2024 Paris Session

SPECIAL REPORT FOR SC C1

POWER SYSTEM DEVELOPMENT AND ECONOMICS

Special Reporters: [1]

Charlotte Higgins	Atha Scott	Jesus Valdson
(Preferential Subject 1)	(Preferential Subject 2)	(Preferential Subject 3)

Chair: ANTONIO ILICETO **Secretary: PETER RODDY**

Introduction to SC C1

The work of Study Committee C1 covers all the system development and economic challenges relevant to the electricity power industry including those relating to asset management.

Planning grids and developing systems world-wide is experiencing a paradigm shift. As decarbonisation targets are driven worldwide, change in the energy sector and choice of generation sources is heavily influenced. With the continued diffusion of distributed renewable generation sources, both distribution and transmission network planning functions are influenced significantly. Holistic system development and coupling with other energy sectors (gas, mobility, heat) and, in particular, new hydrogen applications affect planning and economics assessment; this needs to be researched to allow the energy transition to be fully deployed and lead towards a resilient future system.

SC C1 aims to support electricity system planners worldwide to make the best plans possible in a changing energy environment which includes increased renewable and distributed generation and heightened uncertainty in social, environmental, and regulatory frameworks and expectations. System plans must address these changes, while considering economic and public acceptance difficulties. Such plans require a more resilient and more flexible grid that recognizes the increasingly critical role of integrated transmission and distribution systems as enablers of the Energy Transition.

SC C1 events and engagements in the Paris session 2024

- Group Discussion Meeting (for all delegates) Thursday August 29 8:45 – 18:00
- Committee meeting (for C1 members) Friday August 30 8:30 – 18:00
- Tutorial: “Energy Sectors Integration & impact on power grids” Wednesday August 2810:30 – 12:30
- Workshops:
  - “ Resilience by Design ” Tuesday August 27 , 8:30 – 12:30, joint C1-C4
  - “ Role of Green H2 in the Energy Transition and its impacts across the value chain “ Wednesday August 28 , 16:00 – 18:00 joint C1-C5
- Opening panel: C1 as co-organiser and co-moderator of Forum1
- CEO event (upon invitation): C1 as co-organiser and fire-starting speech
- Side-event “Energy Communities and impacts on the grids” Tuesday August 27, 14:00 – 18:00 room 242 AB joint with ETIP SNET .

[1] Charlotte Higgins charlotte.higgins@arup.com ; Valdson Simoes de Jesus valdson.jesus@eletrobras.com ; Atha Scott atha.scott@eskom.co.za

Contributions for C1 Group Discussion Meeting (GDM)

The GDM of SC C1 shall take place on **August 29, 2024 in Room Bordeaux, starting 8:45 until 18:00**.

Special Reporters have compiled a number of questions, not specifically aimed at the papers' authors, rather synthesised from common issues and trends identified across the papers. This provides the opportunity for a broader response and participation in the discussion session. We encourage you to share your views or experiences in response to the specific questions in this report ("Prepared Contributions").

Prepared Contributions must address each a specific question in this report, and can only be made by registered attendees, who will attend the GDM in person. They have the form of power point slides (to be shown during the GDM) and word document (for Conference proceedings) and must be uploaded to the CIGRE Session platform **by August 10th 2024 for review by the Special Reporters**.

Each prepared contribution will have a time slot of about 2 - 3 minutes (depending on how many we receive), so the number of slides shall be limited to 3 - 4, including the title slide (please do not make the slide too busy), to be easily read and clearly illustrate your message; logo of your company/organisation is allowed, while no commercial information/advertising are allowed. Special Reporters will check and validate the contributions on-line using the Session Papers portal. Any recommendations or changes to the contributions will be provided to the contributors by the Special Reporters directly on the Registration platform **until 17th of August 2024**. Contributors are encouraged to visit their account on the Registration Platform to see and act upon the result of this review.

A **meeting with contributors** shall be held on **August 27, 12.30-14.00 in Room 235 level 2 mezzanine** floor, to check contributor's attendance and finalise the GDM time schedule with contributions slots. Considering the overall time available, there will be a limit of about 30 contributions for each Preferential Subject, also to allow some vivid exchanges in reaction to the prepared contributions (spontaneous verbal contributions). Attendees who provide a spontaneous contribution may provide a summary of it as a short, written text for the Proceedings, to be forwarded **within two weeks after the Session** to the Secretary Peter Roddy: peter.roddy.c1@gmail.com.

Poster session

Independently of Contributions, paper authors are kindly reminded to present their papers during the **Poster Session scheduled for Wednesday 28th August (14:00 to 16:00)** in Halle Ternes on level 1. Template and instructions on poster preparation are available on the CIGRE 2024 Session website. Posters will be displayed on digital screens. **A draft copy** of the poster must be uploaded to the **ConfTool platform by Wednesday 31st July** for review by the poster session convener (Belèn Rodrigues Guerra bdguerra@ree.es . A **final version**, incorporating any requested changes, must be uploaded by **Friday 16th August 2024**. It should be noted that authors will **not** have the possibility to upload their own file on the day of the Poster Session. If the author(s) cannot attend the Poster Session he/she or the relevant National Committee is requested to appoint a substitute for attending the poster session.

