519 limits, but the result is very sensitive to phase alignment.

Questions

Q 2.01: *How should hosting capacity be defined and evaluated across LV, MV, and HV networks under high PV and DER penetration, and how do interacting constraints such as voltage limits, thermal loading, voltage unbalance, flicker, and harmonic distortion jointly determine network limits?*

Q 2.02: *To what extent can advanced operational and planning strategies, such as inverter-based voltage control optimal DG placement, transformer phase reconfiguration, and reactive power management, increase hosting capacity without traditional network reinforcement, and under what conditions do these methods remain effective?*

Q 2.03*: How transferable and scalable are different hosting capacity assessment approaches (deterministic, probabilistic, GIS-based, and AI-driven methods) across different network topologies and regional conditions, and how can local feeder-level insights be consistently integrated into system-wide planning?*

Q 2.04: *How do Dynamic Operating Envelopes and increasing grid observability (AMI, sensors, state estimation) reshape operational hosting capacity in distribution networks, and what level of visibility is required to reliably implement model-free or adaptive operating frameworks?*

Subtopic 2.2: Digitalisation, data models and observability of distribution networks

This subtopic covers the digital transformation of distribution systems through advanced metering infrastructure, standardized data models, and improved state estimation and observability techniques. The papers explore how smart meters, CIM-based network representations, and data-driven estimation methods enable better visibility of low- and medium-voltage grids, even under limited measurement availability. A strong emphasis is placed on interoperability, scalability, and leveraging data to support real-time monitoring and planning. Overall, the contributions show how digital infrastructure forms a foundational enabler for active and data-centric distribution system operation.

Statistics: A total of 4 papers from 4 countries

Summaries:

10620 Transition towards Prepaid Smart Metering in India-Framework for Uninterrupted Operations in Active Distribution Systems

This paper presents the role of prepaid smart metering and AMI in improving India's distribution systems and enabling large-scale rooftop solar integration. Using data from deployments of over 2.5 million smart meters under the RDSS scheme, the study highlights benefits such as improved billing efficiency, reduced aggregate technical and commercial (AT&C) losses, real-time grid visibility, and enhanced consumer engagement. The paper also addresses operational challenges caused by increasing DER penetration, particularly voltage rise issues in low-voltage networks with high rooftop solar adoption. By leveraging smart meter voltage data and implementing inverter reactive power control through standardised communication protocols, the proposed solution demonstrates significant reduction of overvoltage events while maintaining regulatory voltage limits.

11076 Modelling unbalanced LV distribution networks using the IEC Common Information Model

This paper investigates the application of the IEC Common Information Model (CIM) for modelling unbalanced three-phase distribution networks. CIM, defined through IEC 61970-301 and IEC 61968-11, provides a standardised and interoperable framework for representing electrical network components and exchanging utility data. The study explains how CIM classes can model phase-specific characteristics of switches, lines, transformers, loads, generators, and measurements to support detailed unbalanced network representation. Two real-world case studies from are presented to demonstrate practical implementations of unbalanced CIM modelling in low-voltage networks. The analysis shows that while CIM supports advanced phase-level modelling, current utility implementations often rely on custom extensions and partially balanced assumptions for operational and integration purposes. The paper concludes that CIM offers a strong foundation for distribution network interoperability and advanced applications, but additional standard development is still required to fully support unbalanced distribution system modelling.

12140 Standardization as a Foundation for the Digital Transformation of Utilities into DSO: The Case of AMI in Colombia

The paper examines how AMI and smart grid digitalisation support the transition from traditional distribution networks to active DSOs. It highlights the role of smart meters, real-time data, interoperability, and cybersecurity in improving grid reliability, efficiency, renewable integration, and customer participation. A major focus is the Colombian AMI standard NTC 6079, which defines technical and cybersecurity requirements for smart metering systems and has become the foundation for AMI deployment in Colombia and a reference for other Latin American countries. The study concludes that AMI systems are essential for enabling smarter, more flexible, and decarbonized electricity networks.

12434 Error propagation in the state estimation and prediction of distribution grids with a limited database

This paper investigates whether accurate low-voltage state estimation (LVSE) and forecasting can be achieved without transformer or feeder measurements by leveraging upstream medium-voltage state estimation (MVSE) and limited smart meter data. Using a combination of real MV grid data and synthetic yet realistic LV networks, the study evaluates different measurement penetration scenarios and applies weighted least squares estimation alongside a deep-learning forecasting model. Results show that with around 20% smart meter penetration and reliable MVSE outputs, LVSE can accurately estimate line loadings and bus voltages even without secondary substation measurements, reducing the need for costly grid digitalisation.

<u>Questions</u>

> ***Q 2.05***: *How should standardized data models (e.g. CIM and related IEC standards) be extended and applied to enable interoperable, scalable representation of unbalanced, highly distributed, and converter-rich distribution networks, while ensuring cybersecurity and practical deployability in AMI systems?*

Q 2.06: *What is the role of data-driven and AI-based methods (e.g., machine learning, CGANs, deep learning) in improving state estimation, forecasting, and scenario generation in data-scarce environments?*

Q 2.07: *To what extent can digital twins and combined MV-LV observability frameworks reduce the need for physical infrastructure upgrades in distribution system monitoring and planning, and what level of measurement penetration is required for reliable system visibility?*

Subtopic 2.3: Planning, investment prioritisation & decision support for DSOs

This subtopic addresses long-term planning and investment decision-making in increasingly complex distribution systems facing electrification, DER growth, and budget constraints. The papers present frameworks for strategic distribution system planning, risk-based investment prioritisation, and cost-benefit evaluation of grid modernisation measures. Scenario-based analysis and optimisation methods are widely used to assess future uncertainties and quantify reliability and resilience impacts. Collectively, the papers emphasise the need for transparent, data-driven, and economically grounded methodologies to guide infrastructure investments and ensure efficient grid development.

Statistics: A total of 7 papers from 4 countries (US dominant)

Summaries:

10680 Distribution Strategic Planning to Prepare for Disruptive Future Scenarios
This paper presents Distribution Strategic Planning (DSP) as a long-term, system-wide planning approach that helps DSOs address emerging challenges such as electrification, DER growth, large new loads, climate risks, and evolving customer expectations. Unlike traditional tactical planning focused on short-term infrastructure upgrades, DSP uses scenario-based analysis and stakeholder engagement to evaluate future risks, opportunities, and investment strategies across the distribution system. The paper introduces a structured DSP framework covering problem definition, risk assessment, evaluation of alternatives, and strategy implementation, alongside advanced methodologies for strategic capacity and resilience planning. Case studies demonstrate how these approaches can identify future capacity constraints, infrastructure needs, and resilience improvements under high electrification and extreme weather scenarios. The paper concludes that DSP will play a key role in enabling reliable, resilient, and cost-effective grid modernization in increasingly complex power systems.

