Attachment A

Advisory Note for relevant topics.

The following notes are provided for each of the major topics. While CSIRO considers this guidance as useful for EOI submissions, potential respondents may submit against alternative topic areas within a Topic.

Your submission will be considered along with all others. CSIRO would suggest respondents spend some time offering an explanation why an alternate path should be considered.

<u>Topic 0:</u> Program management

Topic 0 is focussed on delivery of the remaining AR-PST topics. This is expected to be up to eight separate research topics but this may vary based on CSIRO deciding not to move forward with a topic, or splitting a topic between separate recipients, which may lead to multiple research projects within a single topic.

Prior to contract signature, CSIRO will know how many topics there will be and if a change is required to topic 0 deliverables, this will be discussed.

Though not specifically completing technical research, a high level of domain knowledge will be required to supervise delivery of the remaining topics.

Other requirements include:

- Compilation of feedback on proposed research projects, timelines, and resource allocations within one month of project commencement or after at least one meeting with each of the CSIRO-appointed AR-PST researchers.
- Preparation of a high-level twelve-month delivery timeline for successful research proposals.
- Conducting regular coordination meetings with appointed researchers, CSIRO staff and AEMO advisors, to track progress and offer feedback.
- A formal monthly progress report to CSIRO summarising research plan developments, with informal updates as needed until the project's final due date in May 2026.
- Provision of general project management services, including ad hoc meetings with CSIRO and AEMO leadership and officers.
- Coordination and facilitation of quarterly workshops with relevant parties to report on progress, planned work, and identified issues.
- Conducting reviews and quality assurance of research project deliverables, by coordinating the assigned CSIRO and AEMO subject matter experts for each research topic.
- Organisation of a final workshop upon completion of all research projects for researchers to present outcomes and discuss next steps.
- Provision of general advice to assist CSIRO in developing the next phase of AR-PST research plans.

Topic 1: Inverter Design – Development of capabilities, services, design methodologies and standards for Inverter-Based Resources (IBRs)

The CSIRO research roadmap for Topic 1 produced in 2021[1], outlines five major research tasks, as well as five more that are shared across other research topics. Within each of these ten tasks are a collection of subtasks that have been categorised in order of urgency, with the highest priority tasks identified as:

1. Defining the response of GFLIs and GFMIs for a credible contingency
2. Interactions between synchronous machine AVR, GFMI AVR and GFLI in providing reactive power support
3. Identifying the nature of oscillations in IBR-dominated grids
4. Standardising the models of IBRs
5. Modelling, analysis, control and coordination of IBRs for oscillation damping
6. Enhancing IBR response during and subsequent to faults
7. New measuring and monitoring systems for frequency and RoCoF

Work has progressed on the most critical tasks, starting with Stage 2 in 2022. The current Stage 4 research is focused on:

1. Enhancement of large-signal stability analysis tools that provide a comprehensive framework for assessing the stability of IBR dominated networks.
2. Sensitivity analysis of Grid Forming Inverters (GFMIs)
3. Expansion of the stability analysis to multi-IBR systems to identify the collective impact of these resources on system stability.
4. Development of tuning and design guidelines for the design and operation of GFMIs using the outcomes and insights of the previous activities.

Based on the ongoing research, as well as industry developments since inception of the Roadmap, CSIRO emphasise the following list of tasks for future stages in Topic 1:

High Priority

1. Broaden scope to include modelling and performance of Inverter-Based Loads (IBLs), especially including modelling performance in weak grid conditions.
2. Expand investigation of grid-forming technology beyond virtual synchronous generators and analyse and quantify the ability of grid-forming inverters to meet power system requirements.
3. Investigate the ability of IBRs to suppress unbalanced faults in studies with negative sequence currents.
4. Use a wide-area model more reflective of the NEM transmission network for studies (model above 33 kV).
5. Development of technical standards for grid forming inverters

Medium Priority

1. Review where assumptions made about inverter performance are becoming more critical to system operations
2. Distributed energy resources interactions with large scale inverters

[1] https://www.csiro.au/-/media/EF/Files/GPST-Roadmap/Topic-1-Inverter-design-Final-Report-with-alt-text-2.pdf

3. Advanced grid synchronization, protection, and reliability in high IBR penetration power systems.
4. Assess adequacy of simulation modelling given complexity of power systems, and explore use of data driven approaches and artificial intelligence machine learning methods
5. Metrology and instrumentation to support real-time operations
6. Advanced control methods (predictive control, artificial intelligence, etc.) for GFMIs.
7. Investigation of the impact of GFMI parameters on transient instability.
8. Exploring the limits to IBR penetration in interconnected power systems due to system technical performance requirements.
9. Frequency stability in high IBR penetration power systems.
10. Voltage stability in high IBR penetration power systems.
11. Interaction mitigation and oscillation damping in high IBR penetration power systems.
12. Power quality improvement in, and harmonic analysis of, high IBR penetration power systems.