Preferential Subjects

The three preferential subjects of C1 and their sub sections for 2024 session are:

PS1. Steering the Energy Transition: Cooperation, achieving Top-Down Targets through Bottom-Up Investment Decisions System

PS2. Flexibility as Pivotal Criterion for System Development

PS3. Resilience as pivotal criterion for system development

Papers and Questions for Group Discussion Meeting

PS1 Steering the Energy Transition: Cooperation, achieving Top-Down Targets through Bottom-Up Investment Decisions

This preferential subject attracted 27 papers.

PS 1.1 Governance of the different sectors of the integrated energy system, role of system operators, role of regulation & markets; achieving public targets through private investments, coordinated decision-making processes and international cooperation.

Paper C1-10434 *Accelerating the Energy Transition: Case Studies and Lessons Learned in the USA*. The authors provide a deep-dive on how the US is accelerating the energy transition, through the lense of grid planning and various associated drivers, with examples of best practice and recommendations on tangible next steps for a fair and just energy transition for all.

Paper C1-10670 *A Novel Framework for Assessing Reform and Transition of The Electricity Supply Sector in Developing Countries*. A diagnosis and framework for assessing approaches to the structure and reform of the electricity supply sector in developing countries, to achieve the energy transition more equitably and effectively. Case studies are provided for South Africa and other countries.

Paper C1-10819 *Changing the Planning Process of Power System of Russia Development to Improve the Accuracy, Efficiency and Openness of Planning at the Time of Energy Transition*. This paper describes the process of transitioning to an advanced, transparent new planning model for a geographically large and complex power system, to support the energy transition. It includes the process, structure and system operator experience and new functions of to support decision making and creating advanced development documents.

Paper C1-10918 *Competitive Process for Transmission Margin Contracting by Wind and Solar Generators in Brazil's Transmission Network*. An innovative approach to renewables connection queue management, to more efficiently manage transmission capacity in a constrained region, is presented. Interested parties compete for network access and usage through a periodic auction called Competitive Procedure by Margin (CPM).

Paper C1-11246 *Governments' approaches to drive private investment in renewable energy infrastructure in Australia*. A detailed review of different jurisdictional approaches for Australian states to incentivise private investment in renewable generation, storage and the required transmission, and their comparative advantages and disadvantages.

Paper C1-11581 *Revamping Policy Framework to Facilitate Renewable Energy Integration with the Transmission Network - Indian Perspective*. A comprehensive analysis of the energy sector policy and regulatory reforms undertaken in India to facilitate renewable energy acceleration, including changes to network access and transmission planning.

Paper C1-11565 *Future-proof Grid Code for Energy Transition*. A strategic review of the Malaysian grid code with recommendations on how to adapt it for the energy transition and with particular attention on renewables integration, energy storage and demand response for flexibility.

Paper C1-11591 *Exploring the Interplay between Market-Based Economic Dispatch and Transmission System Planning in the Context of Renewable Energy Integration*. A detailed review of innovative market reforms to accelerate connection of renewables and an efficient market, and consideration of the impact and interdependencies on transmission planning, in the Indian context.

Paper C1-11819 *Calculation Model of Utilities Green Tariff: A sustainable strategy toward renewable energy adoption for regulated market in Thailand*. Assessment of the pros and cons of various Utilities Green Tariff (UGT) options that could be implemented in Thailand to increase the adoption of renewable energy sources, whilst being fair to all consumers.

Question 1.1.1 What structural reform measures to markets, regulation and governance have been undertaken by others to support long-term planning for the energy transition? How can these be made sustainable, future-proofed and balanced across all parties?

Question 1.1.2 Does government intervention or private investment initiatives lead to better results for increasing RES integration?

Question 1.1.3 What novel queue management and planning approaches are being deployed globally to manage growing renewables connections queues with success?

PS 1.2 Power-to-gas & hydrogen as energy carrier and as long-term storage; energy efficiency & infrastructure efficiency in the interconnected electricity/gas/hydrogen system; large interconnection projects.

Paper C1-10266 The challenges of developing electrolysis for the French electricity system over different time horizons. An exploration of technical, commercial and economic challenges and opportunities for green hydrogen within the French power system with consideration of wider EU interactions and interdependencies.

Paper C1-10516 *Optimal power system planning through P2G and P2H system integration and flexibility*. This paper assesses the role that P2G and G2P have to play in a future low carbon energy system through an integrated energy system analysis and a case study exploring costs, benefits and risks, and sensitivities. Locations of electricity grid curtailment and reinforcement are modelled.