10681 Distribution Investment Prioritization and Justification
This paper examines how DSOs can prioritise distribution investments amid growing pressures from electrification, DER integration, data centre growth, ageing infrastructure, and increasing reliability and resilience expectations, all under constrained budgets. It highlights the role of investment prioritisation within the broader distribution planning process and reviews current DSO practices, including risk-based scoring, benefit-cost analysis, and emerging value-model approaches that translate risks and benefits into a common economic scale. The paper identifies key challenges such as comparing dissimilar investments, inconsistent metrics, limited data availability, stakeholder scepticism, and balancing discretionary and mandatory investments. It also reviews the wide range of metrics used across categories including capacity, reliability, safety, asset condition, customer impacts, and compliance. The paper concludes that DSOs need more transparent, data-driven, and objective prioritisation methodologies to support defensible investment decisions, improve stakeholder

confidence, and enable reliable, resilient, and affordable grid modernization in increasingly complex distribution systems**.**

10721 A Cost-Benefit Framework for Grid Modernization Based on Forecasted Reliability Outcomes

This paper presents the Long-Term Model (LTM), a quantitative framework for supporting electric utility modernization and investment planning. Using Puerto Rico as a case study, the framework combines historical reliability data, forecasting methods, rational-function benefit curves, and constrained optimisation to evaluate the reliability impacts of infrastructure investment portfolios under budget limitations. The methodology estimates expected improvements in reliability metrics such as SAIDI (system average interruption duration index) by linking modernisation programs, including distribution rebuilds and vegetation management, to measurable reliability benefits while accounting for diminishing returns. The results demonstrate how the LTM can support transparent, data-driven comparison of alternative investment strategies and help utilities prioritize investments that improve long-term reliability, resilience, and capital efficiency.

11816 A Conceptual Framework for Planning Active Distribution Systems under Accelerated Expansion of Electric Vehicle Charging Infrastructure

This paper presents a framework for flexible expansion planning of active distribution networks under uncertain EV charging growth. Using a modified CIGRE-14B medium-voltage benchmark network, the study models disruptive fast-charging EVCS demand through stochastic Geometric Brownian Motion (GBM) load growth and high-power charging shocks at downstream buses. The framework evaluates conventional reinforcement planning against an integrated flexibility-based strategy that combines photovoltaic DER and DESS to mitigate voltage drops, overloads, and expected energy not supplied (ENS). Results show that downstream EVCS integration significantly reduces voltage margins and increases feeder stress, while strategically placed DER/DESS improve voltage support, reduce peak loading, and defer costly network upgrades.

Paper 10912 (France). Probabilistic long-term planning method for MV networks facing successive waves of distributed generators with uncertain nominal capacities. Tested on a CIGRE benchmark over 15 years (three 5-year stages), comparing a blind approach, two deterministic approaches (medium and maximum), and a probabilistic one with a tuneable "risk rate" parameter. Main finding: too-tight deterministic sizing creates threshold effects when the real scenario turns out to be heavier than expected; the probabilistic approach sits between the two extremes with an explicit tuning parameter.

Paper 10613 (India). Practical planning challenges of an Indian DISCOM (distribution company) facing 500 GW of non-fossil capacity nationally and 30 % EV penetration by 2030. Identifies the peak shift phenomenon: rooftop solar masks daytime transformer loading, but the actual thermal peak now occurs in the evening when solar drops to zero. Also describes the transition from DISCOM mindset (reactive operation) to DSO mindset (forecasting, real-time awareness, proactive flexibility management).

Paper 10777 (France). OPHELIA project, first field-scale ±5 kV MVDC network for linear PV collection, near Caderousse in the south of France which forms part of a 1 MWp demonstrator above a cycling route. Because no standard fully covers MVDC at distribution level, the project built on HVDC and MVAC standards and validated the system through a Hardware-in-the-Loop test bench. Field installation completed in 2025. Estimated national potential of linear PV in France is around 40 GWp along rivers, dykes, motorways and cycling routes.

<u>Questions</u>

Q 2.08*: How should DSOs design long-term distribution planning frameworks that can robustly handle deep uncertainty in electrification, DER growth, EV adoption, and climate-driven demand changes, while remaining adaptable as system conditions evolve?*

Q 2.09*: How can DSOs compare and prioritise heterogeneous investments (reinforcement, smart grid technologies, flexibility solutions, and maintenance) using unified frameworks that integrate cost, reliability, resilience, and other system-wide value dimensions?*

Q 2.10: *What is the role of probabilistic modelling and scenario-based planning in modern distribution system investment decisions, and how do DSOs balance risk, cost, and regulatory acceptance when moving beyond deterministic planning approaches?*

Q 2.11: *Paper 10613 describes a peak shift phenomenon where rooftop solar masks the daytime loading of distribution transformers, so that the actual thermal peak now occurs in the evening. Do you observe the same pattern in your network, and has it changed how you assess transformer loading and overload risk*

Subtopic 2.4: Advanced operation, control, and reliability

This subtopic focuses on advanced operational methods and control strategies that enhance the reliability, flexibility, and resilience of modern distribution systems. The papers cover topics such as fault location techniques, grid-forming converter control, probabilistic reliability assessment, and scenario generation for system analysis. They also explore novel integration concepts such as MVDC railway microgrids and large-scale innovation platforms for future grid architectures. Overall, the research demonstrates how advanced control, modelling, and reliability assessment techniques are essential for managing highly dynamic and converter-dominated active distribution networks.

Grid operations is evolving with newer centralized control systems like Advance Distribution Management Systems (ADMS) and Distributed Resource Management Systems (DERMS). Combining these systems with the latest technology deployments to the grid like DERs, Electrification, and Flexibility they present challenges to the DSO as we transition into 2030 and beyond. Consumers are also demanding increased system resiliency from their DSOs as their electrical demands increase. These papers address that and more!

Statistics: A total of 16 papers from 13 countries

<u>Summaries:</u>

10977 Fault Locating Using TDR Synchronized with the Phase of Supply Voltage on Overhead Distribution Lines

This paper presents a novel fault-location method for 6.6 kV overhead distribution lines in Japan using Time Domain Reflectometry (TDR) synchronized with the AC voltage phase. Unlike conventional approaches that require continuous acquisition of healthy reference waveforms, the proposed method identifies arc faults using only waveforms captured during the fault period by exploiting the disappearance of fault reflections near AC voltage zero crossings. Experimental validation on a test distribution feeder demonstrated that the method can accurately locate faults within approximately 10 m while avoiding pulse interference through controlled phase offsets between devices. The study highlights the potential of phase-synchronized TDR measurements to improve restoration speed, reduce operational burden under workforce shortages, and support faster reconnection of DERs in future distribution systems.