<u>Topic 2:</u> Stability tools and methods

The overarching objective of Topic 2 laid out in the 2021 Research Roadmap[2] research is to further advance power system stability assessment processes to improve management of our electrical networks. In that Roadmap, four critical and eight high priority research items were identified that targeted the development of tools and processes to determine stability margins of power systems and stability screening methods for rapid analytical assessment of system stability. The Roadmap also noted some lower priority research items that were derivations of the higher order ones, where the critical research proposed includes:

1. Development of tools to evaluate non-linear stability margin using blackbox IBR models at multiple operating points.
2. Development of procedures to use impedance-based methods for small signal stability screening.
3. Development of tools for voltage stability boundary recognition as a criterion for system operation.
4. Development of tools that can improve voltage control, recovery, and collapse assessment to assist operators in considering IBR in Volt/Var dispatch tools and mitigate high voltages due to increases in IBR outputs.

The research conducted to date under Topic 2 is complementary to Topic 1, focussing on the assessment of small signal (oscillatory) stability in power systems with high levels of IBR penetration as described in the first two points above. Given the flow of the current stage work and the priorities that can be tackled somewhat independently, CSIRO emphasise the following proposed list of research topics for future stages of Topic 2:

High Priority

1. Electromagnetic transient (EMT) and impedance scan tools and methodologies for planning, connections, and operational studies with an increasing share of inverter-based resources (IBR).
2. Investigate interoperability of modelling tools, such as converting powerflow models between tool, running compiled DLLs in different tools, etc.
3. Explore increasing simulation speeds for EMT models through hardware, model quality, process improvements, co-simulation, etc.
4. Analysis and quantification of grid-forming (GFM) inverter capability required to support power system stability.
5. Continue investigation of other stability methods, such as frequency-domain analysis and small signal stability.

Medium Priority

1. Review access by generation developers to data and models including what data is needed and investigate differences between how data is managed by different parties in the connection applications process
2. Review accessibility of modelling tools and research ways to enable access to models, data availability and software licences

[2] https://www.csiro.au/-/media/EF/Files/GPST-Roadmap/Topic-2-Stability-Tools-and-Methods-Final-Report-with-alt-text-2.pdf

3. Analysis of AEMO connections workflow historical performance to identify additional opportunities for early scanning studies to identify expected redesign challenges later in the workflow
4. Expand on the application to a real system of frequency domain admittance scans for positive sequence blackbox IBR models.
5. Investigate the computational aspects of the frequency domain admittance scan method and extend this to apply in an operational setting (i.e., near real-time).
6. Utilising multiple frequency network equivalents to represent remote regions not critical to a particular analysis, and through such simplifications further improve large network applications of frequency domain impedance scanning.
7. Develop tools that can improve voltage control, recovery, and collapse assessment, to assist operators in considering IBR in Volt/Var dispatch tools and mitigate high voltages due to increases in IBR outputs.
8. Develop tools and methods for online system strength identification.

A focus of future tasks should be the development of tools and processes that can aid system operators in more effectively managing increasing levels of IBR penetration. Bidders for Topic 2 are advised to clearly identify the practical implementation of the research and the consequent benefits to power system operation and planning. Projects should look to realise completed research as real-world applications where possible.

<u>Topic 3:</u> Control Room of the Future

Operations Technologies Applications

Bidders are advised to strongly link their expected research to the tools, processes, and outcomes for Operations Technologies (OT). That is, the work must have clear and demonstrable benefits to AEMO's control room, including its systems, processes, and human operators. Identified areas include:

High Priority

1. Determine what visualisation capabilities are needed to enable operators to effectively and efficiently interpret relevant information and make these capabilities operational.
2. Identify how operational forecasting capabilities can be improved to manage a VRE-dominated grid, and what tools are needed to manage short-term resource adequacy.
3. Development of tools for the management of energy in grids with high penetration of battery energy storage systems (BESS) and coordinated storage from consumer energy resources (CER)
4. Investigate what additional short-term planning and control room tools are necessary to manage an energy grid with a high penetration of BESS.
5. Comprehensive assessment of data processing and interpretation requirements of the key future control room capabilities listed below, and hence requirements for operator capability, major computational hardware, software, communications systems, metering and sensing hardware, and externally supplied data streams.
6. Increase the focus on machine learning for managing data in the control room and producing task-specific outputs using publicly available or releasable demonstration data.