Paper C1-10963 *Energy Supply Chain from Hydrogen Production to End Use by PtoG for Carbon Neutrality 2050*. An assessment of hydrogen development opportunities and supply chain growth in Japan. The integration of hydrogen can be a key enabler to the energy transition, particularly in locations where there is little opportunity for interconnection and the geography restricts renewables uptake.

Paper C1-10267 *Modelling flow-based exchange capacities in medium to long-term studies*. Describes a new methodology for medium- and long-term adequacy studies, based on flow-based domains, that provides improved scalability and ability to consider more material changes in generation, demand and regulation conditions compared to existing methods.

Paper C1-10636 *Rethinking CGMES. A review of the current short-comings of the Common Grid Model Exchange Standard (CGMES) used by ENTSO-E and others for power system model and data exchange*. Practical recommendations are provided on actions for improvement to support increasing collaboration and coordination between various system operators at transmission and distribution level.

Paper C1-11498 *Energy Transition and System Strength in the Chilean National Electric System*. This paper presents a technical and economic methodology to resolve system strength and voltage stability issues due to high penetration of renewables through economic procurement of ancillary services from synchronous condenser solutions. A practical case study of the end-to-end process is given for Chile.

Paper C1-11165 *Analysis of the current configuration of the capacity calculation regions – towards possible alternatives*. A detailed review of the definition of current capacity calculation regions (CCRs) in Europe based on technical indicators, considering particularly interdependencies of power flows in meshed systems and secure grid operation. Definition of potential alternative CCRs is also assessed.

Paper C1-11346 *The impact of sub-transmission levels' modelling on congestions' visualization for European transmission grid calculations – a CIGRE benchmark models study*. A detailed framework and rationale is provided for enhancement of EHV grid models to improve understanding of grid congestion materiality through a targeted representation of the sub-transmission grid. Success indicators and case studies for validation are proposed.

Paper C1-10370 *An optimization tool for the planning of transmission grid investments and development*. This paper presents an optimisation methodology for prioritising a portfolio of development works on the transmission network and enables consideration of both quantitative metrics and qualitative considerations (that can be monetised) to minimise overall costs.

Paper C1-10371 *Off-shore network development to foster the energy transition*. A novel optimisation methodology based on DC power flow approximation is presented and applied to a future offshore network topology connecting large amounts of offshore wind. It includes consideration of impact on security of supply and levels of curtailment.

Paper C1-10432 *From Regional to Continental Scale System Development: a New Methodological Approach to Studies of an Intercontinental Global Grid*. The paper presents a new methodological approach for optimal development of an inter-continental global grid via HVDC corridors to gain maximum benefit from RES integration. A case study shows results for the EU30+ region.

Paper C1-10962 *Long-term Electrical Power Transmission Network Expansion Plan for Achieving Carbon Neutrality Goals Toward 2050 and Its Implementation*. A long-term transmission network expansion reinforcement methodology for energy transition to 2050 in Japan, considering cost-benefit and inherent uncertainties in RES integration.

Paper C1-10935 *Optimization of Power Utility Portfolio Decarbonisation Pathway - EPBiH Case Study*. A technical-economic approach to help deal with the challenges relating to energy transition and decarbonisation of a traditional power utility. Several decarbonisation pathways are analysed alongside sensitivities to factors such as CO2 emissions allowances/taxes and asset management investment.

Question 1.2.1 Are there examples of whole energy system planning methodologies being developed that incorporate consideration of P2H connections?

Question 1.2.2 What novel modelling techniques are being developed to improve the ability to model large-scale regional power systems and whole electricity systems (T&D at a range of scales) more accurately?

Question 1.2.3 Are there lessons learnt that others can share on achievable decarbonisation pathways for traditional vertically integrated utilities, corresponding challenges and opportunities?

PS 1.3 System aspect aggregation of the electrification of transport, industry, and buildings: conditions and barriers, role of stakeholders in the end-to-end system.

Paper C1-10430 *From Resilient and Ready to Used and Useful: Managing Temporal and Locational Uncertainty in Electrification, DER Adoption, and Climate Adaptation*. A review is provided of the

various technology, technical, consumer and policy sources of uncertainty to grid planning due to the energy transition and practical approaches to manage and mitigate this uncertainty, including new planning tools.

Paper C1-10919 *Challenges and opportunities of massively connecting distributed energy resources in developing countries (Brazil- Cemig Distribuição)*. This paper describes a coordinated technical and economic approach to address the challenges of fast-growing distributed energy connections in Brazil. Technical, regulatory and economic considerations are outlined and expected benefits to consumers and for the future operation of the grid.

Paper C1-11046 *The Relevance and Importance of the Demand and Consumption Forecast in the Long-Term Planning of Electrical System*. The process of forecasting peak demand and consumption for medium and long term planning is detailed for Mexico's National Electric System, taking the energy transition into consideration. Methodologies are outlined including integration of top-down and bottom-up approaches.