11164 Optimizing voltage management and transformer design in MV networks with high distributed energy resource penetration

This paper investigates the use of grid-forming converters, particularly virtual synchronous generator (VSG) control, for improving voltage management in medium-voltage networks with high distributed energy resource penetration. Through EMT simulations, the study demonstrates that VSG-based control can provide stable voltage regulation, synthetic inertia, islanded operation, black-start capability, and effective fault ride-through under varying grid conditions. Compared to grid-following and droop-based approaches, VSG offers improved dynamic support and explicit inertia tuning, although it introduces greater control complexity and sensitivity to parameter tuning. The results also highlight practical implementation challenges, including current limiting, protection coordination, communication delays, and stability issues in high short-circuit-ratio networks. Overall, the paper concludes that grid-forming VSG converters are a promising technology for future active distribution networks, provided that careful tuning, protection adaptation, and further hardware validation are carried out.

11563 A Reliability Assessment Method Integrating CGAN-Generated Source-Network-Load Scenarios for Active Distribution Systems

This paper proposes a conditional reliability evaluation framework for active distribution systems (ADS) that integrates Conditional Generative Adversarial Networks (CGANs) with Monte Carlo simulation (MCS) to model reliability under diverse source-load operating conditions. The framework generates condition-aware renewable generation and load scenarios using CGANs, combines them with sequential system-state sampling, and evaluates the impact of distributed generation-supported load restoration on system reliability. Using an IEEE 37-bus test system with wind-based distributed generators, the study demonstrates that reliability performance is strongly dependent on specific supply-demand conditions, with higher renewable availability improving reliability while increased load demand degrades it. The results show that the proposed conditional assessment approach captures operational dependencies and high-dimensional correlations more effectively than conventional reliability evaluation methods, providing a more realistic basis for ADS planning and resilience analysis.

12294 Linear PV Power Plant Integration into Electrical Railway Microgrid via MVDC Architecture

This paper investigates the integration of linear photovoltaic (LPV) systems into Switzerland’s railway infrastructure as part of the country’s Energy Strategy 2050 and decarbonization goals. By installing solar panels between railway tracks and connecting them through a railway microgrid, the study explores how underutilized railway corridors can support renewable energy generation while leveraging the railway electrical network’s higher tolerance to voltage fluctuations. A case study on a railway line demonstrates a modular LPV design with an 864 kWp capacity, integrated via LVDC and MVDC converter architectures. Simulations show that the system can successfully inject solar power into the railway grid without disrupting train operations, while maintaining acceptable voltage levels and high transmission efficiency. The work concludes that railway-integrated LPV systems are technically feasible and can strengthen grid resilience, diversify energy supply for electric mobility, and contribute to transport decarbonization.

12451 Scaling Innovation to System Impact - How the Kopernikus Flagships Translate Research into Grid-Ready Solutions for 2045 Climate Targets

This paper presents key results from the third phase of Germany’s Kopernikus energy research initiative, focusing on technologies for future climate-neutral power systems. The study investigates solutions for sector coupling, digitalisation, and large-scale system validation, including energy hubs optimised with graph neural networks, scalable low-voltage DC grids for EV and battery integration, regional battery coordination, condition monitoring in 400 kV substations, and cyber-secure firmware and patch management. In addition, the paper introduces standardised flexibility trading using the Energy Flexibility Data Model (EFDM) and a large-scale real-time simulation platform for RMS/EMT and hardware-in-the-loop studies. The results demonstrate that coordinated control, advanced digitalisation, and standardised simulation and communication platforms can improve grid flexibility, operational reliability, renewable integration, and the validation of converter-dominated future power systems.

12465 Targeted Scenario Generation in Low-Voltage Distribution Grids Using a Genetic Algorithm

This paper presents a genetic algorithm-based framework for targeted scenario generation in low-voltage distribution grids with high penetrations of distributed energy resources such as PV systems, battery storage, heat pumps, and EV charging stations. Unlike traditional scenario-generation methods based on historical sampling or stochastic approaches, the proposed framework can explicitly generate grid scenarios with predefined limit violations, including voltage violations, line and transformer overloads, and combinations of these events. The method allows users to define the affected grid elements, the timing and duration of violations, and the severity of the constraints while maintaining realistic time-series behaviour. Using a CIGRE low-voltage benchmark grid, the results demonstrate that the framework can successfully generate targeted overvoltage, overload, and combined violation scenarios. The proposed approach provides a flexible and computationally efficient tool for grid planning, congestion management studies, and the development of future operational and control strategies in active distribution networks.

Paper 10190: This paper presents that integrating Battery Energy Storage Systems (BESS) with advanced tools like ADMS, DERMS, and FLISR (fault location, isolation and service restoration) can significantly improve electric grid resilience. It shows that value stacking of these benefits can be achieved with minimal impact to the original business case(s) of the BESS/DER. It also models out real-life examples of these uses cases showing the potential reliability improvements possible.

Paper 10688: This paper presents control methodologies for DERs using DERMS. It outlines current curtailment methods such as Last in First Out and Pro-Rata and then proposes using a hybrid mythology of the two utilizing DERMS. Simulations show that hybrid method maximizes DER integration. Enabling more DER capacity, while maintaining stability with the real time control of DERMS.

Paper 10978: This paper presents utilizing a full-scale demonstration facility representing a typical distribution grid in Japan to test local automatous control methods. The demonstration shows that by coordinating reactive power control among PV systems it can maintain stable voltages, while effectively adapting to dynamic conditions.

Paper 11127: The paper outlines work to advance static and dynamic state estimation for the grid, improving operational decision making. It uses a Modified Augmented Nodal Analysis framework. Iterative Extended Kalman filters help in estimating variable DER in its decision-making process. Results show that these methods outperform traditional methods in accuracy, while being scalable.

Paper 11815: This paper introduces a new comprehensive approach to outage detection algorithms in Outage Management Systems (OMS). This algorithm provides support towards the ever-facing dynamic of configurations, multiple power sources and evolving operation states. Traditional OMS struggle to incorporate the flexibility of these resources. The paper’s approach enhances diagnostic speed, reduces false positives and improves outage response with crew prioritization.