Medium Priority

1. Evaluating the range of scenarios and uncertainty that could arise in the future, and where are the limitations in terms of the capability to manage uncertainty of real time operations
    a. Understand the implications for real time operations in the control room of the difference between highly granular visibility of the network, versus an aggregated view
2. Assess need for the additional functional capabilities of a future control room to manage high penetration of IBR and impact of this on operator cognitive load
3. Specific functional capabilities
    a. **Outage Management and Reporting**: Automated logging systems and integration with other tools; Network Outage Scheduler (NOS) enhancements with risk assessments and forecasting.
    b. **Frequency Management and Control, Ramping, and Inertia**: Ramping assessment tools; Distributed Energy Resources (DER) demand control architecture and implementation.
    c. **Electricity Market Management System (EMMS)**: General improvements for NEM2025 and WEM market reforms.
    d. **Protection, Control, Blackstart, and Restoration**: Special Protection Scheme (SPS) and protection wide area coordination tools; Blackstart and Restoration tools using Variable Renewable Energy (VRE) and DERs.

e. **Voltage and Reactive Power Management**: Voltage reactive power management tool with look ahead capability.
f. **System Strength and Electro Magnetic Transient (EMT)**: Study automation tools and Real Time Simulations (RTS)
g. **Dynamic Security Assessment (DSA) and Constraints**: Prediction tools for Transient, Voltage, Frequency, and Small Signal stabilities.
h. **EMS SCADA and System Monitoring**: Continued enhancement and integration of Energy Management Systems (EMS) and Wide Area Monitoring Systems (WAMS)
i. **Compliance Monitoring**: Systems for generation demand, DER, model validation and compliance monitoring.
j. **Operational Forecasting**: Integration of operational forecasting tools with general OT tools
k. **Operational Data and Models**: Governance and management system for operational and modelling data; Network Model Management (NMM) framework to service operations, markets, planning and connections.

Research Areas

Topic 3 is defined as the "*Development of new technologies and approaches for enhanced real-time visibility and analysis in power system operator control rooms*".

Applied research that serves the above OT applications are welcomed, including (but not limited to) recent advances in generative AI, human computer interfaces, physics-informed neural networks, data governance/stewardship techniques, and human-AI collaboration. However, they must be firmly grounded in use-cases for control rooms and have practical benefits within the 1-year time frame.

<u>Topic 4:</u> Power System Planning

The need for expansion of our electrical transmission network has been raised by transmission companies, the system operator, and energy producers, across Australia. In outlining the many changes that are occurring in our electrical network from decarbonisation to decentralisation, from electrification and digitisation, and to a transition to asynchronous generation, the 2021 Topic 4 Research Roadmap[3] identified that substantial research is required to define the transmission planning frameworks that will lay the foundation for low carbon and energy system planning. The research roadmap outlined the need for research across five cohesive programs:

1. **Open-Source Tools and Datasets**: The development of open-source tools and datasets for performing integrated planning, and adequacy studies.
2. **Decision making**: All the elements (e.g., metrics, risk appetites, objectives of stakeholders) associated with the design and interactions of modules and tools to determine flexible investments in power system planning under uncertainty.
3. **Power system operation**: Models and tools needed to assess and quantify the technical and economic performance of the system, also considering computational efficiency.
4. **Reliability and resilience**: Methodologies and models to assess the system reliability and resilience under various uncertain or extreme conditions. Definition and design of metrics to assess techno-economic performance in power system planning under uncertainty
5. **Distributed energy systems:** Models for evaluating demand side flexibility, impacts and flexibility embedded in the interactions between power system and other energy systems (i.e., gas, hydrogen), and assessing adequacy and resilience contribution from DERs in planning studies
6. **Long-term uncertainty**: Methodologies and models to define uncertainties and risks in the representation of future power systems.

Within these five programs the Roadmap further nominated 36 potential research projects across multiple streams, with an overall focus on new planning metrics, methods, and tools to capture the characteristics and influence of a changing resource mix.

Previous stages of the Topic 4 research have focused on and delivered tools such as probabilistic decision making trees, and methods that allow consideration of network resilience to extreme events and the contributions of distributed energy systems to transmission systems. Some of this research is significantly advanced, while some is at the early stages of research. Hence, opportunities exist for future research projects that can present practical, scalable, and implementable tools and methods to aid Transmission- and Distribution Network Service Provides and the AEMO Planning departments. Research areas that could be considered priority matters include, but are not limited to:

High Priority

1. The development of open-source tools and datasets for performing integrated planning, and adequacy studies.

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[3] https://www.csiro.au/-/media/EF/Files/GPST-Roadmap/Topic-4-Planning-Report.pdf

