Australian research leadership in the Global Power System Transformation

Australian research opportunities to rapidly accelerate the transition to advanced low-emission power systems

March 2022

Australia's National Science Agency

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The world is taking on a rapid clean energy transition at unprecedented scope and scale.

Making the transition requires collective problem solving across the value chain – from academia to industry experts to global systems operators.

Countries around the world face similar energy-related challenges.

Workforce capability & development

Administrative & leadership structures

Accelerating local technology adoption

Solving technology challenges with best practice engineering

Standards development

Need for open data and tools

CSIRO AEMO

Solving these challenges is urgent for Australia, and the world.

Australian scientists and researchers have an opportunity to lead the way, ensuring security during the energy transition, while creating jobs, investment, export opportunities and earning global recognition.

Why Australia?

1. Australia's rapid shift away from fossil fuels is creating significant technical challenges for power system operators that must be resolved locally to maintain our energy security.
2. Our energy transition to a sustainable energy future with renewables can create employment and investment to drive economic growth in a post-COVID recovery.
3. Global decarbonisation is critical to limit the devastating effect of unchecked climate change – Australia has a global responsibility.

We have the opportunity, right now, to collaboratively solve these complex issues, and co-design the best way forward to navigate this energy transition.

More information: https://globalpst.org/

CSIRO AEMO

"The energy sector is a central tenet of our net-zero future…

It accounts for 54 per cent of Australia's emissions and has the most mature range of low emission technology options for immediate and long-term opportunities… The cost of renewable energy is no longer our major challenge – integrating this energy efficiently into our electricity systems is what we need to solve."

Dr John Ward, *Research Director, Energy Systems Program, CSIRO*

Global Power System Transformation (G-PST)

CSIRO and AEMO are Australian representatives in a global consortium brought together to solve the challenges of integrating renewable energy into electricity networks and accelerating their decarbonisation, globally.

The G-PST Consortium aims to **dramatically accelerate the transition to low-emission and low-cost, secure and reliable power systems.**

The G-PST Consortium connects leading organisations across the world to identify common research questions aimed to inform large-scale national research and development investments.

More information: https://globalpst.org/

CSIRO is driving the growth of Australian knowledge to create solutions for the G-PST established research agenda that can be applied right here.

Over the past 6 months, CSIRO has:

- Identified **9 critical research topics** that will drive accelerated decarbonisation in Australia and beyond.
- Selected leading Australian engineering, academic and research partners to create parts of the roadmap to deliver those research topics.
- Reviewed and managed the development of the research plan roadmap.
- Formed the separate research topic plans into a cohesive program that aligns with other Australian initiatives such as AEMO's National Electricity Market (NEM) Engineering Framework.

The 9 research plans are now complete and ready to move forward, with opportunities for more Australian engineering, academic and research organisations to be involved.

Our roles

CSIRO Energy

"As Australia's premier scientific energy research organisation CSIRO Energy aims to deliver the science and technology that will enable Australia's transition to a net-zero emissions energy future."

CSIRO Energy Mission:

- Resolve the national challenges of electricity generation, transmission, distribution, and consumption using simulation and analysis tools & facilities and know-how to inform investments in stable electricity grid systems.
- Create value chains across sectors and develop sustainable solutions for domestic and export industries through demonstrating viable technologies for creation, storage, transport and uses of hydrogen as well as for other low-carbon industry processes.
- Understand the social and environmental impacts of the key energy technologies, offer solutions for emission reduction and thereby enable generators and industry to shift from high emission fossil energy towards reduced emissions and sustainable solutions.
- CSIRO Energy is part of the G-PST core team and Research Agenda Group (RAG).

AEMO

"AEMO manages electricity and gas systems and markets across Australia, helping to ensure Australians have access to affordable, secure and reliable energy."

AEMO's primary role is to promote the efficient investment in, and efficient operation and use of, gas and electricity for the long-term interests of Australian consumers in relation to price, quality, safety, reliability and security.

With Australia's energy landscape experiencing significant disruptive, transformational changes, designing an energy system that addresses and harnesses these changes in the long term interest of energy consumers has become a key focus.

AEMO provides the detailed, independent planning, forecasting and modelling information and advice that drives effective and strategic decision-making, regulatory changes and investment.

In addition to numerous other functions and responsibilities, AEMO was a Founding System Operator of the G-PST.

A rapid pathway from research to impact.

Teams were tasked with preparing a research plan to identify the future work required and the priorities for Australian researchers.

Now, these plans are complete and ready for action.

An investment to facilitate the next big step of this research will take these plans from roadmap to reality.

The steps taken so far

APR 2021

Review

Current status and technology

Related work by AEMO (NEM Engineering Framework, etc.), government, researchers

JUN 2021

Refine

Research questions

Australian research priorities, vs. what's best-reviewed overseas

JUL 2021

Identify

What's needed to make the plan real

Risks and key stakeholders to support research locally and abroad

Oct 2021

Plan

Prepare the roadmap to undertake the work

Next steps?

Implement the research roadmap

CSIRO AEMO

The burning platform

Due to decentralisation, increasing variability, and step changes in energy sector technology, we are fast approaching an inflection point in the Australian energy transition.

A huge body of work is underway and must continue to deliver the end-state that is needed during this decade.

This work will be essential for solving Australia's major energy transition challenges. Australian findings will also apply to energy sectors across the world.

"The National Electricity Market (NEM) is changing quickly, with up to 100% instantaneous renewable penetration expected by 2025 if current trends continue, and new operational conditions emerging."

Australian Energy Market Operator

Why invest in this research now?