Paper 12507: The paper addresses challenges of DER operation during asymmetric faults by proposing a coordinated voltage support strategy. It introduces coupled sequence network models that account for cross-sequence effects, and an estimation method enabling fast, communication-free coordination among converters. The proposed Sequence-Coupled Coordinated Voltage Support (SCCVS) optimizes current injection to improve voltage stability. Simulations show it significantly outperforms existing LVRT (low-voltage ride-through) strategies, enhancing voltage support and balance across different fault types and network topologies.

Paper 12509: This paper addresses stability risks caused by distribution network topology reconfiguration, particularly for voltage source converters (VSCs). It proposes a software-defined controller (SDC) that evaluates risks, in real time, and executes optimized switching actions. The method suppresses voltage oscillations and instability during switching events without requiring additional hardware. Case studies show voltage disturbances reduced by over 35%.

Paper 11138 (Italy). Real case study on the Milan area, on how the flexibility from MV and LV DERs can be aggregated at the HV/MV interface and made visible to the TSO without exchanging commercially sensitive data. The proposed algorithm combines yearly load and generation profiles at one primary substation, CEI 0-16 capability curves, and the installed DER capacity, to produce an aggregated PQ capability curve. Applied to the "PS Sud" substation (5 MW PV, 0.4 MW hydro, 27 MW CHP) with projection to 2030.

Paper 12303 (Colombia). Strategic analysis of the conditions under which VPPs can be deployed at scale in Colombia. Structured diagnosis of 17 gaps across three dimensions (technology, regulation, business) and 12 strategic actions to close them. The technology gaps are mostly about DERMS interoperability, LV observability and grid-forming BESS adoption; the regulatory gaps focus on the absence of a formal aggregator role; the business gaps relate to IT/OT integration, training of DERMS operators, and strategic vision.

Paper 10716 (USA). Comparison of three strategies a DSO can use to harness EV flexibility: flexible connection agreements (curtailment rights traded against faster or cheaper connection), pay-for-performance services, and time-varying retail pricing. The paper draws on Californian pilots and argues that the three approaches are complementary rather than substitutes. Flexible connection agreements are most useful when the constraint is a long lead-time for grid reinforcement.

Paper 12601 (Brazil) This paper addresses the transition toward active distribution networks driven by increasing penetration of distributed energy resources (DERs). It proposes a Multiperiod Optimal Power Flow (MPOPF) framework to coordinate the operation of DERs, including distributed generation, storage, electric vehicles, and microgrids, for the provision of ancillary services such as voltage support and demand response. The approach is validated using a 90-bus test feeder and a real distribution network in Curitiba, Brazil. In addition, a digital twin of a microgrid is developed to analyse real-time operation and SCADA integration. Results demonstrate improved operational efficiency, cost reduction, and enhanced flexibility for distribution system operators managing evolving grid conditions.

Paper 12637 (Russia) This paper examines the transition toward decentralized, renewable-based distribution systems under the Internet of Energy (IoE) paradigm. It identifies limitations of traditional centralized grids and proposes an intelligent voltage regulator (IVR) as a key enabling technology acting as an energy router. The IVR provides adaptive control of voltage and active/reactive power flows, supporting bidirectional energy exchange and improved system stability. Its performance is validated through modelling, simulation, and pilot implementation. Results indicate enhanced power quality, reduced losses, and increased reliability, particularly in networks with high renewable penetration. The IVR offers a practical solution for integrating distributed energy resources into flexible, cyber-physical distribution networks.

<u>Questions:</u>

> ***Q 2.12***: *How should fault detection, localization, protection, and restoration strategies evolve in distribution networks with high DER and inverter penetration, and what is the appropriate balance between AI-based, rule-based, and real-time control approaches?*
>
> ***Q 2.13:*** *How can distribution systems maintain voltage stability, inertia support, and fault ride-through capability in converter-dominated networks, and what is the role of grid-forming technologies (e.g. VSG, MVDC microgrids) in enabling this transition?*
>
> ***Q 2.14***: *How can probabilistic reliability assessment and advanced scenario-generation techniques better capture the interactions between load, renewable generation, and network topology, particularly under extreme or rare operating conditions?*
>
> ***Q 2.15:*** *How should DERMS, ADMS, state estimation, and hosting capacity tools evolve to support real-time coordination of distributed resources, and what is needed to improve their value beyond system-level constraint management toward local network optimisation?*
>
> ***Q 2.16:*** *How should DSOs and TSOs design coordination mechanisms and market-based approaches (e.g. flexible connection agreements, dynamic pricing, aggregated capability exchange) to efficiently activate DER and EV flexibility while maintaining system security and transparency?*

Sub-topic 2.5: Storage and multi-energy systems in Distribution networks

This sub-topic examines the evolving operational, economic, and system integration roles of battery energy storage systems (BESS) across diverse grid contexts. The contributions highlight distribution-level participation in ancillary service markets enabled by fast automatic generation control response, alongside the continuing importance of value stacking through arbitrage and peak shaving. They further explore optimisation strategies, illustrating trade-offs between revenue maximisation and accelerated degradation, and emphasise the sensitivity of project viability to capital cost assumptions. Industrial and grid-edge applications demonstrate the resilience value of grid-forming BESS, particularly in maintaining critical loads and enabling seamless islanding. System-level studies address their role in weak grids, including stabilisation, energisation, and renewable synchronisation. Advanced control approaches in microgrids underscore the benefits of data-driven optimisation, while network planning analyses reveal the critical influence of fault-level constraints and transformer characteristics on large-scale integration.

A total of 11 papers from 11 countries.

Summaries:

Paper 10606 (India). Kilokari project, a 20 MW / 40 MWh LFP battery connected at 11 kV in South Delhi. First distribution-connected BESS in India authorised to participate in the Secondary Reserve Ancillary Services (SRAS) market. End-to-end AGC (automatic gain control) response is between 8 and 20 seconds, of which only about 3 seconds come from the converter itself. The plant runs around two cycles per day, with most of the revenue coming from arbitrage and peak shaving. The paper points out that downward regulation is currently settled in a way that makes SRAS unattractive for storage in India.

Paper 11391 (Brazil). Hourly co-simulation of a grid-forming BESS over 10 years, comparing a rule-based threshold dispatch and a yearly MILP, coupled with a degradation model combining calendar ageing and equivalent cycles. The MILP increases revenues significantly compared to the heuristic but accelerates state of health (SOH) degradation. Under the assumed CAPEX of 300 MU/kWh, the project is not profitable on arbitrage alone, with a break-even CAPEX around 70 MU/kWh.