Paper C1-10818 *Metropolitan Area and Regional Power System Planning Approach and Correlation with Energy Sector Integration in Energy Transition Period Based on JWG C1/C4.36 Experience*. A detailed review and analysis of Metropolitan Area (MA) and Large City (LC) power system development trends, as power systems with their own features and characteristics, presented in the context of the energy transition.

Paper C1-11729 *Multi-stage optimisation towards transformation pathways for municipal energy systems*. An optimisation methodology for effective transformation pathways of municipal energy systems, considering various technologies, interdependencies and decision making at a range of scales.

Question 1.3.1 What innovative modelling techniques are being adopted for characterising and managing the uncertainty in future demand and generation growth and behaviour in order to efficiently plan distribution and transmission networks?

Question 1.3.2 How can various stakeholders best engage to support the energy transition of metropolitan areas? How can decision-making be coordinated?

PS 2: Flexibility as Pivotal Criterion for System Development

This preferential subject attracted 29 papers.

PS 2.1 Including in the planning process the flexibility options both within and outside the grids: non-network assets and non-electric solutions: storage, demand response, energy communities, behind the meter resources.

Paper C1-10207 *Maximum Efficiency Point Tracking Control for the Water Electrolysis System Based on Power Hardware in the Loop*. This paper describes an innovative development in the modelling and simulation of an electricity-hydrogen coupling system, namely P2H and renewable energy, to explore improvements in efficiency through control strategies using a PHIL (Power hardware-in-the-loop) approach.

Paper C1-10372, *Impact on the power system of the electrification of transport, both light and heavy-duty vehicles*. The paper emphasizes the crucial role of electromobility, especially electric vehicles (EVs), in decarbonizing transport and providing power system flexibility. It highlights the importance of optimal vehicle-grid integration for efficient planning and operation. Additionally, it offers a

comprehensive analysis of Zero-Emission Heavy-Duty Vehicles (HDVs) and their recharging/refuelling infrastructure, covering vehicle technology, charging needs, economics, regulations, market dynamics, and grid impacts, recommending coordinated actions for effective adoption.

Paper C1-10437, *Flexible Capacity Expansion Planning for a Decarbonized Market*. The paper details a Capacity Expansion Planning (CEP) tool for New York State to identify cost-effective decarbonization pathways. This tool aims to minimize Capital Expenditure (Capex) and Operation Expenditure (Opex) for generation and transmission expansion over the long term, while meeting demand, reliability standards, and decarbonization policies. It considers factors like emission limits, Renewable Portfolio Standards (RPS), transfer limits, and reserve margins. Insights from this tool, guide market operators and utilities in making optimal investment decisions for a decarbonized power system.

Paper C1-10633, *Planning Tool Integration of Demand Flexibility: Focus on Electric Vehicles*. This study examines the impact of electric vehicle (EV) charging on power system planning and operations, testing various EV charging models under different incentives: unmanaged, time-of-use, and managed charging. These models are applied to four key planning functions: capacity expansion, resource adequacy, transmission planning, and distribution planning. The objective is to explore the opportunities and limitations of integrating flexible EV loads, focusing on their effects on investment costs, system adequacy, operational costs, CO2 emissions, and infrastructure.

Paper C1-10637, *A planning tool for minimizing overloads through active demand and generation response*. The paper introduces a planning tool to address grid contingencies through demand and generation responses instead of traditional reinforcements. The tool has two key features: (1) A contingency assessment module that uses linear approximations to compute load flows during contingencies, even multiple ones simultaneously. (2) An optimization module that uses the overloads identified to determine the best nodes for adjusting generation and demand setpoints, ensuring sufficient power to minimize overloads. This methodology is used for managing the increasing penetration of variable renewable energy sources like wind and solar.

Paper C1-10970, *Flexibility from electric vehicles - residential charging coincidence factors in Norway*. Overall, the study underscores the importance of understanding residential EV charging behaviour and the potential for smart charging strategies to enhance grid flexibility and efficiency. By leveraging insights from charging patterns and adopting flexible charging solutions, stakeholders can better manage EV integration into the power system while optimizing grid operations.

Paper C1-10971, *The potential and willingness for demand side response among different types of customers in the future renewable power system*. This paper analyses the observed implicit demand response among various consumer groups in Norway, with a specific focus on the period from July 2022 to July 2023. The paper aims to investigate which consumer group exhibits the greatest price response in both the short and long term, as well as which consumer group contributes the most from the power system's perspective. Overall, the research contributes to a better understanding of how different consumer groups contribute to demand response efforts and the overall functioning of the power system, particularly during periods of market stress such as the European energy crisis.

Paper C1-11103, *Machine Learning Method to Improve Stability Requirements Calculation for the Planning Process*. This paper addresses the use of machine learning in conjunction with traditional load flow analysis to enhance the efficiency and scalability of transmission planning processes, ensuring the reliable integration of renewable energy sources into the grid. In the transmission planning process, ensuring system stability as more renewable sources are integrated into the grid is crucial for maintaining system security and minimizing the cost of balancing services. The Network Options Assessment (NOA) framework aims to achieve future network changes economically and sustainably. A key component of NOA is the Stability Pathfinder, which accurately calculates system requirements to identify the most cost-effective approach to manage system stability.