Security
Facilitate a safe, cost-effective energy transition for consumers

Research
Advance critically needed Australian research

Innovation
Drive technology and innovation leadership

Investment
Create more stability and opportunity for investors

Export
Build an Australian powerhouse of exportable energy solutions

Environment
Support achievement of Australian net-zero emission goals


Diagram

Australian research focus areas

Topic 1
Inverter Design

Topic 2
Stability Tools and Methods

Topic 3
Control Room of the Future

Topic 4
Planning

Topic 5
Restoration and Black Start

Topic 6
Services

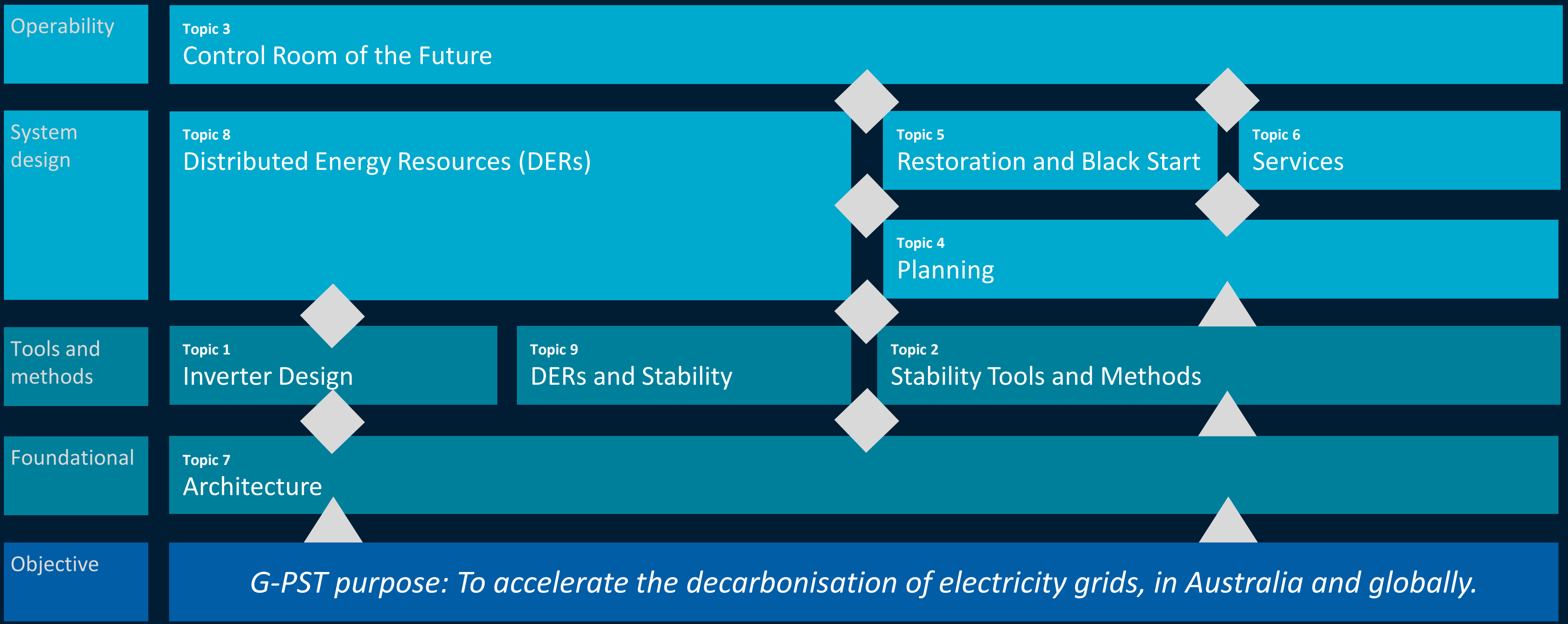
Plus
Australian-specific research areas

Topic 7
Architecture

Topic 8
Distributed Energy Resources (DERs)

Topic 9
DERs and Stability

Working together to achieve the stable, secure, and affordable operation of the Australian power system



Interaction between topics

Key
Agreed interaction
Possible interaction

Inverter Design

Organisation

MONASH University

Priorities

1-2 Years | <5 Years | <10 Years

1 2 3 4 5 6 7 8 9

Key Focus

Power electronic connected generation or inverter-based resources (IBRs) are increasingly the dominant means to connect solar and wind energy to the Australian electricity grid.

But the rate of new connections to the grid and the time required to integrate these successfully is creating operational issues and security constraints.

There are many unanswered questions about IBRs that must be solved as IBRs will be a mainstay in the future grid's generating fleet.

Aim: to contribute to the secure operation of the future IBR-dominant electricity grid, by solving unknowns about IBR design, development and operation.

Expected research deliverables

Five major and five minor tasks, with priority objectives (within 2 years), including:

1. Frequency stability - define advanced IBRs and storage system frequency response requirements and capabilities for future grids.
2. Voltage stability - investigate the reactive capability and voltage control requirements of IBRs.
3. Interaction mitigation and oscillation damping - identify and resolve the source of adverse interaction among aggregated IBRs.
4. Protection and reliability - determine and propose mitigation methods for the adverse impact of IBRs on power system control and protection systems.
5. Trending topics - Develop advanced IBR control methods (grid-forming inverters) for future grid applications.

Along with other subtasks within this research work.

Significance and contribution to Australia

This work would support the bulk connection of IBRs while ensuring that power system stability requirements are satisfied. As a result, this helps reduce or alleviate some security constraints being imposed to maintain energy security. Furthermore, this program will assist with:

- Secure operation of future Australian electricity networks, benefiting all consumers
- Improving investor and developer confidence that projects will connect to the grid
- Ensuring new energy sources can connect as old power sources shut down

This work is built for Australian needs using Australian developer, operator and investor experience and expertise.

Resource requirements

- Up to 45 university-based researchers and academics, including junior and senior experts, over 3-5 years.
- Overseas expertise may be needed for some tasks due to limited knowledge from within Australia.

Key stakeholders needed

- AEMO
- Transmission Network Service Providers (TNSPs)
- Original Equipment Manufacturers (OEMs)
- Australian and overseas Universities

Stability Tools and Methods

Organisation

EPRI

Priorities

1-2 Years | <5 Years | <10 Years

Key Focus

In recent times, our power system has required more frequent operator intervention or operational constraints to be applied to ensure security is maintained. System resilience has become a critical focus as we look to manage the withdrawal of thermal generating plants alongside increasing penetration of Inverter-Based Resources (IBRs). Operator access to advanced and suitable tools play a key role in maintaining this resilience and unlocking the benefit received from integrating renewables.

Assessing, predicting, and managing our future grid under these emerging challenges will require new tools and methods of analysis for our power system planning and operation.

Aim: to better understand how to monitor, predict and maintain the stability of the power system, as traditional power sources that currently keep the grid stable are shut down, and develop tools and processes to better manage this.

Expected research deliverables

New processes and tools from now until 2030, with the most critical tools available in 3 years, including:

1. Tools to assess non-linear stability margins using black-box models and evaluation of stability at multiple operating points (stability margin evaluation).
2. Procedures to use impedance-based methods for stability screening and linear analysis techniques with black box IBR models (small-signal stability screening methods).
3. Tools to identify new boundaries between source and sink regions and recognize voltage stability boundaries as new constraints/criteria for system operation (voltage stability boundary).
4. Improvement in the way loads and IBRs are considered in Volt/Var tools and tools to assist operators with over-voltage mitigation due to an increase in IBR output (voltage control and collapse recovery).

Along with other medium and longer-term tasks.

Significance and contribution to Australia

This work will connect and advance related but solitary research already happening in this field in Australia, including:

- Real-time inertia measurement trials and AEMO's Real-Time Simulator
- New and innovative ways to tune generator control systems for weak grid operation

It will raise our academic and research knowledge base, create tools that will allow us to plan and operate the future grid. This know-how is essential for our future, but it's also exportable.

Resource requirements

- $3.7m - estimated cost to deliver the four critical outcomes.
- Australian researchers and academics.
- Some overseas expertise for up to 3 years.

Key stakeholders needed

- Australian and overseas universities
- International research organisations

Control Room of the Future

Organisation

EPRI

Priorities

1-2 Years | <5 Years | <10 Years

Key Focus

The heart of the modern interconnected electricity grid is a central control room.

It monitors and dispatches electricity production to meet consumer demand. But many control rooms were designed early in the era of electricity grid interconnection and haven't changed since. The control room of 2021 cannot manage our future power system.

Operations, and the way power system operators interact with the system, will have to change rapidly.

Aim: to plan for the Control Room of the Future, highlighting its functions, processes, tools and data.

Expected research deliverables

A five-pillar roadmap implemented in five stages, from now until 2030:

Focus areas include:

1. Functional & capability model and architecture.
2. Data - models and streaming.
3. Energy Management Systems (EMS)/SCADA and Market Management Systems (MMS)/NEM dispatch engine (NEMDE).
4. Operators and human factors.
5. Buildings facilities and hardware.

Each pillar includes distinct milestones: conceptualisation, development, testing and integration. These milestones reflect numerous deliverables of the research topic ranging from establishing the technology status quo, to the harmonisation of platforms used in the control room.

Significance and contribution to Australia

Having the right data and controls is critical to maintaining safe, secure and reliable power system operations. This work will:

- Build on existing projects in Transmission Network Service Provider (TNSP) operations departments across Australia
- Create national alignment and establish industry needs
- Become more important than ever to maintain energy supply throughout large weather events, which are occurring more frequently

Resource requirements

- Initial resource requirements are not yet estimated.
- Actions and milestones focus on the research community and they also require TNSP and AEMO expertise.

Key stakeholders needed

- AEMO for both the National Electricity Market (NEM) and the Wholesale Electricity Market (WEM)
- TNSPs and Distributed Network Service Providers (DNSPs)
- Research organisations
- IT and system architects

Planning

Organisation

THE UNIVERSITY OF MELBOURNE

Priorities

1-2 Years | <5 Years | <10 Years

Key Focus

The electric power system is the backbone of our modern energy supply.