Paper 12090 (Chile). Conceptual engineering of a 5 MW / 15 MWh grid-forming BESS at a refinery, sized as a resilience asset to keep critical process loads alive during voltage sags. Brownfield aspects are central: retrofit of boundary breakers, seamless transition to island mode, and a cost-of-unserved-energy methodology used to monetise avoided crash stops (~USD 1.3 M per event). With the resilience value included, the project shows a positive NPV (USD 2.7 M) and a payback around 5.5 years.

Paper 12221 (Saudi Arabia). EMT simulation of a 100 MW / 400 MWh BESS coupled with a 150 MWp PV plant on a 380/132 kV substation. The grid-forming BESS energises the main transformer with a soft-start ramp that brings the peak inrush from ~6 pu to less than 2 pu and limits voltage dips to 3 to 5%. The PV plant is synchronised in less than 150 ms after the BESS sets a stable reference. The case is interesting because it tests GFM in a weak-grid context with very high ambient temperature.

Paper 12379 (Germany). Comparison of four control strategies (rule-based, MPC, supervised learning, reinforcement learning (RL) with PPO) on the same microgrid test case with 500 kWp PV, varying load and a 1 MWh battery. The RL strategy obtains the lowest operating cost (94 k€/yr vs 118 k€/yr for the rule-based), the highest self-consumption (85 %), and degrades less than MPC under ±15% forecast error. Clean benchmark on identical metrics.

Paper 12577 (Greece). Mixed-integer programme to identify the optimal HV/MV transformers for the connection of about 900 MVA of BESS in the Greek mainland network by 2027. Out of 230 substations, 70 transformers come out as priority sites. The main finding is that short-circuit withstand capability of the transformer, not its thermal rating, is the binding constraint, and that 25 MVA transformers (with higher per-unit impedance) are preferred over 50 MVA units. The methodology was adopted by the Greek Ministry of Environment and Energy.

Paper 11768 (UK / Serbia). Feasibility study for a 100 MW industrial site in Western Europe whose grid connection will not be ready in time for operations start. With a hydrogen pipeline available, the option of modular gas turbines fuelled with 100% hydrogen is studied. The paper goes through the practical issues: flashback risk in lean-premixed combustors, higher NOx emissions, hydrogen embrittlement of materials, larger fuel system, fire detection on an almost invisible flame. The technology works, but burner and auxiliary systems are not yet standard products.

Paper 11805 (South Korea). Distributed optimisation framework for several hydrogen-integrated microgrids interconnected to a distribution network, with peer-to-peer hydrogen exchange and trailer-based delivery to refuelling stations. Consensus ADMM scheme combined with a Wasserstein-based distributionally robust optimisation to handle price uncertainty. About 37% cost reduction compared to a Dijkstra routing baseline, while preserving the privacy of each microgrid operator.

Paper 11891 (South Korea). Integrated planning and operation framework for sector coupling between electricity, heat and hydrogen, applied in South Korea. The carbon cap is treated as a hard design constraint, not as a performance metric. The result is nuanced: sector coupling helps when the grid is constrained, but its marginal value drops as transmission capacity increases, and absorbing curtailment through hydrogen does not automatically reduce emissions if the hydrogen does not displace fossil fuel inside the system boundary.

Paper 11220 (Russia). Methodology for converting existing district boiler houses into mini-CHPs with gas-piston engines, combined with electric boilers, heat pumps and thermal storage. Applied to a real-life settlement, the study shows that integrating flexible thermal resources significantly increases the utilisation factor of cogeneration units and reduces installed gas boiler capacity. Reported payback periods of 3 to 5 years, subject to local energy prices.

Paper 12575 (Greece). Digital-twin study of the hybrid pumped-storage and wind plant on the non-interconnected island of Ikaria, Greece (two reservoirs, pumping station, Pelton turbine). The DT, calibrated against minute-resolution SCADA data, estimates that around 20% of the existing wind park output, currently curtailed, could be valorised by sending it to the pumping station, without any change to the grid. The next logical step identified is to add a BESS for short timescales.

Questions:

> ***Q 2.17:*** *How should battery energy storage systems be economically valued in distribution and transmission systems, and to what extent do current regulatory frameworks enable or restrict value stacking across arbitrage, ancillary services, congestion management, and investment deferral?*
>
> ***Q 2.18:*** *Paper 12577 identifies short-circuit withstand capability of HV/MV transformers as the main constraint on BESS hosting in the Greek mainland network. Do you observe the same constraint in your network, and if yes, how are you addressing it: selective reinforcement, current limiting at the converter, or other means*
>
> ***Q 2.19:*** *Which long-duration storage technologies (e.g. pumped hydro, hydrogen, compressed air, thermal storage, second-life batteries) are most likely to play a dominant role in future energy systems, and what are their most suitable applications in power system operation and planning?*

PREFERENTIAL SUBJECT 3 – Rural and industrial electrification: standards, practices and technology options

Special Reporter: Kurt DEDEKIND (South Africa)

PS3 received 17 papers for review with authors from 12 different countries providing inputs into this preferential subject. The following topics are addressed in PS3:

- Advanced Microgrids and Power System Stability for Remote and Industrial Applications. **Papers 10980, 11218, 11271, 11386, 11694 and 11695**

- Network and Asset Design for Efficient Rural and Industrial Power Supply**. Papers 10258, 11216 and 11219.**
- Sectoral Electrification and End-Use Transformation in Rural and Agricultural Contexts. **Papers 10623, 10625 and 11564.**
- Intelligent Planning, Coordination and Monitoring for Distributed Rural Systems. **Papers 10107, 10805, 11935, 12032 and 12134.**

The sub-topics may thus be expanded as follows:

Sub-topic 3.1: Advanced Microgrids and Power System Stability for Remote and Industrial Applications under the banner of *"Microgrid Stability, Protection and Resilience for Rural and Industrial Systems"*

Technical focus:
Islanded/remote microgrids, stability and protection, black-start, fault detection, and frequency control using storage.

These papers are united by a focus on dynamic behaviour, protection, and operational robustness of microgrids serving rural communities or industrial loads, rather than on new network topologies or AI methods.

<u>Questions:</u>

Q 3.01: Storage-assisted stability versus cost and complexity

Several contributions show energy storage being used to stabilise frequency and voltage under abrupt load changes and contingencies, sometimes in place of aggressive load shedding. In remote or industrial microgrids, how should planners balance the technical benefits of sophisticated EESS control (fast droop, coordinated active/reactive support) against added cost, complexity, and operational risk, and what "good practice" design criteria or performance metrics would you recommend as a baseline?