2. Investigate other types of strategic planning, engineering assessments, and time sequential modelling other than ISP capacity output modelling, as it is difficult to adapt the ISP capacity modelling methods to industry because of its specific constraints.
3. Shift focus to resource adequacy and resilience in the approach to planning a high IBR system.
4. Investigate what planning models and metrics are required to account for resource scarcity and reliability, taking load forecasting, DER modelling, and coordinated CER storage.
5. Development of a conceptual framework, consistent with the planning method developed to date, for assessing the benefit of reducing uncertainty associated with limits of average and instantaneous IBR penetration for secure power system operations. Incorporate sensitivity to
    a. The electrical network's system strength and system inertia requirements and other operability constraints and incorporating them into the network expansion problem.
    b. The uncertainty regarding the future operation of synchronous generating units, emerging technology, and innovations that enable IBR to provide sought-after system services, demand levels, regulatory change, operational measures, and other emerging security issues in pre- and post-security events.
    c. The uncertainty associated with short-term and long-term system adequacy conditions in the planning decisions under extreme conditions such as low reserve conditions.
    d. Management of energy in grids with high penetration of battery energy storage systems (BESS)
6. Modelling and assessment of integrating distribution and transmission network planning within the expansion planning process
    a. Modelling investment decisions (including demand response at high DER penetration) at the distribution network level and determining appropriate methodologies to integrate them in transmission system planning.
    b. Modelling the impact of high DER penetration on power system transmission planning.

Medium Priority

1. Development of tools and methods to incorporate the assessment of non-network solutions value streams into the network expansion problem.
    - Whole of system planning, including distribution, DER aggregation and investments in system visibility. Assess impacts of dynamic operating envelope in distribution networks on whole of system requirements.
2. Including network security considerations to accurately capture the benefit of the operational flexibility of different technologies.
3. Development of approaches to integration of power system resilience requirements for transmission networks in the transmission planning framework.
4. Methodological developments to assess the integrated expansion planning of electricity-gas-hydrogen infrastructure under uncertainty.

5. Assessment of impacts and benefits of other infrastructure and sector coupling (e.g., electricity, gas, hydrogen) on reliability and resilience.
6. Modelling the steady-state operation of the system (at least 220KV and above) considering the trade-off between computational efficiency and model precision
7. Minimisation of renewables curtailment through a range of options including smart technology, and latent capacity,
8. Case study for planning: evaluation of the interconnection of the NWIS and SWIS in WA.

Bids for future projects with Topic 4 are strongly recommended to consider research that develops scalable (i.e., computationally efficient) methodologies capable of informing energy system planners (transmission, distribution, natural gas, hydrogen) about the required developments to successfully perform integrated energy system infrastructure planning in Australia that will support the energy transition. Research into the regulatory frameworks that govern transmission investment expenditure in the NEM and WEM will also be considered.

<u>Topic 5:</u> System restoration and black start

Modern power systems are transitioning from conventional synchronous generation powered by coal and gas to asynchronous renewable types. Presently the former technology forms the basis of the restoration capability of our power system i.e., the generating facilities that can restart a power system after a blackout.

As detailed in the 2021 Research Roadmap[4], Topic 5 investigates the potential role and impact of inverter-based resources during power system restoration. The Research Roadmap defined high priority matters such as:

1. Performance of grid forming inverters during, and their contribution to system restoration processes.
2. Performance of grid following inverters during system restoration.
3. Impact of distributed energy resources on the black start process.
4. The role of synchronous generators and synchronous condensers in an IBR dominated power system.
5. Impact of control systems on system restoration.
6. Impact of protection systems on black starting.
7. Power system modelling and simulation tools for system restoration assessment.
8. Assessing the need for and benefits of decision making tools for control centers.
9. Technical standards and regulatory processes for system restoration.

The most recent Stage 4 of the Research Roadmap has progressed research in assessing the impact of DER on the system restoration process using IBR, the impact of network control and protection systems in restoration in system with a high share of IBR, and considered an end to end system restoration in a power system with high shares of IBR.

Informed by the priority research areas of the Roadmap, the Topic 5 Stage 4 Interim report, and general industry feedback, CSIRO emphasise the following proposed list of research topics

High Priority

1. Determine how Renewable Energy Zones (REZs) can be best exploited as future System Restart Ancillary Service (SRAS) sources and how long (after loss of supply) is required for a typical REZ to complete the self-start stage and to become ready to energise the network, whether a small nearby portion or beyond. Study possible REZ restart methods and requirements.
2. Quantify the aggregate reliability of SRAS sources when wind and solar farms are the black-starters.
3. Investigate the technical feasibility of using hybrid GFM BESS and IBRs as reliable SRAS sources. Broaden scope of investigation to include modelling and performance of Inverter-Based Loads (IBLs), especially including performance in weak grid conditions.
4. Evaluate the fundamental technical requirements for inverters for system restart including grid forming capability as a basis for developing technical requirements and standards.

