Australian Research Planning for the Global Power Systems Transformation

TOPIC 7:

# Power Systems Architecture

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Prepared for:

As part of the Australian Research Planning for the Global Power Systems Transformation Consortium

**Topic 7 – Power Systems Architecture:**

Integrated methodologies and activities for navigating the systemic complexity of Australia's power system transformation, deepen stakeholder engagement and social license and help align the new technology, regulatory and market design developments required for a high-VRE / high-DER future.


Lead Author: Mark Paterson

Collaborating Authors: Matt Bird, John Phillpotts & Peter Howe

International Expert Panel: Dr Jeffrey Taft, Dr Lorenzo Kristov, Paul De Martini & Phil Lawton

# ACKNOWLEDGEMENTS

The study of power system transformation and the underpinning structural shifts impacting these ultra-complex 'cyber-physical-economic' systems is – unsurprisingly – inordinately complex.

Therefore, as even Isaac Newton famously said: *"If I have seen further it is by standing on the shoulders of giants."* This report attempts to stand on the shoulders of several giants who have served the global power sector for many years.

In particular, we recognise the expertise of the following individuals and organisations for the quality and diversity of their published contributions to the field of Power Systems Architecture:

+ Dr Jeffrey Taft, Pacific Northwest National Laboratory (PNNL);
+ Dr Lorenzo Kristov, formerly of Californian Independent System Operator (CAISO);
+ Paul De Martini, Newport Consulting and Pacific Energy Institute;
+ Phil Lawton, Energy Systems Catapult;
+ Dr Ron Melton, Pacific Northwest National Laboratory (PNNL); and,
+ Past and present members of the GridWise Architecture Council (GWAC).

These esteemed colleagues foresaw many of the transformational challenges that we now confront well before the acronyms 'VRE' and 'DER' were popularised.

We express our appreciation for their collaboration, in some cases over almost a decade, and the generosity with which many have offered their views on various aspects of this work while noting that any errors are the responsibility of the authors alone.

Mark Paterson
Lead Systems Architect

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# EXECUTIVE SUMMARY

Decarbonisation, decentralisation and democratisation are driving unprecedented levels of technological, market and regulatory complexity in global electricity systems. Australia's GW-scale power systems are now experiencing a once-in-a-century scale of change that is impacting all layers of the system including bulk energy, transmission, distribution and retail. Most importantly, customers are both actively participating in and directly impacted by these transformational shifts.

What is now the world's most rapid, large-scale transformation is being driven by the progressive retirement of Australia's synchronous generation fleet and the deployment of Variable Renewable Energy (VRE) and Distributed Energy Resources (DER) at massive scale.

The Australian Energy Market Operator (AEMO) recognises that by 2025, Australia's power systems must be capable of supporting 100% of instantaneous demand being served by variable generation sources. By 2050, the National Electricity Market (NEM) must be capable of accommodating levels of VRE and DER at multipliers of 9x and 5x respectively compared to todays already world-leading levels!

This is uncharted territory for GW-scale power systems anywhere in the world. And it is in this increasingly dynamic future that...

> *Bulk energy, transmission and distribution systems – together with deep demand-side flexibility – will need to function holistically to enable reliable and efficient operation, including during periods where >100% of instantaneous demand is served by centralised and distributed VRE.*

The challenge of provisioning the power system, the sector and diverse stakeholder groupings to collectively navigate these profound shifts provides the context and timing for this report.

For some years now, the United States, United Kingdom, European Union and Canada have been examining how the underlying 'architecture' of their power systems inherited from the early 20th century may need to be adapted to safely and efficiently enable the energy transformation. While Australia has numerous individual technology demonstration projects underway, it has no direct current equivalent.

Given the world-leading pace and scale of Australia's power system transformation, a focus on the underlying architecture or structure of the system becomes pivotal as this scale of change unfolds. This is because, while less tangible and 'exciting' than technologies such as energy storage and electric vehicles, the architecture of any complex system will always have a disproportionate impact on what both the system and even the most exciting technologies can reliably and cost-effectively perform.

The established Systems Architecture engineering discipline is a key tool for transforming highly complex systems of any type.  'Power Systems Architecture' (PSA) is a generic term for an integrated set of disciplines applied to the transformation of legacy power systems to meet changing policy and customer expectations and cost-efficiently enable COP26 commitments. Purpose-built for power system transformation, PSA is based on the combined application of Systems Architecture, Network Theory, Control Theory and Software Engineering complemented by Energy Economics and Strategic Foresight disciplines.