The high-performance decision-making frameworks that incorporate every element of our changing energy system need to be defined.

Many parts of our existing planning frameworks need additional, and new work, to plan for future power systems.

This will also help determine the investments we need to make.

Aim: to create the tools, methods and frameworks needed to plan the future electric power system that underlies our energy supply.

Expected research deliverables

36 research projects within 16 separate streams under 5 research programmes to:

1. Quantify long term uncertainty: develop future scenarios and investigate climate change impact and uncertainty in policy and market developments.
2. Model power system operation: develop both steady-state and dynamic models for planning purposes and the formulation of security constraints.
3. Assess reliability and resilience: develop reliability and resilience metrics, study the system-level impact of climate change, identify credible and non-credible contingencies, and characterise DER/IBR responses to various events.
4. Develop novel decision-making approaches factoring: model metrics, the objectives and risks of stakeholders, and investigate methodologies under uncertainty and the interdependencies of power system planning.
5. Investigate DERs: study the impacts from multi-energy systems, distributed energy markets & demand-side flexibility and DERs.

Significance and contribution to Australia

This work would create real solutions for the Australian power system industry and unlock significant new value for its stakeholders, including:

- Leveraging the best talents of Australian industry and its research partners
- Focusing on “burning” challenges – climate change, modernised and dynamic planning frameworks, aging infrastructure
- Making our increasingly decentralised, intermittent power system work effectively

For Australia to continue to enjoy the energy security and stability of the past, this work is vital.

Resource requirements

- Up to 84 full-time resources over ten years (~15-20 FTE pa) for delivery of all tools and processes.
- Combination of industry and research-based resources.
- Most of the resource requirements are front-loaded.

Key stakeholders needed

- AEMO
- Australian Energy Regulator (AER)
- Transmission Network Service Providers (TNSPs)
- Distributed Network Service Providers (DNSPs)
- Generation companies

1 2 3 4 5 6 7 8 9 ? Diagrams

Topic 5

Restoration and Black Start

Organisation

aurecon

Priorities

1-2 Years | <5 Years | <10 Years

Key Focus

Black starting – or restoring after a total or partial shutdown – power systems is essential, particularly as occurrences of extreme weather events increase.

A stable future energy supply depends on new procedures for black starting systems with high or 100% inverter-based resources (IBRs).

Restoration is not only about black starting a single IBR plant. It needs careful sequencing to restore the entire system while ensuring stability, security and protection. The work includes:

- Grid code specifications for IBRs to be able to black start or assist with the restoration process
- Methods, procedures and analysis techniques to black start and restore a power system with various penetrations of IBRs, up to 100%

Aim: to create specifications, methods and procedures to black start, or restore, power systems with high and 100% IBRs.

Expected research deliverables

Key areas of research each deliver specific outcomes within this topic:

1. Establishing IBRs as restoration support.
2. Network impact of system restoration methodologies due to changes in control and protection.
3. Tools and techniques to develop wide area simulation models to test and evaluate the restart processes.
4. Technical and regulatory requirements that include specific restoration requirements into long-term planning requirements.
5. An end-to-end restoration process that optimises the use of IBRs and manages the increasing amount of Distributed Energy Resources (DERs).

Significance and contribution to Australia

This work would solve significant barriers to a stable power supply in Australia:

- Reliance on ageing generation assets – coal-fired power stations – and the increasing forced outages associated with them
- Increasing risk of cyber-attacks or sabotage on wide-area power system infrastructures

It would also factor in reducing the increasing impact of global warming on our energy supply, particularly with extreme weather events.

Resource requirements

- 8-24 full-time resources.
- 3-8 years for research and implementation.
- Resources are drawn from academia and industry, e.g. AEMO and Transmission Network Service Providers (TNSPs).

Key stakeholders needed

- AEMO and TNSPs
- IBR manufacturers
- Original Equipment Manufacturers (OEMs)

Services

Organisation

RMIT UNIVERSITY

Priorities

1-2 Years | <5 Years | <10 Years

Key Focus

The System Operator uses Essential System Services to keep our electricity grid stable.

This means keeping frequency close to 50Hz, network voltages within acceptable levels and maintaining overall security.

These critical services are mainly provided by a generating fleet that will retire in the coming decades. Meanwhile, we are transitioning to decentralised, variable and asynchronous technology, and Distributed Energy Resources (DERs) are growing. This creates challenges, but also opportunities.

There are technical, economic, and social aspects to consider.

Aim: to ensure essential system services that keep the electricity grid stable are recognised and resolved as more renewables are integrated into the grid.

Expected research deliverables

Five critical areas of essential system services with immediate priority, mid-term and long-term outcomes. Short term deliverables include:

1. Defining technical services needed for flexibility and distribution systems.
2. Frequency support services arrangements – Define optimised treatment of new Fast Frequency Response.
3. Voltage support arrangements – establish what existing equipment can do to manage high IBR penetration, including the use of energy storage systems.
4. Evaluating the performance of metrics used to assess the quality of essential services.
5. Proposing how to integrate new services into the electricity market to maximise benefits to consumers.

Significance and contribution to Australia

This work would light a path forward for system security, and for more efficient essential services that integrate new technologies. Key outcomes are pathways to:

- Optimise essential service provision from new technologies
- Integrate DERs
- Facilitate electric vehicle uptake in Australia

The work would compliment AEMO's Engineering Framework, the post-2025 market development from Energy Security Board (ESB), and many other crucial activities.

Resource requirements

- The plan will be implemented over short-, medium-, and long-term horizons.
- Resourcing requirements are not currently available.

Key stakeholders needed

- AEMO and Australian Energy Market Commission (AEMC)
- State and Federal Government
- Transmission Network Providers (TNSPs) and Distribution Network Service Providers (DNSPs)
- Other industry bodies

Architecture

Organisation

STRATEGEN

Priorities

1-2 Years | <5 Years | <10 Years

Key Focus

Australia's electricity system is more complex than ever, and it is going through an unprecedented change. Shifting to renewables and decentralised energy sources means that Australia is in unchartered territory.

The key to managing such complexity is having an organised underlying structure or 'architecture'.

A plan for an orderly transition of Australia's power systems would use established principles of Systems Architecture. It would deliver on changing policy, customer expectations and technological innovations.

Aim: to deliver an immediately actionable and customised plan for applying Power Systems Architecture disciplines to support the orderly transition of Australia's power systems.

Expected research deliverables

An 18-month plan focused on delivering a Future Options and Transition Pathways Report that will:

1. Identify emerging trends and system issues and identify future system objectives.
2. Document existing architecture and contemporary issues.
3. Explore future system properties and functional requirements.
4. Propose a set of future architectural options to support secure operations and transactional enhancements.

Moreover, Topic 7 is seen as a central and foundational piece to the overall program, able to connect to the other topics.

Significance and contribution to Australia

Australia has the most decentralised energy system among developed countries today. Robust and sustained power system architecture planning is critical to delivering a carefully considered and cost-effective energy transition, benefitting consumers. This work will:

- Examine system architectures for Australia, and identify which ones are most likely to lead to the best outcomes for consumers and industry
- Streamline future demonstration projects and system evolution
- Minimise over-build and unnecessary customisation

The work is highly aligned with AEMO's Engineering Framework and the mapping of operational requirements for the future grid.

Resource requirements

- 18-months for full execution.
- Engineering experts and academia, and the community of practice.
- Resourcing requirements are not currently available.

Key stakeholders needed in the community of practice

- Residential & small and medium-sized enterprise (SME) customers
- Large commercial & industrial customers
- Regulatory & market bodies and relevant departments in federal, state and local governments
- Generators, TNSPs and DNSPs
- DER service providers & aggregators
- Technology vendors, academia, financial bodies

Distributed Energy Resources (DERs)

Organisation

THE UNIVERSITY OF MELBOURNE

Priorities

1-2 Years | <5 Years | <10 Years

Key Focus

The growth of DERs in Australia has been phenomenal, enabling consumers to actively participate in the energy transition.