Q 3.02: From case studies to scalable design frameworks

The papers show strong case-specific designs (remote communities, off-grid industrial plants, small islanded systems) optimised for reliability, LCOE and dynamic performance. How can the community move from individual case studies to more generalised design and operation frameworks for microgrid stability, protection and resilience—what are the key modelling assumptions, test cases, or standardised benchmarks that should be shared internationally to accelerate learning and comparability?

A high-level review of the impacted papers follows:

Summaries:

Paper 10980 Simulation and Experimental Verification of Inrush Mitigation and Fault Detection in Inverter-Based Microgrids - Japan

This paper investigates fault detection and inrush-current mitigation challenges in inverter-based microgrids operating in islanded mode. It focuses on earth-fault detection difficulties arising from the disconnection of earth-voltage transformers (EVTs) and reduced system capacitance during microgrid operation. Simulation models validated against experimental results are developed to evaluate countermeasures, including the connection of EVTs and line-to-ground capacitors, across various microgrid configurations. Results demonstrate that these measures consistently restore reliable earth-fault detection, regardless of network scale. The study further examines soft-start strategies for suppressing inverter inrush currents during microgrid startup, confirming their effectiveness while highlighting potential conflicts with regulatory earth-fault protection requirements if soft-start durations are excessively long. The findings provide practical guidance for protection coordination in inverter-based microgrids.

Paper 11218 Stabilisation of Frequency and Voltage in an Off-Grid Power System with Energy Storage under Abruptly Variable Load - Russia

This paper addresses frequency and voltage stabilization in off-grid power systems supplying industrial facilities with abruptly variable loads, where generator capacities are comparable to large consumers. Such conditions cause severe frequency and voltage deviations, including electromechanical resonance and shock frequency changes, leading to accelerated equipment degradation. The study proposes a methodology for analysing generator sensitivity to the load power frequency spectrum and identifying resonant conditions using models of diesel and gas turbine generator sets. Based on this analysis, coordinated electrical energy storage system (EESS) control algorithms are developed, combining disturbance-based and deviation-based control of active and reactive power. Simulation results using real industrial load profiles demonstrate that the proposed algorithms significantly mitigate shock transients and reduce frequency and voltage deviations to levels characteristic of unified power systems.

Paper 11271 Deploying battery energy storage system to enhance the primary frequency response and under frequency load shedding schemes in islanded microgrids – South Africa

This paper investigates the role of battery energy storage systems (BESS) in enhancing primary frequency response and the effectiveness of under-frequency load shedding (UFLS) schemes in small (<100 kW) islanded microgrids. Two real South African case studies—a residential and a commercial microgrid—are modelled using to assess frequency stability following sudden loss of solar photovoltaic generation. Simulation results show that BESS with fast droop-based control can arrest frequency decline within prescribed islanded grid limits, significantly reducing reliance on UFLS. In scenarios without BESS support, tailored UFLS schemes are shown to maintain system stability, although substantial load curtailment is required. The study demonstrates that optimal UFLS settings and reserve requirements are highly dependent on load characteristics and must be designed on a case-specific basis for islanded microgrids.

Paper11386 Serra da Saudade Microgrid: Validation of Operational Autonomy Through Power Flow Simulations and AMI Measurements – Brazil

This paper evaluates the feasibility and operational performance of a microgrid solution implemented in Serra da Saudade, Brazil, as an alternative to costly and slow conventional grid reinforcement. The study focuses on assessing the autonomy of a system combining photovoltaic generation and battery energy storage under islanded operating conditions. Using real consumption data from advanced metering infrastructure, typical load profiles were developed and integrated into power flow simulations to estimate system behaviour. Results show that under favourable solar conditions, the microgrid can sustain continuous operation, while under reduced irradiance it can maintain supply for at least 48 hours. The findings demonstrate that microgrids offer a cost-effective and resilient solution for improving power quality and reliability in remote distribution networks, while enhancing operational flexibility for utilities.

Paper 11694 The development of a hybrid microgrid system to improve the robustness of electrical services in Al Uyaynah City, - Saudi Arabia.
This paper presents the design and evaluation of a hybrid renewable microgrid intended to deliver robust and fully reliable electricity supply to the remote community of Al Uyaynah, Saudi Arabia. A data-driven sizing methodology is developed that integrates photovoltaic generation, wind turbines, and battery energy storage while jointly considering life-cycle costs, component degradation, and resource variability. Using long-term meteorological data and realistic residential load profiles, the study systematically evaluates all feasible generation–storage combinations to achieve 100% power availability. Reliability metrics and the levelized cost of energy (LCOE) are employed as key decision criteria. Results demonstrate that a PV-dominant microgrid configuration with appropriately sized battery storage achieves the lowest LCOE while maintaining full supply reliability, outperforming benchmark solutions obtained using commercial optimization software.

Paper 11695 Black-start Capabilities of the Arholma Microgrid - Sweden
This paper evaluates the black-start performance of the Arholma microgrid in the Stockholm Archipelago, focusing on practical challenges associated with inverter-based energy storage systems. Eight field black-start tests were conducted using grid-forming battery inverters with soft-start voltage ramping, of which only two were fully or partially successful. Repeated failures were primarily linked to current spikes occurring during voltage ramp-up, causing voltage collapse or protection trips. To investigate potential demand-side contributions, Power Hardware-in-the-Loop experiments were performed on a residential heat pump, revealing transient current responses at similar voltage levels. The combined results indicate that customer-side motor loads, particularly heat pumps, may significantly impair black-start success, highlighting the need for coordinated load management and improved inverter protection strategies in islanded microgrids.

Subtopic 3.2: Network and Asset Design for Efficient Rural and Industrial Power Supply under the banner of "*Efficient Network and Asset Design for Rural and Industrial Electrification*"

Technical focus:

Primary/secondary distribution design, cable concepts, automation and reliability enhancement in standalone industrial or rural networks.

These papers share a distribution-network-engineering view of electrification, dealing with voltage levels, line configurations, and protection/automation investments that underpin reliable rural and industrial supply.

<u>Questions:</u>

Q 3.03: Rethinking LV voltage levels and configurations

Raising LV distribution voltages (for example to around 1 kV) and changing conductor configurations can significantly cut technical and non-technical losses and help combat theft in rural networks. How should utilities and regulators decide when such non-standard LV schemes are justified, and what have been the most important practical lessons—both positive and negative—from pilots or roll-outs in terms of safety, customer interfaces, and long-term asset performance?

Q 3.04: Towards integrated planning frameworks for efficient rural networks

The papers address losses, conductor and cable design, and protection/automation as relatively separate decisions. Looking ahead, how can the community better integrate these aspects into unified planning frameworks for rural and industrial networks—for example, combining loss reduction, theft mitigation, EM-field constraints, and reliability targets—so that utilities in different regions can share comparable design methodologies and benchmark their solutions?

