Appendix A – Detailed list of System Operator priority questions

Table 1 presents a detailed list of System Operator (SO) priorities across all six topics related to inverter performance, modelling tools, control room tools, planning, system restoration and system services.

Table 1 Detailed list of System Operator priority questions

Priority question	Primary topic	Secondary topic
1. System needs: What are the needs of a power system for secure and reliable operation, expressed in technology-neutral form, and how do these needs map to performance that any resource, including grid-scale IBR, DER or synchronous machines can provide?	Inverter performance	System services
2. Inverter capability: How feasible is it to provide from IBR (both new and existing) to provide each power system service, what "cost" does it add and what limitations exist on its magnitude and duration of service?	Inverter performance	System services
3. Inverter controls: What are the advantages and limitations of different IBR technologies to provide: • Frequency control services, and how do the various frequency services overlap and compete? • Voltage control services at different MW levels? • Voltage control capabilities between neighbouring IBR plants? • Adaptive IBR controls?	Inverter performance	System services
4. Control system tuning: How should IBR control system performance be demonstrated by OEMs and proponents to give confidence in current and future performance (including synchronization), to smooth out connection assessment process, and improve power system performance/ mitigate risk of undesired performance (such as oscillations/tripping)?	Inverter performance	System services
5. Inverter frequency behaviour: As an extension to 4, what recommendations should be made for standard behaviours of IBR in certain frequency ranges for different power system conditions to aid system design? For example, should a contribution to damping be mandatory at certain frequencies?	Inverter performance	System services
6. / 2025_01 IBR capabilities: What inverter capabilities (which may include GFM) are required to operate a 100% IBR power system in future? How should technical performance and compliance requirements should be specified in grid codes to ensure stability?	Inverter performance	Control room of the future
7. Inverter modelling: What are the trade-offs between different modelling approaches, encompassing model representation and application in analysis software?	Inverter performance	Modelling tools
8. Inverter impedance requirements: What impedance requirements should be placed on IBR to suppress negative-sequence and low order harmonic currents?	Inverter performance	N/A
9. Power system protection: How will protection systems need to change to accommodate high penetrations of IBR and what possible actions might an inverter take during a fault that would aid fault detection and location? How can IBR fault current waveforms be characterized based on their control type/strategy and its impacts on conventional protection systems? What grid code requirements or system services are needed to incentivise the desired performance?	Inverter performance	N/A
10. Inverter-based frequency control: What is the future of frequency control as the synchronous generation fraction reduces? Might tightened or loosened frequency limits lead to a more reliable, secure, lower-cost IBR-based power system?	Inverter performance	N/A
11. Inverter flexibility: At what point is it better to break from trying to replicate synchronous machine features and exploit the wider flexibility of inverters?	Inverter performance	N/A