This project is part of Australia's Global Power System Transformation (G-PST) program jointly advanced by CSIRO and AEMO.  It is based on a study of relevant global and local initiatives with the input of several international experts.  It delivers an immediately actionable and customised plan for applying PSA disciplines to support the orderly transition of Australia's power systems.  As such, it is informed by the wide range of technology trials underway in Australia and closely aligned with AEMO's Engineering Framework.

Given the nature and rapidity of Australia's power system transformation, the Action Research Plan provided is designed for full execution over a finite 18-month period.  It provides an evidence-based methodology for establishing and upskilling a diverse and informed 'community of practice' that is equipped to collaborate on the many trade-off decisions that impact customer and system outcomes.  As such, the Action Research Plan is design to further strengthen process coherence and transparency, deepen informed stakeholder engagement and enable more mature trade-off choices that foster trust and enhance the social license for change.

PART A

# Action Research Plan - Context & Development

# 1. INTRODUCTION

## 1.1 Transformational Context

Modern power systems are highly complex cyber-physical-economic systems that are foundational to life and economic wellbeing in a modern economy. They are arguably the largest and most complex 'machines' ever created by humanity.

The power systems developed in the 20th century were already defined as Ultra-Large-Scale[1] (ULS) complex systems[2]. Across the developed world, these already massively complex systems are now experiencing the most profound transformation since the dawn of electrification. In the process, they are becoming even more dynamic and complex by orders of magnitude.

Australia is experiencing the world's fastest and most profound power system transformation. By 2025, our power systems must be capable of operating reliably during periods where 100% of instantaneous demand is served by variable generation sources[3]. Further, when compared with 2021 levels, by 2050 the NEM will plausibly need to efficiently and securely accommodate:

+ 9x Centralised VRE: A nine-fold increase in the installed capacity of utility-scale wind and solar VRE generation (from 15GW to 140GW);
+ 5x Distributed VRE: Almost a five-fold increase in the installed capacity of distributed solar VRE / DER generation (from 15GW to 70GW); and,
+ 3x Dispatchable Firming Capacity: A three-fold increase in the installed firming capacity that can respond to a dispatch signal[4].

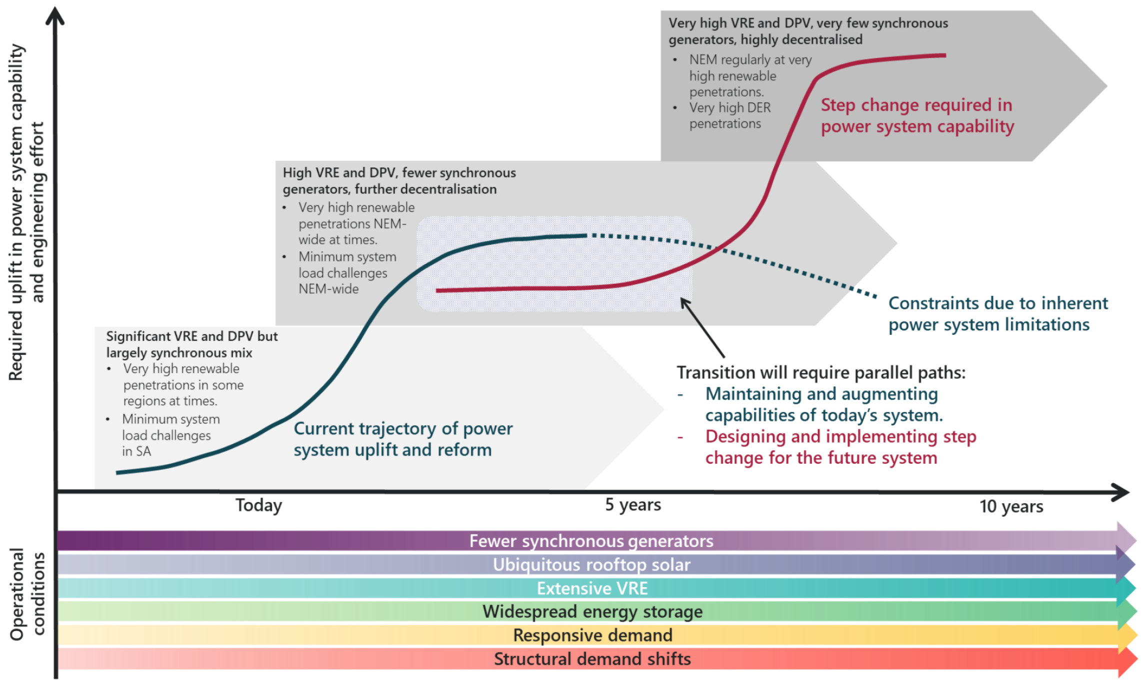



Figure 1: Provisioning the power system and diverse stakeholder groupings to collectively navigate the profound shifts of this next decade provides the context for this report[5]