A high-level review of the impacted papers follows:

<u>Summaries:</u>

Paper 10258 A smart 1.1kV distribution: The future of loss reduction - India
This paper proposes a novel distribution network design aimed at significantly reducing both technical and non-technical losses in low-voltage power systems, particularly in developing regions. The approach involves increasing the secondary distribution voltage from the conventional 0.433 kV to 1.1 kV and deploying single-phase pole-mounted transformers to supply consumers at standard utilization voltages. By shifting overhead conductors to a higher voltage level, opportunities for electricity theft through direct hooking are effectively eliminated, while reduced current levels lead to lower I^2R losses. The methodology was validated through a pilot implementation in Gujarat, India, demonstrating improved billing efficiency, enhanced system reliability, measurable energy savings, and a cost recovery period of approximately three to four years, indicating strong technical and economic viability.

Paper 11216 Application of Cable Lines of Innovative Designs in Power Supply Systems of Industrial and Agricultural Consumers - Russia
This paper investigates the application of innovative high-voltage cable line designs employing cross-linked polyethylene (XLPE) insulation for power supply systems serving industrial and agricultural consumers. Two alternative transmission configurations—two-phase and four-phase cable lines—are analysed using multiphase computer models developed in AC–DC software. The study evaluates power flow performance, electromagnetic field distribution, energy efficiency, and power quality under various operating conditions. Results demonstrate that both configurations can substantially reduce capital investment and material usage compared to conventional three-phase lines, while maintaining compliance with regulatory limits on electromagnetic exposure and power quality. The proposed models provide a versatile tool for the design and operation of cable networks, including applications in renewable energy integration and geographically constrained environments.

Paper 11219 Optimal Recloser Placement for Improved Reliability in Stand-Alone Industrial Power Supply Systems -Russia
This paper presents a cost-based optimization framework for the strategic placement of FLISR-enabled reclosers in stand-alone industrial power distribution systems operating without connection to centralized grids. The proposed approach minimizes total expected cost by jointly considering recloser capital expenditure and monetized reliability impacts quantified through expected energy not supplied (ENS), while enforcing voltage and thermal operating constraints via penalty terms. Reliability assessment is performed using an analytical N–1 contingency model combined with a two-stage fault isolation and service restoration logic based on graph-theoretic connectivity analysis. A binary genetic algorithm is employed to solve the non-convex placement problem. Application to a real Arctic oil-and-gas distribution network demonstrates significant reductions in ENS and SAIDI and shows that longer planning horizons justify higher automation levels while remaining economically optimal.

Subtopic 3.3: Sectoral Electrification and End-Use Transformation in Rural and Agricultural Contexts under the banner of "*End-Use Electrification of Rural and Agricultural Sectors*"

Technical focus:
Electrification of specific productive sectors (agriculture, remote construction, industrial customers), including new loads and sector-specific risks.

The unifying thread is how electrification and new DER/EV assets reshape specific rural or industrial activities, including their technical and risk characteristics, rather than the design of the network or microgrid per se.

Questions:

> ***Q 3.05: Productive use, flexibility and system risk***
>
> *As agriculture, remote construction and industrial processes electrify—through assets like electric tractors, hydrokinetic systems and EV charging—new load profiles and flexibilities emerge alongside new risks for sensitive customers. How should planners and operators characterize and manage these sector-specific load behaviours (daily/seasonal usage, mobility, process criticality) so that productive use of electricity grows, flexibility is harnessed, and risks such as power-quality issues or process interruptions remain acceptable for rural and industrial users?*

The following paper summaries support this sub-topic:

Summaries:

Paper 10623 Electrifying Agriculture: A Sub-National Roadmap for the Adoption of Electric Tractors - India
This paper presents a sub-national feasibility assessment and strategic roadmap for the adoption of electric tractors in Maharashtra, India, aimed at decarbonizing agricultural mechanization. It analyses tractor usage patterns, crop profiles, and mechanization intensity to evaluate the technical, economic, and environmental viability of replacing diesel tractors with electric alternatives. The study demonstrates that electric tractors offer substantial lifecycle greenhouse gas emission reductions, lower operating and maintenance costs, and competitive payback periods despite higher initial capital costs. It further examines infrastructure requirements, including rural charging ecosystems, solarized feeders, battery swapping, and vehicle-to-grid integration. Policy, financing, and market enablers are proposed to overcome adoption barriers, providing a structured framework to support scalable deployment and sustainable agricultural electrification.

Paper 10625 Seasonally Informed Design and Development of Hydrokinetic Turbines for Off-Grid Power Generation in a Himalayan River - India
This paper presents a seasonally informed design, optimization, and deployment framework for hydrokinetic turbines intended for off-grid power generation in Himalayan riverine environments. Focusing on tailrace flows at a hydropower site, the study integrates long-term discharge analysis, laboratory experimentation, and numerical modelling to develop a site-adapted cross-flow Darrieus hydrokinetic turbine. Parametric optimization of blade number, aspect ratio, and solidity identified an optimal configuration achieving a peak power coefficient of 0.2895. To address challenges posed by seasonal flow variability, debris, and water level fluctuations, a novel suspended dual-turbine floating array is proposed. The results demonstrate the technical feasibility of replacing diesel generator sets with modular hydrokinetic systems for sustainable construction power in remote Himalayan regions.

Paper 11564 Analysis of the Causes and Evolution Mechanisms of High-Voltage Sensitive Industrial Customers' Power Usage Safety Risks with the Integration of Emerging Grid-Connected Entities - China
This paper investigates power usage safety risks faced by high-voltage-sensitive industrial customers following the integration of emerging grid-connected entities such as distributed photovoltaics and electric vehicle charging infrastructure. It proposes a systematic, closed-loop hazard analysis framework that combines multidimensional coupling modelling, dynamic fault evolution analysis, and quantitative risk evaluation. Electrical, equipment, and environmental factors are jointly represented to construct a structured hazard cause database. Hazard evolution is characterised using T–S dynamic fault trees and continuous-time Markov chains, while key risk contributors are identified through Failure Mode and Effects Analysis and Sobol global sensitivity analysis. A digital–simulation dual-drive architecture enables rapid hazard identification and precise source localisation. A real industrial park case study validates the approach, demonstrating over 90% accuracy in detecting and tracing harmonic-induced overheating risks.