When you combine the 12 GW of DERs installed across Australia today, DER is the single largest generator of electricity in this country and is key to reducing day-time system demand. And, DERs is potentially set to double by 2030.

Rooftop solar PV makes up most DERs today. Soon, we expect to see similar growth in electric vehicles and home batteries. This will add to the expected growth and also introduce different requirements to that of solar PV. This work will recognise and support consumer contributions to the energy transition, enabling consumers to fully realise the benefits of a modernised power system.

Aim: to be able to access information, predict outcomes and better control DERs using technical and economic measures for the benefit of consumers.

Expected research deliverables

A ten-year plan broken down into high-priority research, mid-term implementation and long-term investigation. Highest priority delivery items target foundational research including:

1. Evaluating the communication and control architecture for DER orchestration.
2. Defining the role of standards for successful orchestration of DERs.
3. Establishing the requirements for modelling of DERs within the distribution system in planning studies.
4. Evaluating the required regulatory changes to enable the provision of ancillary services from DERs.
5. Investigating the feasibility of establishing a distribution level market for DERs.

Significance and contribution to Australia

This work is critical since DERs are already prevalent in Australia. But it also presents a huge knowledge export opportunity. Key contributions are that:

- Australia is leading the way due to high DER uptake – there is no one else to solve these issues for us.
- Australia faces increasing challenges to system security through the growth of electric vehicles and home batteries.
- Finding solutions will ensure our own system security, and create global export opportunities as other countries meet this challenge.

Resource requirements

- The ten-year plan includes short-term research, trials, and long-term research using a mix of industry and research organisation based resourcing.
- Specific resourcing requirements are not currently available.

Key stakeholders needed

- Research institutions including CSIRO and universities
- AEMO and Distribution Network Service Providers (DNSPs)
- DER Aggregators
- Engineering consultancies & experts
- International research organisations (e.g. EPRI, NREL, EDF, RSE)

1 2 3 4 5 6 7 8 9 ? Diagrams

DERs and Stability

Organisation

UNSW SYDNEY

Priorities

1-2 Years | <5 Years | <10 Years

Key Focus

Inverter-based resources (IBRs) like wind and solar are increasing within both the transmission and distribution system. Similarly, volumes of Distributed Energy Resources (DERs) are also increasing, which creates challenges as this form of generation can behave unpredictably and often is less visible

This research focuses on real-world applications related to DER. It includes laboratory testing, in-field data analysis, and simulation to build a comprehensive understanding of DER behaviours during disturbances and apply this knowledge to broader system planning and operations.

Aim: to ensure system operators and network providers can maintain power system security with high levels of DERs.

Expected research deliverables

The early deployment of improved models that transmission network and market operators can use. These models capture small-scale IBR responses to:

1. Develop an improved DER model toolset that supports AEMO's development of transmission network service provider (TNSP) models.
2. Expand UNSW's inverter benchmarking: The small inverter market share is fluid, changing, and creating 'stranded' technologies as more innovative devices enter the market.
3. Start benchmarking portfolios of three-phase inverters, hybrid- and storage-only inverters.
4. Assess the impact of AS4777.2020 on inverter performance.
5. Further develop our excellent control hardware in the loop (CHIL) and power hardware in the loop (PHIL) capabilities to assess inverter controller response to grid disturbances.

Significance and contribution to Australia

Australia is uniquely positioned to be a global leader in this research area because:

- We have some weakly interconnected regional power systems with increasingly decentralised energy production
- Our solar PV and growing distributed Battery Energy Storage Systems are world-leading
- With this research, we can establish world-first practices amongst inverter vendors and manufacturers, consumers and consumer groups, network operators and network service providers, and the market operators, regulators and commissions.

Resource requirements

- $7m over 5 years.
- 7 researchers and several PhD students.

Key stakeholders needed

- AEMO
- TNSPs and Distribution Network Service Providers (DNSPs)
- Inverter OEMs

The complementary interaction between G-PST topics and AEMO's NEM Engineering Framework and related actions

Topic 1 Inverter Design	Performance Standards; Advanced Inverter White Paper
Topic 9 DERs and Stability	Performance Standards
Topic 2 Stability Tools and Methods	System Analysis
Topic 3 Control Room of the Future	Control Room and Support; Operations Technology Roadmap
Topic 4 Planning	Resilience; Resource Adequacy
Topic 5 Restoration and Black Start	System Restoration
Topic 6 Services	Frequency Management; Voltage Control; System Strength
Topic 8 Distributed Energy Resources	Distributed Energy Resources
Topic 7 Architecture	Foundational support for embedding the Engineering Framework in decision-making processes

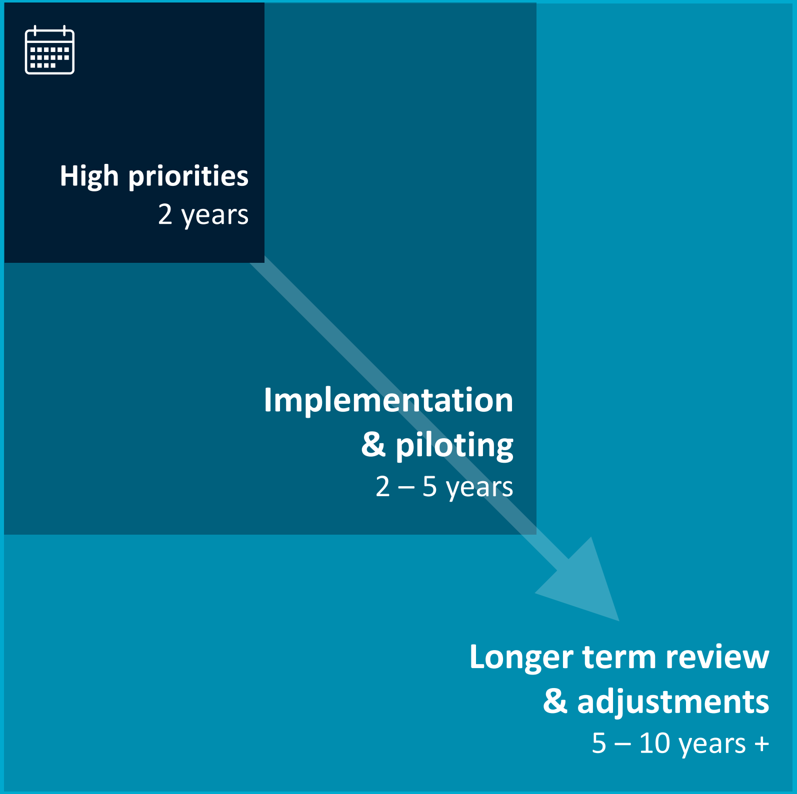
More information: https://aemo.com.au/en/initiatives/major-programs/engineering-framework

What next?

There is a huge body of work needed across industry over the next 10 years which will necessitate a material uplift in the depth and breadth of power system engineering expertise in industry and academia, which the work by CSIRO helps build the foundation for.

This research aligns with the **AEMO's National Electricity Market (NEM) Engineering Framework,** a roadmap to enable a secure and efficient energy transition.