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[4] https://www.csiro.au/-/media/EF/Files/GPST-Roadmap/Topic-5-Blackouts-and-System-Restoration-Final-Report-with-alt-text-2.pdf

Medium Priority

1. Initial techno-economic analysis of IBR restart options compared to conventional technology as a baseline.
2. Consideration of how the future provision of any existing and anticipated restart services should be incentivised and maintained, either through technical standards and/or market mechanisms. Explore different market structures that may more efficiently and effectively provide restart services. What incentives are required to encourage connection of grid forming inverters including additional incentives for those that are black start capable.
3. Assess the ability of existing restart planning tools to be adapted to include IBR restart pathways and their data requirements.
4. Evaluate the capability of an expanded set of technologies to assist in a system restart, such as pumped hydro devices and modern HVDC links, in addition to evaluating their other possible interactions with GFM IBR restart sources.
5. Extend DER studies to consider the representation of other consumer energy resources (CER) such as residential BESS, EV charging, and heat-pumps. Explore whether conclusions to date regarding DER performance differ significantly or whether materially different distribution system performance is expected, for this expanded set of equipment.
6. Investigate what changes to design principles or technical standards could better enable CER to participate more effectively in system restart. Should distribution connected inverters be under the control of a distribution network service provider?
7. Investigation on the extent to which network support equipment, such as SVCs, STATCOMs, and series compensated devices, needs to be altered to better support power system operation during 100% IBR restart, and whether certain limited capability equipment (such as SVCs) will remain appropriate for network voltage support in the medium- to long-term.
8. Consider how new network topology changes, that are expected over the next ten years, may aid or hinder the restart process (e.g., increased meshing of the network versus a propensity to connect new generation centres using higher-voltage, and series-compensated, circuits).
9. Investigate and establish a GFM-BESS restart test plan for a real plant, to develop confidence in the capability of the device to restart a portion of the system. This could be through the use of Hardware-In-Loop (HIL) / real-time simulation facilities or even through testing of a real, full scale-scale, in-NEM, facility.
10. Testing of real network protection relays within a HIL setup to confirm that the conclusions made through the investigations into network protection relays conducted in Stage 4 through simulation also apply to common, manufacturer-specific, devices used in the NEM.
11. Where HIL studies are conducted, a comparison of the results between offline EMT studies and HIL studies to confirm the validity of the tools used for analysis.
12. As outlined the list of potential research topics above, increased focus of future research should be placed on practical testing of to-date completed research and pilot projects to validate concepts developed since commencement of the Roadmap.

<u>Topic 6:</u> System Services

Essential system services are an integral part of power system operation, from traditional services that control electrical frequency and network voltages in interconnected power systems, to more recently introduced requirements for system strength and inertia. Without these services, the power system would not operate securely and reliably. Hence, understanding and addressing the system service requirements of the future power system is the focus of Topic 6.

The Topic 6 Research Roadmap published in 2021[5] proposed five critical areas of system services research:

1. Technical requirements (necessity and adequacy) of Australia's future grid,
2. Frequency regulation,
3. Voltage regulation,
4. Metric development for new services, and
5. Financial benefits.

To date the delivery of the research plan has progressed the second and fourth research area listed above, as well as more recently commenced a more holistic analysis of the ESS requirements in a power system with very high penetration of IBR, using an electromagnetic transient (EMT) simulation of a simplified NEM model. The latter work conducted during Stage 4 of the research considered not only system services, but also changes to system control and protection to facilitate these services. This most recent stage of research has also conducted a review of the Roadmap, as well as creating a catalogue of all anticipated future system services and system functionalities to support these has been developed to guide future research. This catalogue and the reviewed Roadmap will be available in the Stage 4 final report.

For future stages of the system services research, research that would address open matters and provide practical and useable outcomes to the operation of the Australian power system could include:

High Priority

1. A simplified EMT NEM model that is cleared for confidentiality and shared with the wider community.
2. Shift focus towards developing more robust system strength metrics, and how system strength is maintained with few or no synchronous generators.
3. Consideration of how the future provision of any existing and anticipated system services should be incentivised and maintained, either through technical standards, or wholesale, distribution, and/or retail market mechanisms. Explore different market structures that may more efficiently and effectively provide services.
    a. Identify the extent to which various essential services are quantifiable at whole of system scale in a way that contributions of individual plant can be attributed in a straightforward manner that is simple to aggregate.

Medium Priority

1. Characterise the relationship between minimum demand and essential system services identified in previous work, and give an account of how minimum demand requirements

[5] https://www.csiro.au/-/media/EF/Files/GPST-Roadmap/Topic-6-Services-Final-Report-with-alt-text.pdf

might be expressed more fundamentally in terms of essential services as a derived operability constraint.