Paper C1-11500, *Long-Term Power Expansion Considering Hydrogen Production*. The study highlights the strategic management of hydrogen production through electrolysis to enhance power system operations. By optimizing hydrogen production timing and quantity, significant reductions in total operation costs can be achieved. This approach uses electrolysis as demand response, influencing long-term investment decisions in generation plants and technology choices. The authors developed a model that co-optimizes the expansion of the hydrogen industry and the power system, showing that strategic hydrogen management can lead to cost savings, reduced fossil fuel reliance, and improved system efficiency. The study underscores the importance of integrating operational and infrastructural aspects to fully realize hydrogen's potential in a sustainable energy future.

Paper C1-11601, *Flexibility potential: A building cluster study case*. The paper highlights the importance of recognizing and quantifying the broader carbon savings associated with the flexibility services provided by UK Distribution Network Operators (DNOs). While DNOs currently account for the immediate carbon impact of these services, the paper identifies a gap in acknowledging flexibility providers' contributions to broader carbon savings. The study primarily focuses on residential buildings equipped with electric underfloor heating (UFH) and electric vehicle (EV) charging stations. It emphasizes the significant revenue potential of residential flexibility services while assuring minimal impact on consumer comfort. The research suggests that leveraging flexibility from residential buildings can offer a feasible revenue stream with limited drawbacks.

Paper C1-11606, *Evaluating Strategic Day-ahead Scheduling of Power-to-Hydrogen Facilities in Power Systems with Pervasive Renewable Energy Integration*. The paper addresses the need for flexibility in power systems due to increased renewable energy integration and the resulting grid congestion. It focuses on enhancing grid flexibility through technical and economic approaches. A key aspect is the decision-making process for power-to-hydrogen (P2H) facility operators, who adjust their day-ahead scheduling based on grid price signals. The paper uses a bi-level programming framework, with the upper level for P2H plant scheduling and the lower level for the TSO's optimal power flow calculations.

Question 2.1.1: What are the key challenges and solutions associated with optimal vehicle-grid integration? How can stakeholders benefit from efficient planning and operation of vehicle-grid integration?

Question 2.1.2: How do new EV loads influence power system investment costs, system adequacy, operational costs, CO_2e?

Question 2.1.3: Are the implementation of on-network assets and non-electric solutions substantially contributing to the overall stability and optimisation of the grid and are they economically viable?

PS 2.2 Matching flexibility needs with flexibility sources: market design evolution, value of various flexibility products, optimal flexibility portfolio; prioritisation of sector coupling initiatives; role of forecasts of demand and variable generation.

Paper C1-10208, *Deep Learning-Based Wind Power Low Output Process Forecast Using CGAN and Convolutional Residual Network*. This paper introduces a hybrid forecast method utilizing a conditional generative adversarial network (CGAN) and a deep convolutional residual network (DCRN) to predict wind power low-output processes accurately.

Paper C1-10209, *Analysis and prediction of load demand response characteristics based on demand-side data mining*. This paper proposes a method of analysis and prediction of load demand response

characteristics based on demand-side data mining. The proposed method can effectively assist the construction of a large capacity adjustable load resource pool and play an essential role in power demand response in ensuring the balance of supply and demand, promoting renewable energy consumption, and ensuring the stability and reliability of power supply.

Paper C1-10269, *Scenarios for changes in the needs and means of flexibility*. The article provides a comprehensive overview of studies concerning power system flexibility, with a specific focus on forecasting flexibilities related to the national supply-demand balance across different time horizons (daily, weekly, and annual). Flexibility requirements are defined based on the residual demand placed on the power system's dispatchable resources, with energy and power indicators used to characterize flexibility needs for each horizon.

Paper C1-10435, *A New Class of Flexibility Products: DER-Provided Reserve Services*. The paper explores the potential of Distributed Energy Resources (DER) to offer flexibility services to both distribution system operators and wholesale market operators. It focuses on reserve services as an example of such products that system operators can procure from DER, noting that while reserve services from transmission-connected sources are common, the concept is relatively new for distribution-connected sources. Specifically, it recognizes that the existing, "legacy" reserve products as currently defined in wholesale markets may be supplemented by a new class of reserve products through which DER could provide additional support to distribution and wholesale operators in a more flexible manner.

Paper C1-10889, *Reducing balancing power requirements through the complementarity of RES based technologies in hybrid power system concepts*. This paper proposes the strategic development of hybrid power systems (HPS) by leveraging the synergies among diverse technologies co-located in the same geographical area. The paper underscores the potential benefits of HPS in minimizing the need for balancing power in the energy grid, with specific emphasis on the synergies between wind and solar power generation technologies. Additionally, the incorporation of energy storage solutions, such as batteries, further enhances the system's ability to mitigate imbalances and improve overall grid stability. The potential flexibility and optimized smart charging demand provide benefits for the power grid by reducing peak demand.