Research process stages



In alignment with the AEMO's NEM Engineering Framework

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Thank you

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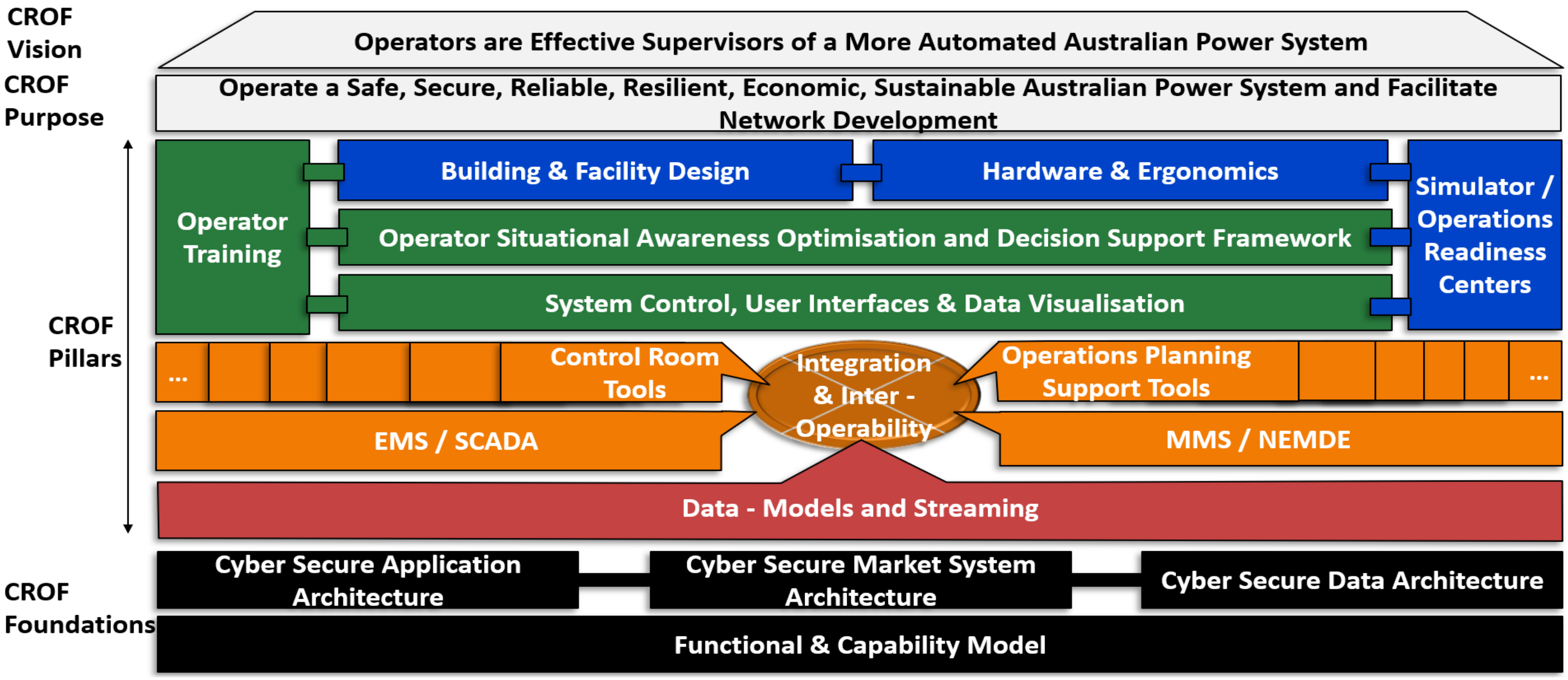
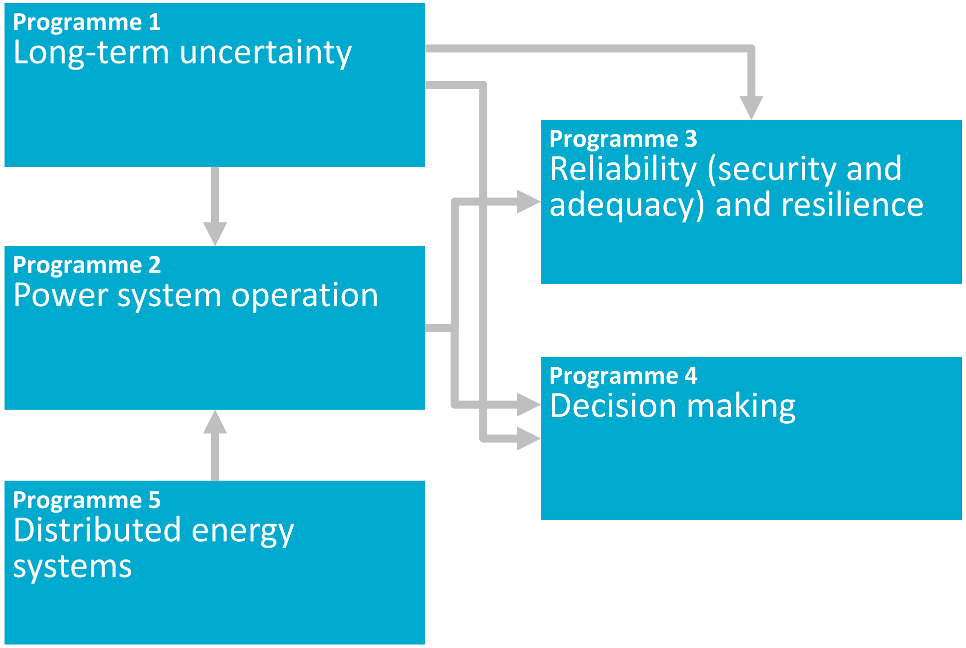
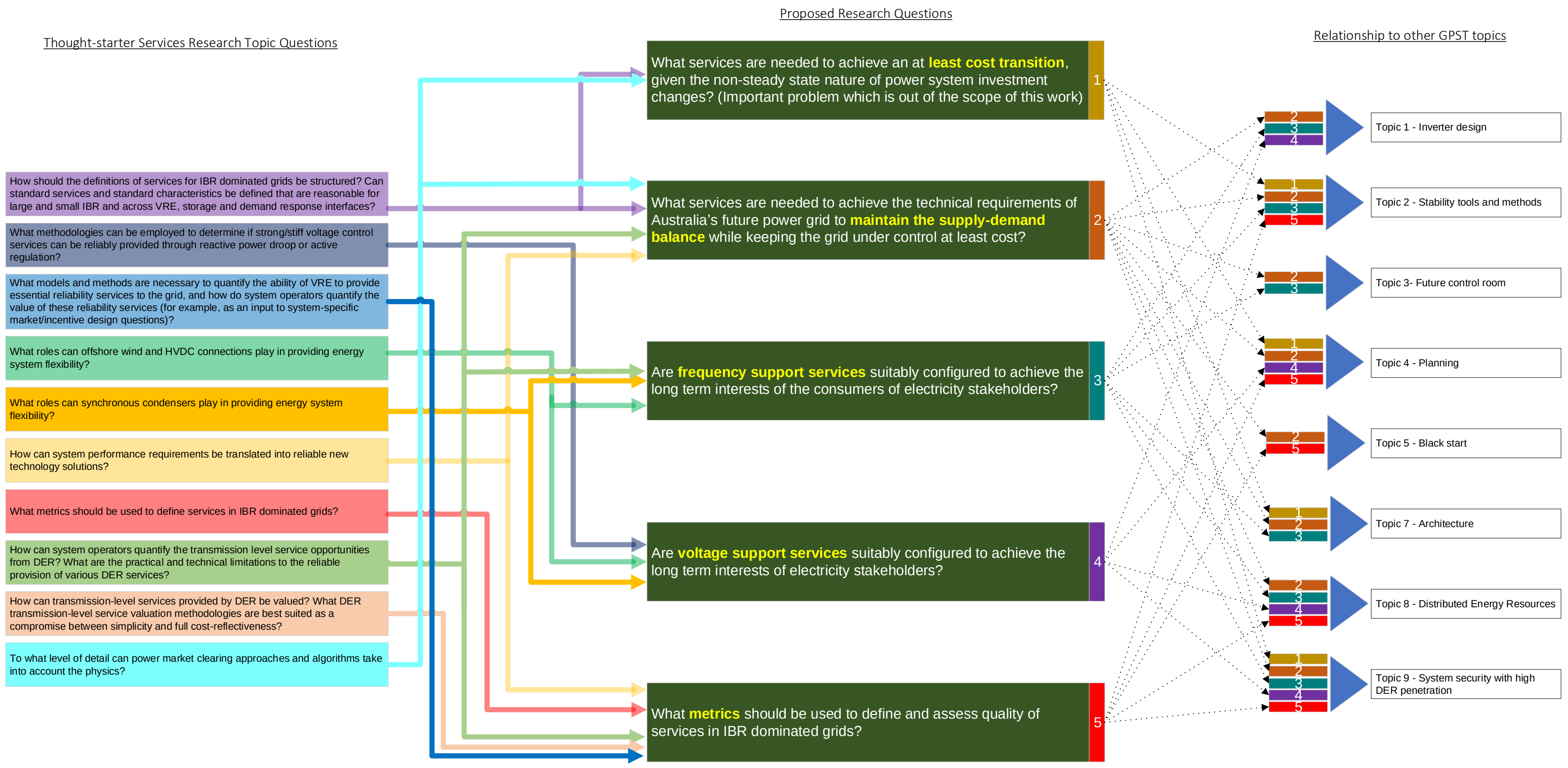
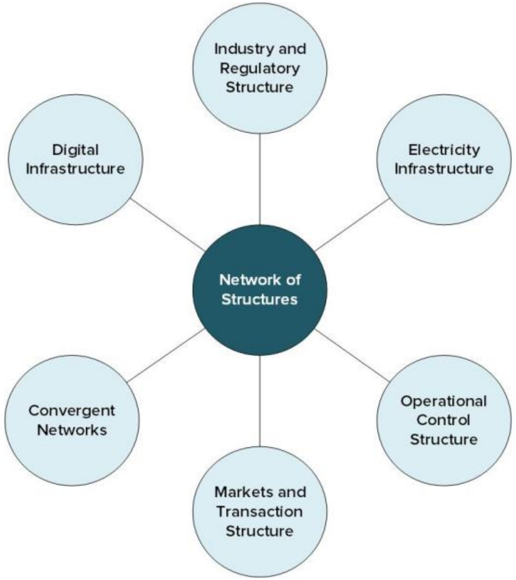
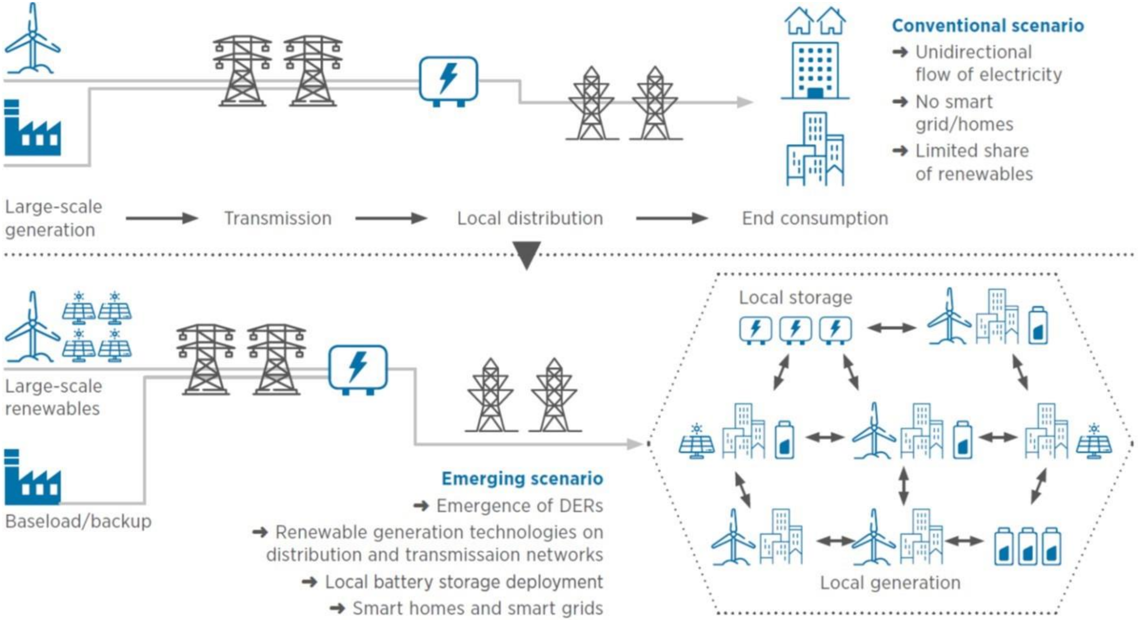