2. Load modelling and coordination and provision of services from loads, including aggregated models of small loads, pumped hydro etc. What framework for modelling the power system is required to enable this to be evaluated?
3. Real-world trials, or a roadmap to real-world trials, with industry partners to demonstrate provision of services from newer technologies
4. Expansion and further refinement of the developed wide-area EMT model to consider additional scenarios and ensure its fitness-for-purpose for evaluation of a wider set of system needs / potential system services.
5. Enhance the draft catalogue of essential system services and estimates of the time frames over which they might no longer be provided by identifying consequences of inadequacy and assessing their significance.
6. Development of tools and models for quantifying the system inertia requirements and remediations in case of variations in the future 100% renewable operation scenario of least/no synchronous generating units, more emerging technology, and innovations that enable IBR to provide sought-after system services, demand levels, regulatory change, operational measures, and other emerging security issues in pre- and post-security events.
7. Development of tools and models for quantifying the system strength requirements and remediations in case of variations in the future 100% renewable operation scenario of least/no synchronous generating units, more emerging technology, and innovations that enable IBR to provide sought-after system services, demand levels, regulatory change, operational measures, and other emerging security issues in pre- and post-security events.
8. Investigating how DER and distributed flexible loads on the distribution grid can provide frequency balancing services to TSOs.
9. Future Underfrequency Load Shedding / Emergency Underfrequency Response requirements.
10. Assess the opportunities for system services to enhance power system resilience.
11. Develop ontology for language used to describe, and help build a common understanding of, services including system restart.

Topic 7: Power System Architecture (PSA)

Research Topic 7 explores the applicability of systems architecture to the characterisation and planning of large scale electrical power systems undergoing a transition from conventional, centralised, dispatchable generation to variable, inverter-based, and distributed energy resources. Key steps in the research plan are outlined in the Research Roadmap[6] of this topic.

Previous work has progressed development of a power systems architecture for a whole-of-power-system, considering the multiple layers within the structure of structures that is our modern energy system. In the most recent research, the project has applied principles of Model Based Systems Engineering (MBSE) to test the structures and architectures developed and assessed these against actual NEM use cases such as CER/DER integration projects.

In addition to extensive collaboration with AEMO on the application of PSA and MBSE tools to address the complex, end-to-end CER/DER Functional Requirements in the near, medium and long-term futures, other initiatives have been stood up by the Commonwealth and Market bodies that are also directly relevant to the Topic 7 research[7].

In recognition of the many parallel activities being conducted across the NEM and the establishment of a short term focused PSA research program at AEMO, the next stage of the Topic 7 work will seek to focus on the long-term aspects of PSA, recognising that more substantial changes to the NEM's architectural structures will be required to ensure future scalability beyond 2035.

Priority goals include

1. Detailed design architecture of a distribution system operator
2. Application of systems engineering principles to understanding limits and constraints of various role and responsibility choices for transmission system operator, distribution system operators, system operator and so on.
3. Detailed assessment of alternative data exchange models in terms of ability to satisfy requirements identified by architectural analysis.

Building upon the prior stages of CSIRO-funded work, it is envisaged that Stage 5 will have maximum practical value by addressing the following three interrelated topics, each with several sub tasks:

1. Future System Capabilities Analysis (2035+)

a. Map systemic differences between 2050 scenarios
b. Identify systemic commonalities across 2050 scenarios
c. Cross-check with Emerging Trends & Systemic Issues analysis

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[6] https://www.csiro.au/-/media/EF/Files/GPST-Roadmap/Topic-7-Power-System-Architecture-Final-Report-with-alt-text.pdf

[7] Including: DCCEEW National Consumer Energy Resources Roadmap, AEMO CER/DER Functional Requirements Co-design, AEMC Distribution System Operator (DSO) and Distribution Markets initiatives, DCCEEW National Electricity Market Review, ARENA/AEMO CER/DER Data Exchange Co-design

d. Identify least regrets system requirements for 2035+
e. Map relevant existing system capabilities
f. Analysis of key capability gaps critical to enabling transition beyond 2035
g. Identify least regrets system capabilities for 2035+

2. Detailed Architecture for a High-CER/DER Power System (2035+)

Informed both by the Future System Capabilities Analysis and progressive outputs of relevant Commonwealth and other parallel initiatives:

a. Undertake a detailed review of the NEM Step Change Reference Architecture developed in G-PST Stage 2;
b. Employ PSA and MBSE tools to collaboratively develop a 2035+ Detailed Architecture that maps the whole-system structural and functional relationships required between the key entities such as e.g., the system operator, the Transmission Network Service Providers, the Distribution Network Service Providers, and CER aggregators.