Paper C1-11832, *30 Years of Reform of the Colombian Electricity Sector: A Macroeconomic Perspective to the Challenges Facing of Energy Transition*. The paper examines the Colombian electricity market's evolution over three decades, emphasizing its significance in the ongoing energy transition. It discusses milestones and challenges, including structural reforms and the adoption of new technologies to address environmental concerns. The energy transition, a global imperative to combat climate change, plays a central role in this discussion. Overall, the paper provides insights into Colombia's journey towards a more sustainable and resilient electricity sector amid the global energy transition. It highlights the importance of balancing economic development with environmental stewardship and social equity in shaping the future of the country's energy landscape.

Question 2.2.1: What investments considerations can be derived for long-term flexibility solutions and impact of pluriannual variability on system costs?

Question 2.2.2: How can energy markets and pricing structures balance the coordination and optimisation of energy generation and distribution as well as customer reaction and investment in the changing energy landscape?

PS 2.3 Storage device evolution, technical & economic performances, short/medium term measures for balancing the grid, and managing the energy system in the longer term, including thermal & molecular long duration energy storage.

Paper C1–10238, *A Date-driven Planning Method for Regional Hybrid Energy Storage Systems (HESS) with Decoupled Operation and Planning Stages*. This paper proposes a data-driven planning method for regional HESS with decoupled operation and planning stages. Unlike the conventional multi-stage planning method, this approach offers a unique perspective and solution on the planning problem of HESS.

Paper C1-10369, *How storage is implemented in the network of the major global operators of GO15*. The paper presents the results of a survey conducted by the Grid Operators GO15, an association comprised of some of the world's largest power grid operators. GO15 is an association of the world's very large power grid operators. It meets more than half of the world's electricity demand. The survey focuses on the challenges faced by Transmission System Operators (TSOs) in decarbonizing the energy mix and the role of storage solutions in facilitating the integration of renewables.

Paper C1-10539, *Characterisation of Flexibility Resources in Integrated Electrical and Thermal Systems: A Novel Short-term Flexibility Quantification Method*. The paper introduces an innovative flexibility quantification methodology designed specifically for thermal networks. Thermal networks have the unique advantage of being able to provide both electrical power flexibility and heating or cooling services. The methodology enables thermal network owners to actively participate in intraday flexibility markets and effectively capitalise on their flexibility resources.

Paper C1-10554, *Unlocking the Potential of Distributed Energy Storage Systems for Island Power Systems*. The paper introduces a new methodology for quantifying flexibility in thermal networks, which can provide both electrical power and heating/cooling services. This potential, especially through co-generation and power-to-heat units, is largely untapped. The methodology allows thermal network owners to participate in intraday flexibility markets and capitalize on their resources, addressing the shift towards higher liquidity in energy markets.

Paper C1-11388, *Battery Energy Storage System Techno-Economic Performance to Meet the Grid Flexibility: Case Study of Jordan's Power Sector*. The paper investigates the techno-economic performance of battery energy storage systems (BESS) in Jordan's electricity system. It integrates energy storage into unit commitment and optimal dispatch problems, considering various operational constraints. The results show variations in economic dispatch across scenarios, highlighting the benefits and challenges of integrating renewable energy and energy storage in Jordan's power system. Different operational use of the BESS is analysed and summarized in a cost-benefit-analysis.

Paper C1-11389, *Enhancing Grid Stability and Renewable Integration: Examining the Potential of Pumped Hydro Storage as a Key Player in Jordan's Power Sector*. This paper provides an overview of the assessment methodology, and the potential role and benefits of PHES in Jordan in terms of grid stability and renewable integration. The manuscript provides a detailed description of the conducted analysis, developed optimization settings, and a detailed evaluation of the benefits of the planned PHES at the Mujib site.

Paper C1-11392, *Experimental Studies on Jordan's power grid stability with integrated electricity storage systems*. This study provides a comprehensive analysis of deploying energy storage systems (ESS) for power system stability. It explains advanced algorithms for controlling power flow and managing electricity storage/discharge through flow chart diagrams. The experimental discussion investigates various ESS to enhance Jordan's national grid stability, eliminating the need for more conventional power plants and reducing maintenance and operating costs. Several scenarios are presented to optimize the generation curve by integrating ESS with traditional power plants.

Paper C1-11447, *"Use instead of curtail" in Germany – Power to Heat technology as flexibility for TSOs to optimize RES feed-in and manage congestion*. The paper examines the use of flexible power-to-heat (PtH) technology for congestion management and renewable energy integration in the transmission system. It simulates various scenarios with adjusted substation generation and considers N-1 contingency cases. Highlighting Germany's challenges with uneven renewable energy distribution

and slow grid expansion, it introduces the "Use instead of curtail" scheme. This scheme funds PtH systems, aiding in congestion management, renewable integration, and decarbonization of district heating.