Priority question	Primary topic	Secondary topic
12. / 2025_02 Performance standards for inverter-based loads: What performance standards are appropriate for loads – in particular power electronic-based load types such as EV chargers, hydrogen electrolysers and data centres – to ensure they can be successfully and reliably integrated into the system without adverse impact to power system operations, considering their susceptibility to voltage and frequency fluctuations and the impact on system security? What power system model requirements are appropriate?	Inverter performance	Modelling tools
13. Inverter design for system restart: What technical standards and capabilities are required for inverters to a) enable provision of black start services, and/or b) assist in the system restoration process?	Inverter performance	System restoration
14. Simulation model performance: What approaches can be taken for planning and operational time frame system modelling to evaluate system stability with a high proportion of IBR? What methods and techniques can be used to maximise simulation performance encompassing: • Equivalencing/ aggregating models? • Splitting models into sub-systems? • Use of co-simulation techniques? • Enhanced Root Mean Square (RMS) modelling? • Screening methods and techniques to tune controls and identify risk of interaction between power electronics-interfaced devices (PEIDs), such as load flow, impedance scan? • Pass/fail detection and early termination?	Modelling tools	Inverter performance
15 / 2025_03 Stability modelling: What methods and tools are needed for off-line and on-line analysis and detection of instabilities including oscillations? What thresholds are appropriate for planning and operational studies?	Modelling tools	Control room of the future
16. Contingency analysis: What type of on-line contingency and stability analyses capabilities are required for SOs with an increasing share of IBR to evaluate: • Transient stability phenomena? • Frequency phenomena? • Electromagnetic Transient (EMT) phenomena?	Modelling tools	Control room of the future / Planning
17. System performance tools: What analytical tools and models should be provided to planners and operators for robust assessment of system performance for longer-term planning to real-time operations, including, but not limited to: • Representation of IBR in small signal analysis tools? • Evaluation of impacts due to reduced operation / decommissioning of synchronous generators? • Assessment of power quality performance and emission limits? • Evaluation of GFM and GFL inverter performance including interoperability and impact of mode changes in operation? • Evaluation of high impact events including appropriate models for primary protection, special protection schemes and under-frequency load shedding? What guidelines are needed to determine the applicability of each tool and method, including screening processes to identify boundaries of applicability of a particular tool and model? What approaches and processes should be used to evaluate ongoing compliance and that control and protection schemes continue to meet their design and performance objectives?	Modelling tools	Planning
18. GFL and GFM simulation tools: As an extension to 17, what analytical methods and tools should be used to evaluate system performance with a mix of GFL and GFM inverters? What are the challenges and opportunities associated with integrating many GFM inverters, synchronous machines and synchronous condensers?	Modelling tools	Inverter performance
19. Modelling tools for high impedance grids: What tools are needed for analysis of high impedance grids?	Modelling tools	Inverter performance
20. Frequency modelling: What are the appropriate analytical methods and tools to evaluate inertia and frequency control requirements of a given power system?	Modelling tools	N/A

Priority question	Primary topic	Secondary topic
21. Voltage stability modelling: What tools and methods can be used to identify the mitigation strategies for voltage-collapse problems under high IBR conditions and to optimise the use of available reactive power resources?	Modelling tools	N/A
22. Model validation: What are appropriate methodologies to validate wind, solar and DER inverter models based upon bench-testing, HIL testing, evaluation of real system events, and representation of performance in computer models?	Modelling tools	Inverter performance
23. Inverter-based load modelling: What are appropriate model requirements for inverter-based load types across a range of simulation domains and frequency ranges?	Modelling tools	N/A
24. Computer hardware performance: What computer technology solutions offer the best simulation performance, encompassing clock speed, number of cores, and other techniques such as Remote Data Memory Access and Graphics Processing Units (and how can current simulation software and models be deployed using such solutions)?	Modelling tools	N/A
25. Model interoperability: What opportunities are there to use existing and new tools to enhance model interoperability and reduce software and software version dependence, encompassing steady-state and dynamic model formats?	Modelling tools	N/A
26. GFM capabilities: What are the challenges and opportunities relating to: • Implementation of GFM controls in HVDC. State of the art. Challenges, risks and opportunities for different applications – e.g. off-shore wind farm connections, embedded HVDC connections and point-to-point between different synchronous systems. • GFM control interoperability under strong grid conditions. • GFM behaviour under current-limited conditions. • Feasibility of manual or automatic switch between GFM and GFL (and vice-versa) controls depending on the system state.	Modelling tools	Inverter performance
27. Component model requirements and validation: How can we define component model requirements (generators, dynamic loads and other dynamic equipment) in a vendor agnostic form across different simulation domains, that is fit for purpose for evaluating relevant phenomena for power system planning and operations? What are effective methods and processes for validating models pre- and post-connection? What approaches can be used to improve existing/legacy dynamic models? What are the challenges associated with DC side modelling for IBR plants?	Modelling tools	Planning
28. EMT models: What specification, verification and validation methods are required for EMT models?	Modelling tools	N/A
29. Real-time stability assessment: As an extension to question 15, how can operators identify system normal and post-contingent stability issues in real time?	Control room of the future	N/A
30. Situational awareness: How can SOs get relevant real-time visibility and situational awareness of the state of the power system with increasing penetrations of IBR? How can SOs get relevant real-time visibility and situational awareness of the state of the power system with increasing penetrations DER, considering potential for expansion of network models further into the distribution network, and associated requirements for monitoring and state estimation?	Control room of the future	N/A
31. / 2025_04 Operational capability: What real-time operational capabilities are required for power systems with high levels of variable, inverter-connected generation across transmission and distribution networks, with few or no synchronous machines?	Control room of the future	N/A
32. / 2025_05 Visualisation capabilities: What visualisation capabilities are needed to enable operators to effectively and efficiently interpret relevant information and make operational decisions (in the context of the vast increase in number of connections and data, alarms, new phenomena such as oscillations)?	Control room of the future	N/A
33. Grid Enhancing Technologies: How can operators effectively utilise GETs for effective power system operations?	Control room of the future	Planning