3. Structurally informed Allocation of Roles& Responsibilities

Informed by the above, apply formal clustering analyses (graph partitioning, design structure matrix, etc.)to provide an objective, scalable and structurally informed approach to the allocation of future system Roles& Responsibilities. This requires the following activities:

a. Define each new capability (or capabilities) needed to meet new power system requirements.
b. Decompose all new capabilities into sets (clusters) of functions.
c. In conjunction with existing system functionalities, consolidate the functions list so that it consists only of unique, non-overlapping functions (mathematically, create an orthogonal set). Information on existing capabilities, functionalities, and components/systems are necessary inputs.
d. Partition the functions into clustered sets or groups. The clustering criteria are largely technical in nature and every function must cluster to one and only one function group.
e. Define discrete roles, ensuring that each functional group maps to one and only one role. This step will surface details such as access to infrastructure needed for Step 6.
f. Informed by the detailed industry structure documentation developed in the previous Detailed Architecture step, map roles to entities and assign responsibilities, ensuring that each role can only map to one entity (while any entity can have several role).
g. Confirm inter-entity integration to ensure that functionalities which reside in separate entities but must coordinate effectively to fulfill capabilities have the necessary means to do so.

In addition to the very specific scope of work outlined above as a complementary long term focus to AEMO's operation short term research, there are other PSA based areas of research that CSIRO would welcome submissions for, including:

1. Recommendations for the future use of systems architecture tools and methods by either the academic power systems research community, power systems industry, or policy makers.

2. Demonstration of the use of a power systems architectural model to evaluate two or more alternative deep design options for a power system in terms of one or more

metrics characterising the power systems functional requirements identified in Stage 1 of Topic 7.

3. Demonstration of the use of a power systems architectural model to identify, more deeply understand, elucidate, or communicate, a cross-cutting systemic issue to either a technical or non-technical audience.
4. Demonstration of the use of a power systems architectural model to facilitate collaboration or communication among technical experts that is significantly more productive than in absence of the model.
5. Verification of the sufficiency of a given power systems architectural model to make valid predictions about the behaviour, and preferably performance metric, of specific instantiations of the model.
6. Evaluation of the consistency between power system architectural models developed to investigate various alternative power systems functions. To what extent would a particular model developed for one investigation provide a suitable starting basis for investigation of a second? To what extent would two models developed for alternative investigations be inconsistent? How simple or complex would it be to combine two alternative power system architectural models into a single, common, consistent architectural model?
7. Demonstrate the applicability of a power systems architectural models to provide insight into the components of the system of interest relevant to one of the other eight AR-PST topics.
8. Demonstrate the applicability of a power systems architectural model to provide insight into the relationship among the system(s) of interest relevant to two or more AR-PST topics.

<u>Topic 8:</u> Distributed Energy Resources

Australia leads in rooftop solar photovoltaic (PV) adoption, with more than one-third of households equipped with PV systems. To prevent local network congestion resulting from the increasing adoption of solar PV by customers, Distribution Network Service Providers (DNSPs) in Australia are moving away from static export limits, which are inherently conservative by design, to flexible connection agreements known as Dynamic Operating Envelopes (DOEs). These DOEs manage bidirectional power flows while preserving infrastructure integrity, i.e. operating the network within the combined thermal and technical envelopes.

Topic 8 of the research program investigates the implementation and optimisation of DOEs, by considering five DER related challenges, each detailed in the 2021 published Roadmap[8] for Topic 8:

1. Control architecture of DERs
2. Communication requirements for monitoring and control of DER
3. Ancillary services provided by DER
4. Influence of DER on system level planning
5. Overcoming institutional challenges

During the past three years of research implementation, progress has delivered numerous insights such as performance of various DOE models when applied to single distribution systems (i.e., neighbourhoods), the impact of multiple neighbourhoods on DOE operation, and exploration of Volt/Var controls in actual DOE managed pilot projects.

Future stages of Topic 8 should build on the body of knowledge collated during the past stages and consider research topics such as:

High Priority

1. Management of energy in grids with high penetration of battery energy storage systems (BESS).
2. Coordinated storage from consumer energy resources (CER).
3. Investigate the best ways to improve operational coordination between AEMO, DNSPs, and aggregators for DOE.
4. Determine what data exchange requirements should be in place between parties for providing DOE limits
5. Develop a performance management framework for DOE

Medium Priority

1. Engagement of distribution network service providers in prioritisation of this research.
2. Assess the potential for dynamic operating envelopes to address the issue of minimum demand.
3. Understand how DER constraints should be communicated to AEMO for enhanced visibility and operability
4. Develop scalable technology for managing DER that can be applied in any number of systems in both Australia and internationally

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[8] https://www.csiro.au/-/media/EF/Files/GPST-Roadmap/Topic-8-DERs-Final-Report_with_alt_text-2.pdf