Paper C1-11582, *100% RES Power System Supported by Flexibility Resources. The paper presents a comprehensive look at a power system powered 100% by RES*. The subject of the analysis is the infrastructure planned in the NEOM region. It presents a capacity expansion optimization model to identify the most cost-effective sequence of investments in electricity generation, transmission, and energy storage technologies up to 2045. This model integrates various flexibility sources, ensuring energy balance at each investment step while accounting for various system constraints. The paper illustrates the viability of a renewable energy-based system, highlighting the role of energy storage, active demand management, and a controllable transmission grid in ensuring its economical and efficient operation. The model also considers the climate variability affecting renewable energy sources.

Paper C1-11586, *Operational analysis of Purulia Pumped Storage Plant (PPSP) and Maximizing the benefits using Mixed Integer Linear Programming (MILP) Model from Flexible Operation*. The report discusses the analysis of operational data from the successful Purulia Pumped Storage Plant (PPSP) and presents an optimization model developed using Mixed Integer Linear Programming (MILP) in the GAMS platform to maximize the plant's operational benefits.

Paper C1-11796, *Application of BESS in Power Systems with Challenges of Security, Stability and Flexibility*. The article examines optimal strategies, modelling assumptions, and potential scenarios related to the technical and economic aspects of sizing and determining parameters for battery energy storage systems. It explores how these factors can address various operational challenges in power systems, including stability, flexibility, and security, ensuring effective management of these issues.

Paper C1-11803, *What are the economic conditions for the feasibility of a high variable renewable penetration power system?* Investments considerations for long-term flexibility solutions and impact of pluriannual variability on system costs. The paper investigates the economic feasibility of a 100% variable renewable power system, focusing on the role of long-duration storage (LDS) in balancing generation and consumption. It highlights the challenges posed by the variability of renewable energy sources, such as wind and solar power, and the need for long-term flexibility solutions to maintain grid stability, i.e. long duration storage (LDS), such as hydrogen stored in salt caverns, helps balance production and demand. Their research examines the sensitivity of system costs to various parameters.

Question 2.3.1: Playing off the cost and the availability of generation, grid and storage assets, how to determine the optimal portfolio?

Question 2.3.2: Integration of energy generation sources seem to be the way to go - what are the restrictions in these combinations - what should you not try to do? What is the ultimate balance to optimise the system*?*

PS 3: Resilience as pivotal criterion for system development

This preferential subject attracted 13 papers.

PS 3.1 Metrics and criteria to plan resilience and strength of the future power system; flexibility means as enhancers also of resilience.

Paper C1-10373, *Application of a Multi-Hazard Risk-Based Resilience Assessment Methodology to Real Cases in the Italian Transmission System* describes a collaboration at the Italian Transmission System to develop a comprehensive risk-based methodology to enhance power system resilience

against extreme weather events. This methodology assesses threats, analyzes infrastructure vulnerability, and prioritizes interventions through Cost-Benefit Analysis to improve system resilience effectively.

Paper C1-11462, *Assessment of the Resilience of the Colombian Electricity Sector* focuses on assessing the resilience of Colombia's electrical systems, emphasizing adaptation to various disturbances. It introduces a methodology that involves threat identification, impact assessment, vulnerability assessment and risk calculation with sector data. Risk matrices identify critical threats and vulnerabilities, leading to recommendations to increase the sector's resilience.

Paper C1-11505, *Proposed Methodology for Incorporating Resilience Criteria into Transmission Planning Based on Risk Mapping* presents a methodology to improve transmission planning in Chile, incorporating resilience criteria. It focuses on identifying risk areas, assessing the impact of critical events and proposing solutions. By using risk maps and a structured six-step approach, the methodology aims to strengthen network resilience against geographical and geological challenges.

Paper C1-11576, *Improving Distribution Network Climate Resilience Using Statistical Models For Conventional And Technology Agnostic Solutions* highlights the critical need for climate-resilient public energy infrastructure, proposing a new methodology for planning resilient distribution networks taking into account climate risks. It highlights the importance of incorporating advanced technologies, such as rooftop solar systems and battery energy storage systems, to mitigate the impact of severe weather events on energy distribution systems.

Question 3.1.1 - What are the key components for a risk-based methodology to enhance power system resilience against extreme weather events?

PS 3.2 Optimal planning and efficient use of resilience measures: risk assessment, prevention, mitigation, adaptation, re-start measures.

Paper C1-10614, *Evaluation of Substation Configuration as an Element of Resilience Management in System Development* highlights the importance of key objectives in power system development, including energy security, infrastructure capacity, efficient fault rectification, optimal efficiency, regulatory compliance, customer service and cost-effectiveness. In this context, substations play a crucial role, requiring flexibility to ensure the integrity, adequacy and resilience of the power system for the continuous supply of electricity.