Priority question	Primary topic	Secondary topic
34. / 2025_06 Forecasting and management of high VRE grid: • How do control rooms more optimally address uncertainties in weather conditions that impact loads and renewable energy output and rate of change (ramps)? How can probabilistic forecasting techniques be better incorporated into real-time operations? What operational forecasting capabilities are required in the context of a VRE-dominated grid? • What platforms, tools and mechanisms are needed to manage an increasing mix of renewables (including battery energy storage) and evaluate and manage short-term resource adequacy/capacity/reserve requirements hours to days ahead?	Control room of the future	N/A
35. Managing high impact low probability (HILP) events: How can system operations incorporate the risk of HILP events in security assessments to help mitigate the impact of a range of phenomenon, events and conditions (including primary and secondary plant failures, power system phenomena and disturbance events)?	Control room of the future	N/A
36. Flexible resources: How can SOs effectively utilise flexible resources such as VPPs and flexible demand, including those in distribution systems, to support effective overall power system operations?	Control room of the future	Modelling tools
37. Digital architecture: What digital architectures are needed to enable the range of software required for effective control room operations, enabling capabilities to adapt and evolve as the power system transforms, and facilitating future autonomous operation?	Control room of the future	N/A
38. Grid topology optimisation: Beyond the use of GETS, battery energy storage systems (BESS) and DER, how can grid topology be flexibly adapted and optimised at various operating conditions to manage congestion, resilience, and (high and low) fault levels?	Control room of the future	N/A
39. DER/IBR data architecture: What is a suitable data architecture for DER and IBR monitoring/prediction and control in real-time to enable efficient utilisation of DER resources, support of different control architectures for DER, and management of high and low demand operating conditions? Once aggregated spatially and temporally, and potentially by capability grouping, how should DER-related information be provided to the control room?	Control room of the future	N/A
40. DER/IBR communications and control: What communication capabilities, information models, protocols and architectures are needed to support monitoring and control of DER and IBR?	Control room of the future	N/A
41. / 2025_07 DER monitoring and control: Based on the relevant SO control architectures, roles and responsibilities, how can SOs most effectively manage DER, including for resource adequacy, contingencies and minimum load management in the control room?	Control room of the future	N/A
42. Big data: What is the best way to integrate large data sets, streaming information, and historical system performance to secure data availability for useful and actionable operational insights in the control room environment relating to reliability, security and resilience?	Control room of the future	N/A
43. Voltage control optimisation: How can voltage control be effectively optimised on large systems with dispersed transmission- and distribution-connected variable generation?	Control room of the future	System services
44. Operational transition points: What are the possible approaches to move to new system combinations/new system states operationally as the power system transitions to higher levels of VRE/IBR and fewer synchronous generators as the technical envelope and our understanding of it evolves, including prudent monitoring, testing and risk management?	Control room of the future	Planning
45. Operational risks: What approaches should be used by SOs to identify and evaluate operational risks, how they are evolving and the need to uplift relevant capabilities?	Control room of the future	N/A
46. Minimum system load management: What capabilities are required to effectively manage periods of minimum system load, including regional negative load, for example, load turn-up services, and to enable effective operation of regional islands in such conditions?	Control room of the future	N/A