5. Quantification of the potential for CER demand flexibility to exacerbate or mitigate the controllability and forecastability of demand.
6. Improving the representation of voltage management in DOEs such as by modelling of transformer tap changers or other dynamic reactive power sources present in the system
7. Address network model issues at HV/LV levels and propose recommendations for resolution, such as improving automatic calibration of network models through the use of smart meter collected network information.
8. Development of network planning methods taking the presence of DOEs into account that make it easier for DNSPs to accurately consider all future network conditions
9. Informing on distribution network market integration and policy to enable aggregators through assessment of the compatibility/ complementarity of DOEs with distribution flex markets or technical orchestration, and DOE forecasting.
10. Develop or enrich non-Ideal OE calculation algorithms to address voltage violation issues in HV-LV integrated networks. Enhancing these algorithms will allow for better management of voltage levels and mitigation of violations, especially in scenarios where DER penetration is high and network conditions are dynamic.
11. Explore the fairness concept in HV-LV integrated networks and determine standardization requirements. Assessing fairness ensures equitable distribution of resources and benefits among network participants, which is crucial for fostering collaboration and acceptance of DER integration efforts.
12. Assess communication requirements for OE calculation algorithms in integrated HV-LV networks. Understanding the communication needs for these algorithms will facilitate efficient data exchange and coordination among different network components, enabling seamless integration of DERs and improved grid management.
13. Revisit the 2021 roadmap in light of changes to the power system including smart meter rollout
14. Investigate further the implications of Australian PV inverter Volt-Watt and Volt-var requirements on the effectiveness of Operating Envelopes (OEs). Understanding how these requirements affect the DOEs of the network is crucial for optimizing DER integration and ensuring grid stability.

<u>Topic 9:</u> DER and Stability

The CSIRO funded research roadmap on Topic 9 defined a program of work to deliver five practical deployment outcomes to ensure that ISOs and TSOs can maintain power system security under very high penetrations of IBR such as distributed PV, energy storage, and other resources including inverter-based demand, namely:

1. Support AEMO toolset development for load-DER modelling relevant to high IBR penetration throughout LV distribution networks.
2. Support IBR technology development and deployment.
3. Inform inverter standards revisions.
4. Support AEMO's need for technical expertise and testing capabilities of IBR.
5. Contribute to increase stakeholder engagement and knowledge sharing through dissemination of findings.

Previous research has focused on laboratory testing of large quantities of solar rooftop inverters and appliances such as air conditioners, refrigerators, and freezers, to system disturbances. The measurement results of these tests were then used to develop composite load models that could be used by AEMO and network service providers in power system analysis. The presence of accurate load models in such analysis provides a more accurate system response.

During the past years the testing was expanded to include domestic battery energy storage systems, hybrid energy storage systems, and electric vehicle charging infrastructure, as uptake of these new technologies increased. The nature of tests was also expanded to include reconnection testing such experienced after blackouts, large phase angle jumps, and point on wave testing.

For future research stages, CSIRO anticipates that research proposals should focus on further developing testing and validation methodologies of loads and CER. Potential research topics could include:

High Priority

1. Expand on current work through investigating DER ride-through challenges and the impacts of low system strength on DER and model development
2. Develop model of electric vehicle aggregate response to disturbances.

Medium Priority

1. Development of fault ride-through standards for single-phase inverters
2. Review existing methodologies for model validation (testing) for the aggregate composite load models developed by AEMO based on bottom-up DER testing.
3. Identify suitable mathematical and probabilistic formulations of aggregate models such as AEMO's CMPLD to explore maximum likelihood methodologies for aggregate load model parameter estimation.
4. Explore and benchmark machine learning methodologies to parametrise aggregate load models such as AEMO's CMPLD based on measured data.
5. Data driven identification of DER in the network — to identify where electric vehicles are charging and the capacity on the system
6. Expanded testing of large three phase inverters, particularly those rated between 30kW and 200kW. These are some of the biggest growth areas currently in the NEM and for which, disturbance behaviour is poorly understood.

1. Conduct advanced wave disturbance analysis on residential PV inverters, focusing on a testing point on wave (POW) disturbance analysis on the fleet of residential PV inverters to grid disturbances to identify the most vulnerable point for disturbance, informing future updates to standards, and informing ongoing development of dynamic models representing distributed PV.
2. Surveying and testing of further residential and commercial loads in order to better tune and improve dynamic load models. Load models remain the largest source of uncertainty in NEM dynamic models.
3. Investigate provision of system strength from community grid forming inverters in the distribution network
4. Testing of EV charging infrastructure to understand responses during disturbances will inform the development of suitable performance standards for EVs regarding impacts on grid stability and dynamic power system models for EVs.
5. Explore strategies and technologies for effectively aggregating DERs and EVs into composite load models, probabilistic load models and the development of algorithms and control systems for real-time management and optimization of the distribution network.
6. Additional and closer collaboration with related topics, e.g. Topic 8, on informing model development and inverter responses under different network operating conditions.

Emphasis of the research proposed by bidders should be on the delivery of practical outcomes that can be implemented by the system operator and network service providers in modelling of the performance of their power networks.