Subtopic 3.4: Intelligent Planning, Coordination and Monitoring for Distributed Rural Systems under the banner *of "Intelligent Planning, Coordination and Monitoring of Distributed Rural Power Systems"*

Technical focus:
Advanced optimisation, AI/ML, and signal analysis to plan, coordinate, or monitor decentralised systems that underpin rural or industrial electrification.

These papers are linked by algorithmic or data-driven methods to design, coordinate, or observe distributed systems that support rural/industrial electrification, cutting across specific geographies or sectors.

Questions:

> ***Q 3.06: Trustworthy "intelligent" planning and operation in data-scarce rural systems***
>
> *Advanced optimisation, AI/ML methods and signal-based diagnostics are increasingly proposed for planning and operating distributed rural systems (for example, AI-designed microgrids, dual-optimisation sizing, EMT-based DER detection, and coordinated multi-energy scheduling). How should utilities and system operators in rural or emerging-economy contexts judge when these intelligent methods are mature and trustworthy enough for real-world use—given scarce data, evolving DER portfolios and limited local skills—and what good practices exist globally for validating, explaining, and governing such algorithms so that engineers, regulators and communities can rely on them?*

The following paper summaries are supportive of this sub-topic:

Summaries:
Paper 10107 Efficient energy management architecture of distributed energy resource microgrid site with electrical vehicle supply equipment - USA and Taiwan

This paper examines energy management challenges in behind-the-meter commercial and industrial microgrids integrating distributed generation, battery energy storage systems, and electric vehicle supply equipment. It highlights the increasing complexity of such systems and the inadequacy of existing protocols—particularly the limitations of the Open Charge-Point Protocol (OCPP) for site-level load control. To address this gap, the authors propose a dual gateway microgrid architecture comprising an IEEE 2030.5 client gateway for standardized grid communication and a novel OCPP gateway that enables effective integration of EVSEs into the site energy management system. The proposed architecture facilitates coordinated demand response, load reservation, operational optimization, vehicle-to-grid services, and islanded operation while maintaining interoperability with utilities and preserving user experience.

Paper 10805 Distributionally Robust Coordination Framework for Scheduling and Trading in Large-Scale Networked Hydrogen-Integrated Microgrids with Coupled Transportation and Power Networks – South Korea

This paper proposes a fully distributed coordination framework for scheduling and trading in large-scale hydrogen-integrated microgrids interconnected with distribution and transportation networks. A distributionally robust adaptive consensus ADMM (DRAC-ADMM) approach is developed to jointly optimize point-of-common-coupling electricity exchanges, peer-to-peer hydrogen trading, and transportation-aware hydrogen delivery while preserving agent privacy and scalability. Price uncertainties in electricity and hydrogen markets are addressed using a Wasserstein-based distributionally robust optimization formulation, achieving near sample-average approximation performance with fewer data samples. A KKT-based closed-form consensus update significantly improves convergence speed and numerical stability. Case studies on an IEEE 85-bus network demonstrate enhanced robustness, rapid convergence, and a reduction in operating costs compared with conventional routing-based strategies.

Paper 11935 Determination of Optimal Hybrid Distributed Generation System Using Two Optimization Schemes - Jordan

This paper presents the optimal design of an off-grid hybrid distributed generation system for supplying residential, industrial, and educational loads in a remote region of Jordan. A dual-optimization framework is proposed, integrating a techno-economic assessment and particle swarm optimization for detailed performance validation. Hourly load profiles are developed alongside multi-year solar irradiance and wind speed data to determine optimal sizing of photovoltaic arrays, wind turbines, battery storage, and auxiliary generation. The system is evaluated using key metrics including cost of energy, total net present cost, greenhouse gas emissions, and reliability. Results demonstrate that tailored hybrid configurations significantly reduce lifecycle cost and emissions compared to conventional solutions, with wind turbine hub height and battery capacity identified as critical sensitivity parameters.

Paper 12032 Intelligent Design of Microgrids for Rural Areas Using cGANs and Reinforcement Learning applied in the village of La Marina, Valle del Cauca - Colombia

This paper proposes an artificial intelligence–driven framework for the intelligent design and operation of rural microgrids using conditional Generative Adversarial Networks (cGANs) and Deep Q-Network (DQN) reinforcement learning. The methodology automates the selection and sizing of solar, wind, and hybrid microgrid configurations under variable climatic and demand conditions, using real meteorological and load data from La Marina, Colombia. The cGAN model generates technically feasible system designs, while the DQN agent learns optimal operational strategies that balance reliability, cost, and stability. Compared with conventional forecasting approaches such as ARIMA (autoregressive integrated moving average) and LSTM (long short-term memory), the proposed method achieves significantly lower prediction error and higher reliability. Field validation using a 20 kWp pilot installation confirms the model's practical applicability for resilient rural electrification.

Paper 12134 Detection of the Connection of Distributed Energy Resources through an innovative EMT Signal Analysis approach - Colombia

This paper proposes an electromagnetic transient (EMT) signal–based methodology for detecting and classifying the connection of distributed energy resources (DERs) in modern power systems. The approach exploits the distinctive time–frequency characteristics of transient voltage and current signals generated during DER connection events. EMT simulations are conducted on the IEEE 14-bus system using a power system analysis tool, considering photovoltaic units, wind generators, diesel generators, and resistive loads under varying connection times and power levels. Wavelet-based feature extraction, including energy density, peak responses, and selectivity indices, is combined with frequency-domain spectral classification and a brute-force interval search algorithm. Results demonstrate that each DER type exhibits a unique transient spectral signature, enabling accurate identification without machine-learning classifiers. The method is computationally efficient and suitable for real-time monitoring in networks with high DER penetration.

Other important SC C6 events: (Venues will be announced at a later stage)

1. Tuesday 25 August 2026, 08h30 – 12h30 – POSTER SESSION
2. Tuesday 25 August 2026, 14h00 – SC C6 Tutorial
3. Wednesday 26 August 2026, 08h30 – SC C6 Meeting
4. Thursday 27 August 2026, 08h30 – Group Discussion Meeting

Study Committee C6 sincerely acknowledges and appreciates the valuable contributions of the 44 reviewers and the Special Reporters, whose thorough and rigorous assessments of all C6-related papers for the Paris Conference have been instrumental. Their efforts have significantly supported the development of this Special Report, enabling the thoughtful selection and synthesis of key material. It is anticipated that the questions formulated herein will stimulate further reflection, innovation, and engagement among authors and stakeholders interested in the diverse range of C6 topics.

Study Committee C6 looks forward to continued contributions from the global community and trusts that the questions presented in this Special Report will foster meaningful discussion and debate during the Group Discussion Meeting in Paris on 27 August 2026.