Priority question	Primary topic	Secondary topic
47. Application of AI/ML: How can automation and new AI/ML capabilities be leveraged to assist operators, reduce operational risk and / or improve security/resilience? How can AI/ML help operators identify complex system states and operational patterns including operational security margins and suggested actions / constraints where decisions need to be made promptly following a major event?	Control room of the future	N/A
48. Performant information technology/information systems (IT/IS) infrastructure: How can communication and computational infrastructure support power system applications including Wide Area Protection and Control fast enough in a DER and IBR low inertia system?	Control room of the future	N/A
49. High speed monitoring: What is the feasibility and benefits of implementing state estimation using PMU data?	Control room of the future	N/A
50. AI/ML risks: What risks may emerge (and how should these be managed) with increasing application of AI/ML, such as generator market bidding algorithms?	Control room of the future	N/A
51. Control room support: What capabilities can SOs apply to assist control room operators, encompassing use of voice, accessing operational procedures, control room layout, and fatigue monitoring?	Control room of the future	N/A
52. IT system resilience: What are the appropriate functionalities and capabilities to provide IT/IS/IT operational system resilience including change management and cyber risks (resilience and recovery)?	Control room of the future	N/A
53. Cyber threats: How should international cyber threats to secure trust and integrity of information to the control room of the future be managed, when information is exchanged between millions of assets and actors in the future power system? And how can a widespread adoption of these cyber security paradigms be materialised?	Control room of the future	N/A
54. Cyber security: How should international cyber threats to secure trust and integrity in processes for control and protection for the control room of the future be managed?	Control room of the future	N/A
55. Probabilistic planning: What changes to probabilistic planning methods and tools are necessary for planning a power system with a high share of IBR and in particular, VRE resources, for both low and high fault level conditions? What tools and methods are required to undertake market modelling of power systems with up to 100% VRE? What additional planning models and methods are needed to plan for various levels of uncertainty and no-regrets investments in a paradigm of increasing electrification and growing IBR and DER penetrations? What information can SOs provide to effectively support industry investment generation and load investment decisions?	Planning	Modelling tools
56. Hybrid and VPPs: As an extension to 55, what studies and metrics are required to evaluate resource adequacy with hybrid plants (such as photovoltaics [PV]-plus-storage) and VPPs?	Planning	N/A
57. Accounting for resource scarcity: What studies and metrics are required to identify long term scarcity of energy and capacity to maintain reliability?	Planning	N/A
58. Planning for system restart capability: How should sufficient black-start capability and the performance and integrity of the protection system be modelled in long-term reliability studies?	Planning	System restoration
59. / 2025_08 Planning for operability / integrated planning: • What tools, methodologies and metrics are appropriate for SOs to plan for operability and resilience (integrated planning approach for longer-term planning), accounting for emerging power system phenomenon and system needs? • What tools, methodologies and metrics are required to evaluate resource adequacy in the context of a high IBR/VRE power system? • What scenarios do SOs need to consider, including methods for development of future models 5+ years out, including assumptions?	Planning	System services
60. Planning for resilience: How can planning for power system resilience be balanced against lower costs for operation and investment (and considering relevant renewable targets)?	Planning	N/A
61. Planning for HILP events: How do SOs adequately account for extreme events in planning studies, particularly those that impact the resources used in a high renewable energy future (wind, solar, demand side flexibility)?	Planning	N/A