CROF Vision
Operators are Effective Supervisors of a More Automated Australian Power System
CROF Purpose
Operate a Safe, Secure, Reliable, Resilient, Economic, Sustainable Australian Power System and Facilitate Network Development
CROF Pillars
Operator Training
Building & Facility Design
Hardware & Ergonomics
Simulator / Operations Readiness Centers
Operator Situational Awareness Optimisation and Decision Support Framework
System Control, User Interfaces & Data Visualisation
...
Control Room Tools
Integration & Inter - Operability
Operations Planning Support Tools
...
EMS / SCADA
MMS / NEMDE
Data - Models and Streaming
CROF Foundations
Cyber Secure Application Architecture
Cyber Secure Market System Architecture
Cyber Secure Data Architecture
Functional & Capability Model

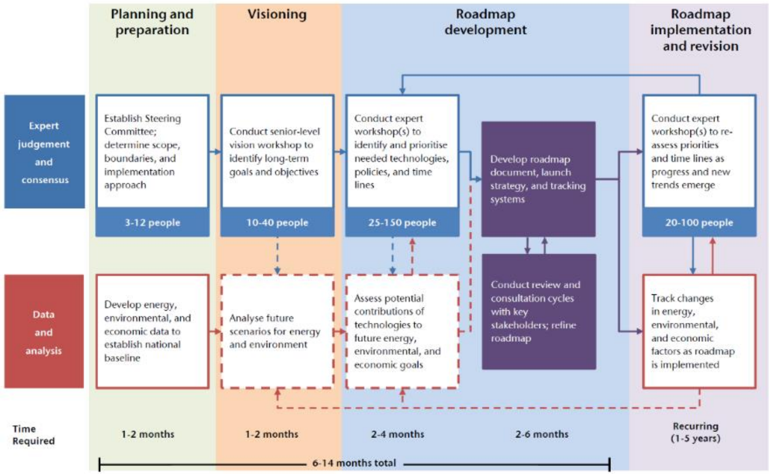

Programme 1
Long-term uncertainty
Programme 2
Power system operation
Programme 3
Reliability (security and adequacy) and resilience
Programme 4
Decision making
Programme 5
Distributed energy systems