Paper C1-10924, *Governance and its importance for the success of an electric power company from the point of view of resilience* focuses on the resilience of the energy system in relation to corporate governance in the electricity sector. Evaluates challenges and opportunities to improve system performance, avoid interruptions and ensure continuity of energy supply. A real blackout case study illustrates the importance of effective governance in addressing resilience issues.

Paper C1-10925, *Energy Transition – Risks Related to Underestimation of Security Issues* explores challenges and strategies for integrating intermittent renewable energy sources into the Brazilian National Interconnected System during the energy transition. Emphasizing revised planning criteria and regulation, it highlights the impact of expanding renewables, underscoring the importance of synchronous generators. International experiences in reliability metrics are analyzed for insights.

Paper C1-11796, *Application of BESS in Power Systems with Challenges of Security, Stability and Flexibility* investigates optimal strategies for scaling battery energy storage systems to address operational challenges in power systems. It explores energy system stability, reserve capacity and the impact of integrating renewable energy sources, emphasizing the need for suitable BESS parameters to

improve grid stability, frequency control and renewable energy integration. Recommendations include using BESS to provide ancillary services.

Question 3.2.1 - Have others performed studies on how to address operational challenges in power systems through scaling battery energy storage systems, and what parameters are emphasized to improve grid stability and frequency control?

PS 3.3 Resilience improvements from grid architecture and grid components: including the role of power electronics control and grid forming features, smart load shedding, and fast restoration methods.

Paper C1-10198, *Application of Flexible Low Frequency Transmission Technology in Zhejiang Province* discusses the development and practical applications of flexible low-frequency AC (LFAC) power transmission technology, highlighting projects in China. It covers key equipment, application scenarios, challenges, and future research directions, showcasing the potential of LFAC technology in improving power transmission capabilities effectively.

Paper C1-10211, *The Power Adequacy and Flexibility Assessment in the Process of Energy Transition in the China's Power Sector* examines power adequacy and flexibility needs in China's power sector during the energy transition until 2060, focusing on the challenges posed by variable renewable energy (VRE). It analyzes VRE intermittency, transmission capacity growth, and the role of pump storage hydropower in ensuring supply security and managing VRE integration.

Paper C1-10281, *System impacts of IBR power reduction after a short-circuit* examines the impact of short-circuits on critical substations and the behavior of inverter-based resources in the French electrical grid. It assesses active power reduction effects on Continental Europe's frequency stability and discusses mitigation measures through potential evolution of Connection Network Codes for long-term grid stability and reliability.

Paper C1-11184, *Reliability and Resilience Needs for Future Hybrid AC/DC Grids* describes the HVDC-WISE project that aims to improve AC/DC hybrid networks through the development of reliability and resilience tools. Resilience is defined in terms of system outcomes. Through a survey of HVDC links, trends in HVDC architectures were identified. The project, involving five TSOs, seeks to address common concerns such as cybersecurity and improve system performance.

Paper C1-11625, *Less connection for more security – Novel transmission and power grid design in NEOM grid with 100% renewable* has a proposal of a high-security power supply system that integrates small multi-terminal HVDC transmission modules and islanded Giga-grids. It utilizes a modular MTDC backbone with VSC HVDC technology for enhanced controllability and stability. Segregated islanded Giga-grids allow controlled power exchange between AC grids, enhancing security and system efficiency.

Question 3.3.1 - Paper 11625 describes a proposed high-security power supply system that integrates small multi-terminal HVDC transmission modules and islanded Giga-grids. Have others used this technique or applied other technology for enhanced controllability and stability?

Question 3.3.2 - Planning HVDC transmission systems embedded into an AC interconnected grid leads to a variety of challenges. Are there limits for this interconnection, regarding short-circuit, reliability or resilience?

A few words about Session Papers

Session Papers focussed on a number of Subjects – referred to as 'Preferential Subjects' – selected in advance by the 16 Study Committees of CIGRE and available in the Call for Papers .
Session Papers are selected through a two-phase review process – abstracts and full Papers.
Have a look at the Technical Programme - the list of selected Papers for the Session, and so have an overview of subjects that will be discussed. It is updated as Full Papers review proceeds.

Specificity of CIGRE Sessions

At CIGRE Sessions authors are given the opportunity to present their Paper during half-day specific meetings – the Poster Sessions.
Four days are also dedicated to 'Group Discussion Meetings' organised by Study Committees. Four meetings run simultaneously each day from Tuesday to Friday, under the presidency of the Study Committee Chairs. The purpose of these meetings is the discussion of the Session Papers on the basis of "Special Reports" which incorporate the gist of the Session Papers and raise a number of questions for discussion.
The Special Reports are available to all on free access – at the end of May - on the CIGRE website, on the Session page.
For fruitful discussions delegates are strongly encouraged to read the Papers before the Session.
The set of Session Papers is made available for downloading to all duly registered delegates before the Session through their private account on the registrations portal.
Papers are also readable on the Session smartphones application on site in Paris.
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