Priority question	Primary topic	Secondary topic
62. Evaluating and modelling HILP events: What additional methods and tools are necessary to incorporate resilience concepts[1] into planning a power system with a high share of renewables?	Planning	Modelling tools
63. DER forecasting: What methods are necessary to accurately account for DER in planning and short-term forecasting to ensure a reliable power system is being planned and operated in real time? What data (and in what granularity) is necessary to accurately model various levels/paradigms of DER control, including influence on under-frequency load shedding schemes and for short-term forecasting of load?	Planning	N/A
64. Load forecasting: What load and resource forecasting models are necessary to account for electrification of the transportation and building sectors?	Planning	N/A
65. Planning for resource limitations: What additional planning models and methods are needed to plan for a system that can withstand expected or unexpected lulls in the weather driving much of the resource mix, such as an extended wind drought?	Planning	Control room of the future
66. DER modelling: What DER modelling methods are required to support transmission-level modelling for a) resource adequacy, and b) power system stability studies in RMS, EMT and other domains? How should the dynamic performance of DER be considered in planning and operational studies, including the impact of distributed PV (DPV) on total contingency sizes, and effect of DPV on effectiveness of under-frequency load shedding schemes?	Planning	System services
67. Storage requirements: What models and methods are necessary to quantify the need and requirements for long duration energy storage for 100% renewable energy operation? What type and capacity of storage and other services are needed to operate power systems dominated by VRE, taking into account potential wind and solar droughts?	Planning	Inverter performance
68. Maximum contingency risks: How should SOs plan for and mitigate risks associated with maximum contingency sizes (for example, maximum load/ generation /flow on single and double circuit lines)?	Planning	N/A
69. Balancing cost and impacts: How can planning processes evolve to provide security of supply and meet decarbonisation targets at least cost to the consumer, balanced with cost, environment and the community impacts (social acceptance)?	Planning	N/A
70. Project cost and delivery: How can accurate cost estimates be developed for projects and augmentation taking into account risks and uncertainties including supply chain?	Planning	N/A
71. / 2025_09 System restoration: What capabilities including study tools, monitoring systems, and processes are needed by SOs to black start power systems with high levels of transmission and distribution connected IBR/VRE, potential for multiple islands during the restoration process, and very few (or no) synchronous generators?	System restoration	Inverter performance
72. Equipment requirements for system restoration: What additional power system equipment is needed to support system restoration?	System restoration	Planning
73. System Services: How should the definitions of services for IBR-dominated transmission grids be structured? Can standard services and standard characteristics be defined that are reasonable for large and small IBR and across VRE, storage and demand response interfaces? What services are needed by the system, defined in a technology-agnostic way, to ensure efficient and reliable provision and coordination of: • Voltage control services? • Frequency control services? • System strength and grid reference? • Ramping and balancing?	System services	N/A
74. Services from VRE: What models and methods are necessary to quantify the ability of VRE to provide essential reliability services to the grid, and how can SOs quantify the value of these reliability services (for example, as an input to system-specific market/incentive design questions)?	System services	N/A

[1] These resilience concepts can be summarised as to i) anticipate and prepare ii) resist and absorb iii) respond and adapt and iv) recover.

Priority question	Primary topic	Secondary topic
75. Offshore wind and HVDC services: What services (considering potential future control system algorithms) can be cost-effectively provided by offshore wind and HVDC (including voltage, frequency control, fault ride-through, GFM, black start and participation in remedial action schemes)?	System services	N/A
76. Services from DER: How can SOs quantify the transmission level service capabilities from DER? What are the practical and technical limitations to the reliable provision of various DER services? How can transmission-level services provided by DER be valued? What DER transmission-level service valuation methodologies are best suited as a compromise between simplicity and full cost-reflectiveness? What are DER capabilities to provide frequency response, and how can the distribution network impacts be considered?	System services	N/A
77. Device-level demand response: How can SOs deploy device-level demand response in a cost-effective manner, as well as effectively verify performance?	System services	N/A
78. / 2025_10 System strength: What capabilities are needed to ensure adequate system strength stability when operating a power system with few (or no) synchronous generators?	System services	Modelling tools
79. Wholesale electricity market design: Considering the interaction between energy markets and system operations, what are the strengths and challenges by different market designs for efficiently and effectively enabling the energy transition? How could these market designs evolve as power systems move to "service" provision with periods of energy abundance? What targeted structural interventions may need to be considered to address non-scalable constraints with legacy architectures?	System services	N/A
80. / 2025_11 DER system architecture: What core functions, capabilities and roles will SOs, transmission businesses, distribution businesses and DER aggregators need to enable whole-system models of visibility, data exchange, control and operational coordination?	System services	N/A
81: Dynamic pricing: How could DER dynamic pricing influence power system operations, stability and reliability?	System services	N/A