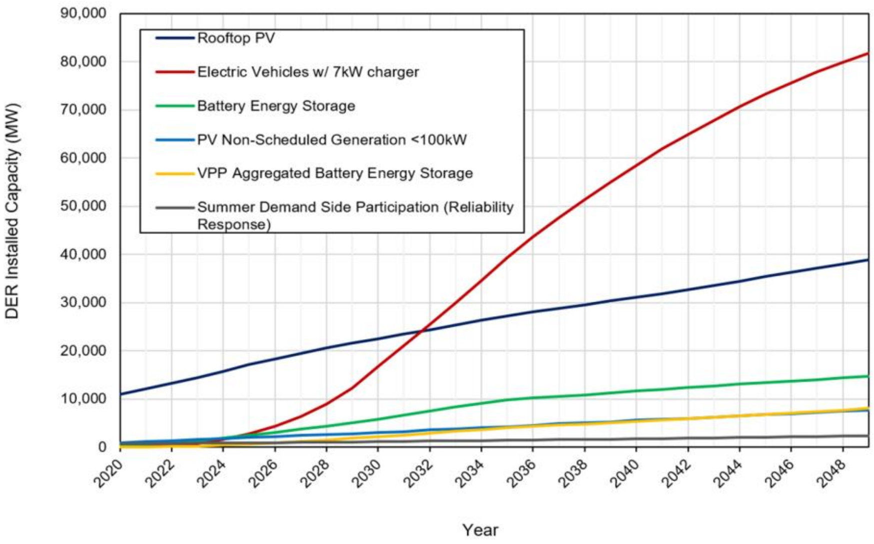
Proposed Research Questions
Thought-starter Services Research Topic Questions
Relationship to other GPST topics
How should the definitions of services for IBR dominated grids be structured? Can standard services and standard characteristics be defined that are reasonable for large and small IBR and across VRE, storage and demand response interfaces?
What methodologies can be employed to determine if strong/stiff voltage control services can be reliably provided through reactive power droop or active regulation?
What models and methods are necessary to quantify the ability of VRE to provide essential reliability services to the grid, and how do system operators quantify the value of these reliability services (for example, as an input to system-specific market/incentive design questions)?
What roles can offshore wind and HVDC connections play in providing energy system flexibility?
What roles can synchronous condensers play in providing energy system flexibility?
How can system performance requirements be translated into reliable new technology solutions?
What metrics should be used to define services in IBR dominated grids?
How can system operators quantify the transmission level service opportunities 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?
To what level of detail can power market clearing approaches and algorithms take into account the physics?
What services are needed to achieve an at least cost transition, given the non-steady state nature of power system investment changes? (Important problem which is out of the scope of this work) 1
What services are needed to achieve the technical requirements of Australia's future power grid to maintain the supply-demand balance while keeping the grid under control at least cost? 2
Are frequency support services suitably configured to achieve the long term interests of the consumers of electricity stakeholders? 3
Are voltage support services suitably configured to achieve the long term interests of electricity stakeholders? 4
What metrics should be used to define and assess quality of services in IBR dominated grids? 5
2 3 4
Topic 1 - Inverter design
1 2 3 5
Topic 2 - Stability tools and methods
2 3
Topic 3- Future control room
1 2 4 5
Topic 4 - Planning
2 5
Topic 5 - Black start
1 2 3
Topic 7 - Architecture
2 3 4 5
Topic 8 - Distributed Energy Resources
1 2 3 4 5
Topic 9 - System security with high DER penetration

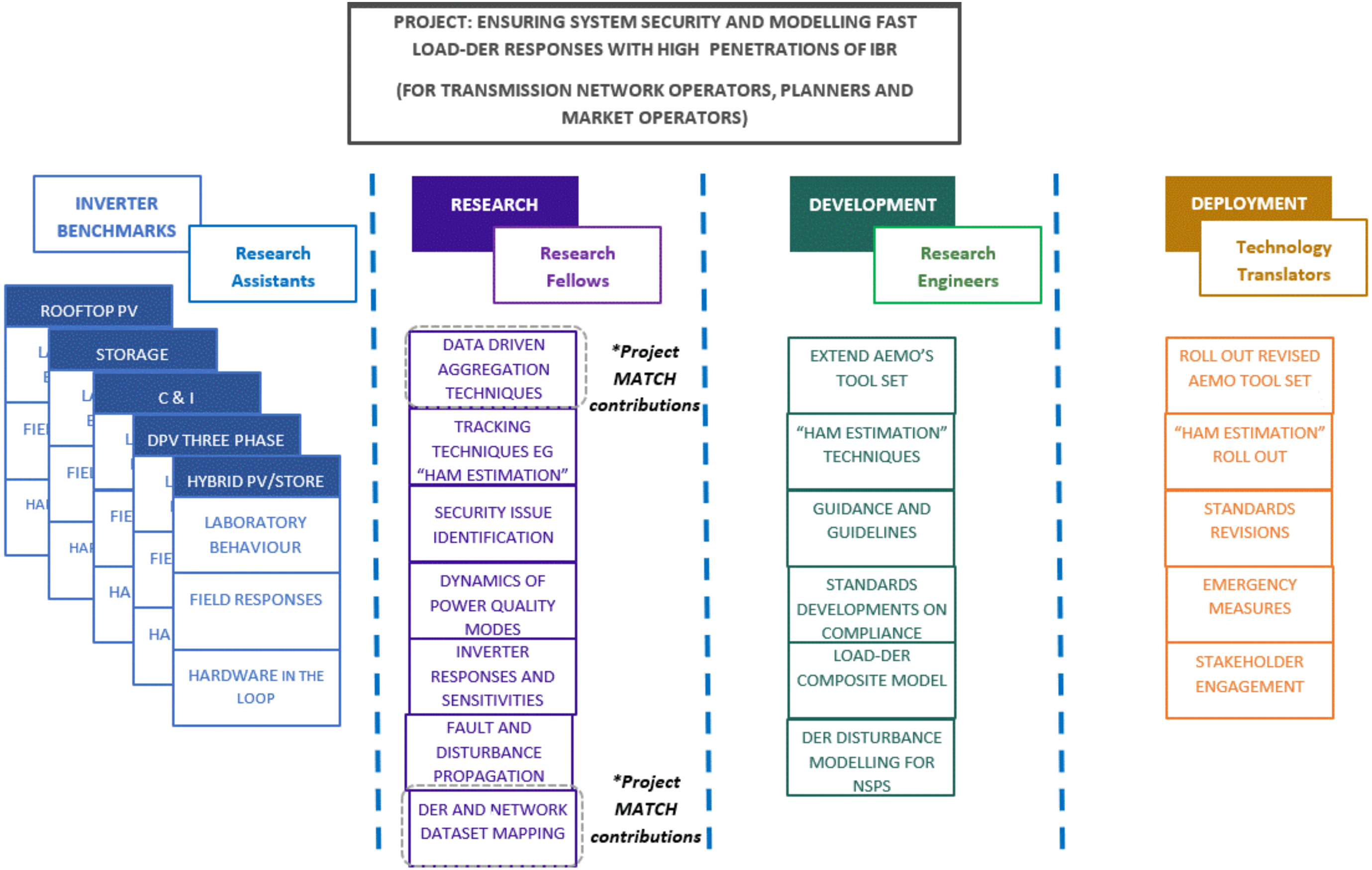

Industry and Regulatory Structure
Digital Infrastructure
Electricity Infrastructure
Network of Structures
Convergent Networks
Operational Control Structure
Markets and Transaction Structure


Conventional scenario
➜ Unidirectional flow of electricity
➜ No smart grid/homes
➜ Limited share of renewables
Large-scale generation
Transmission
Local distribution
End consumption
Large-scale renewables
Baseload/backup
Emerging scenario
➜ Emergence of DERs
➜ Renewable generation technologies on distribution and transmissaion networks
➜ Local battery storage deployment
➜ Smart homes and smart grids
Local storage
Local generation

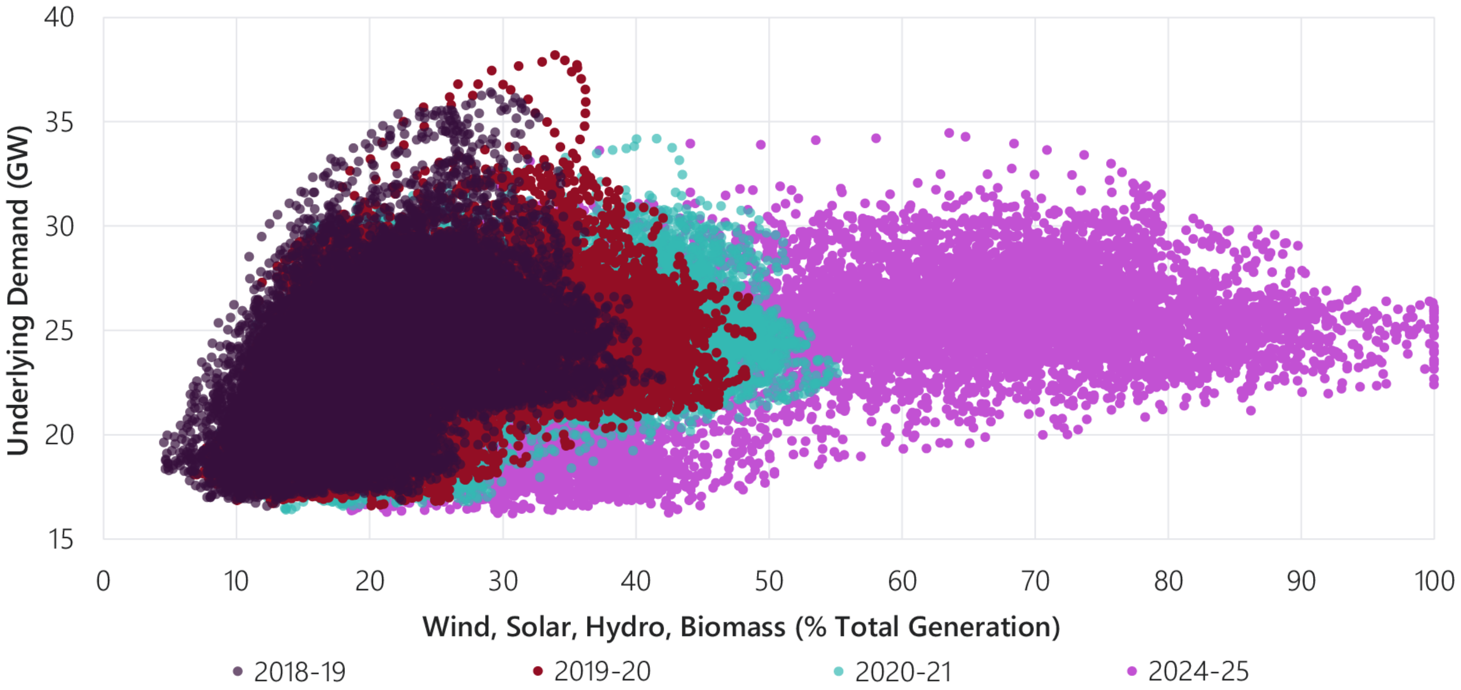


Note: Dotted lines indicate optional steps, based on analysis capabilities and resources.

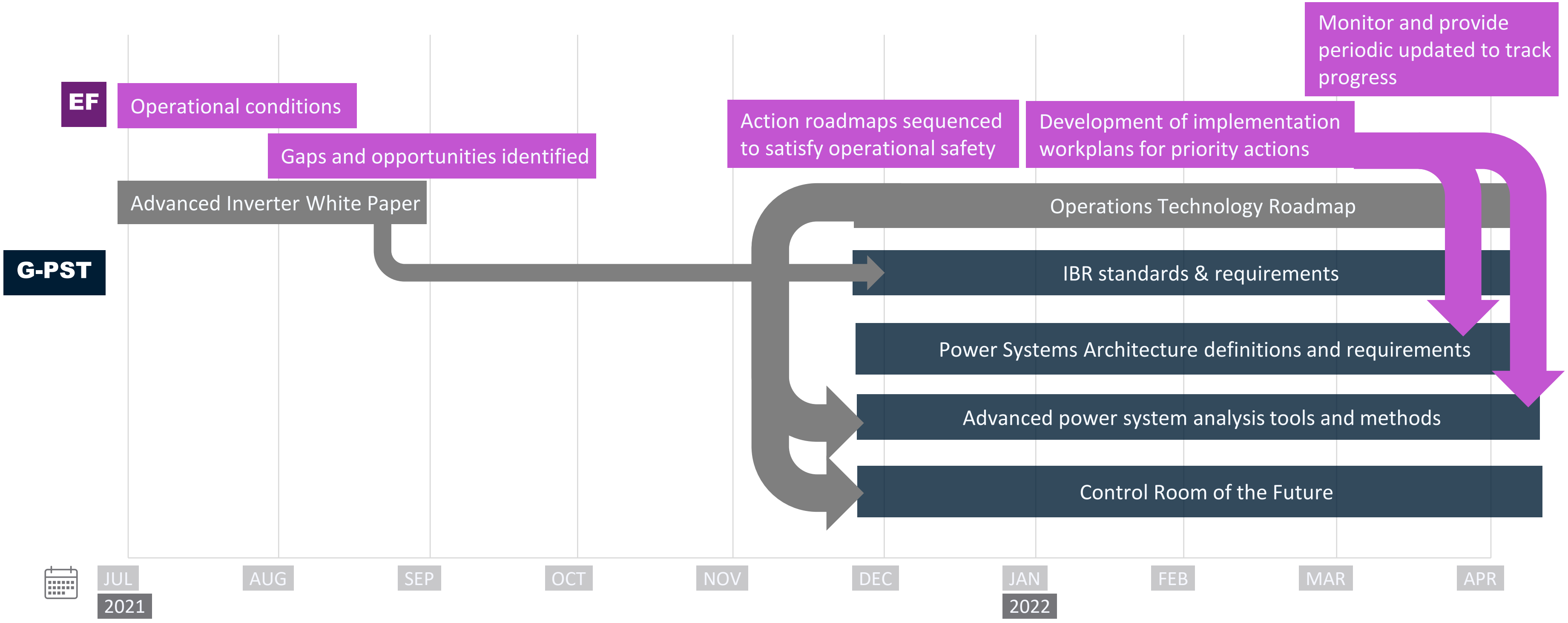



PROJECT: ENSURING SYSTEM SECURITY AND MODELLING FAST LOAD-DER RESPONSES WITH HIGH PENETRATIONS OF IBR
(FOR TRANSMISSION NETWORK OPERATORS, PLANNERS AND MARKET OPERATORS)
INVERTER BENCHMARKS
Research Assistants
ROOFTOP PV
STORAGE
C & I
DPV THREE PHASE
HYBRID PV/STORE
LABORATORY BEHAVIOUR
FIELD RESPONSES
HARDWARE IN THE LOOP
RESEARCH
Research Fellows
DATA DRIVEN AGGREGATION TECHNIQUES
*Project MATCH contributions
TRACKING TECHNIQUES EG "HAM ESTIMATION"
SECURITY ISSUE IDENTIFICATION
DYNAMICS OF POWER QUALITY MODES
INVERTER RESPONSES AND SENSITIVITIES
FAULT AND DISTURBANCE PROPAGATION
DER AND NETWORK DATASET MAPPING
*Project MATCH contributions
DEVELOPMENT
Research Engineers
EXTEND AEMO'S TOOL SET
"HAM ESTIMATION" TECHNIQUES
GUIDANCE AND GUIDELINES
STANDARDS DEVELOPMENTS ON COMPLIANCE
LOAD-DER COMPOSITE MODEL
DER DISTURBANCE MODELLING FOR NSPS
DEPLOYMENT
Technology Translators
ROLL OUT REVISED AEMO TOOL SET
"HAM ESTIMATION" ROLL OUT
STANDARDS REVISIONS
EMERGENCY MEASURES
STAKEHOLDER ENGAGEMENT

NEM-wide penetration of renewable resources (large-scale and distributed), 2018-19 to 2020-21, with indicative resource potential forecast for 2024-25 based on existing, committed, and anticipated projects and distributed PV forecasts



AEMO's NEM Engineering Framework roadmap



More information: https://aemo.com.au/en/initiatives/major-programs/engineering-framework