[1] A detailed Glossary is provided in Appendix B. The first use of key terms in this document are hyperlinked to the Glossary for convenience and available in the embedded bookmarks of this document.
[2] P. Feiler et al, Ultra-Large-Scale Systems: The Software Challenge of the Future, Software Engineering Institute, 2006
[3] https://aemo.com.au/en/newsroom/news-updates/the-view-from-the-control-room
[4] https://www.aemo.com.au/newsroom/media-release/nem-prepares-for-step-change.
[5] Image: Engineering Framework – Interim Roadmap, AEMO, 2021 adapted from A Gambit for Grid 2035 – A systemic look into the disruptive dynamics underway, Pacific Energy Institute, 2021

### *A once-in-a-century scale of change*

What we know as 'the power system' is, in reality, a multi-structure network that has evolved gradually since the early 20th century. This inter-dependent 'Network of Structures' consists of the electrical infrastructure, control structure, regulatory structure, industry structure, digital superstructure, convergent networks, and coordination frameworks. It spans bulk electricity generation, transmission, distribution, and transactional systems. Collectively, this network of structures functions as the 'architecture' of a modern power system which has a major influence on what the whole system can efficiently and reliably do[6].

Inherited from the 20th century, the architecture of the power system has served us well. As with any system's underlying architecture or structure, it was originally configured in a specific context and for a particular set of purposes. For much of the past century, these complex systems, together with their regulatory and coordination structures, functioned in a historical context characterised by:

+ almost all generation served by a fleet of centralised and dispatchable MW-scale plant connected to the transmission system;
+ comparatively slow, incremental technological change;
+ steady load growth correlated with economic growth;
+ end-users as relatively passive consumers;
+ limited business model and value proposition innovation; and,
+ negligible incumbent risk of 'product substitution' at scale.

Fast-forward to the early decades of the 21st century and many aspects of this traditional model are being upended around the world. Various parts of Australia are now recognised as facing some of the world's most dramatic transformational forces.

**Architecture / Systems Architecture**

Every technological system created by humanity has an underlying 'architecture', although it is often less visible than the components or elements of the system (such as transformers, inverters, control rooms, etc. in the case of the power system).

Well-established Systems Architecture disciplines have a primary focus on the underlying structure of complex systems. This is because the structure or architecture of any system always has a disproportionate influence on what that system can efficiently and reliably perform.

The need for to review the architectural structures of a complex system is especially critical where the system is experiencing profound transformation that requires it to perform an expanding range of different and new functions.

[6] It is important to note that while formalised approaches to Power Systems Architecture and Enterprise Architecture will significantly benefit each other, they are distinct and have different functions. Refer to Appendix B for more information on this topic.

These include:

+ declining levels of synchronous generation which is being progressively replaced by centralised and decentralised Inverter Based Resources (IBR);

+ significant and accelerating growth in utility-scale wind and solar Variable Renewable Energy (VRE) generation;

+ world-leading adoption of residential Distributed Energy Resources (DER) connected to Australia's distribution networks;

+ emerging and increasingly frequent periods where VRE / DER output drives minimum and negative regional demand;

+ AEMO's recognition that by 2025, our power systems must be capable of operating securely and reliably during operational time windows where 100% of instantaneous demand is served by centralised and decentralised VRE;

+ the reasonable anticipation that the proportion of these operational time windows will continue to increase year-on-year beyond 2025 as VRE / DER / IBR levels increase and synchronous generation is progressively retired;

+ a longer-run future where traditional supply-side / demand-side bifurcation is largely redundant as supply can be located anywhere;[7] and,

+ in the Australian context, this may mean in the order of 50% of annual volume being served from either side of the transmission-distribution interface which will require significantly enhanced transmission-distribution coordination.

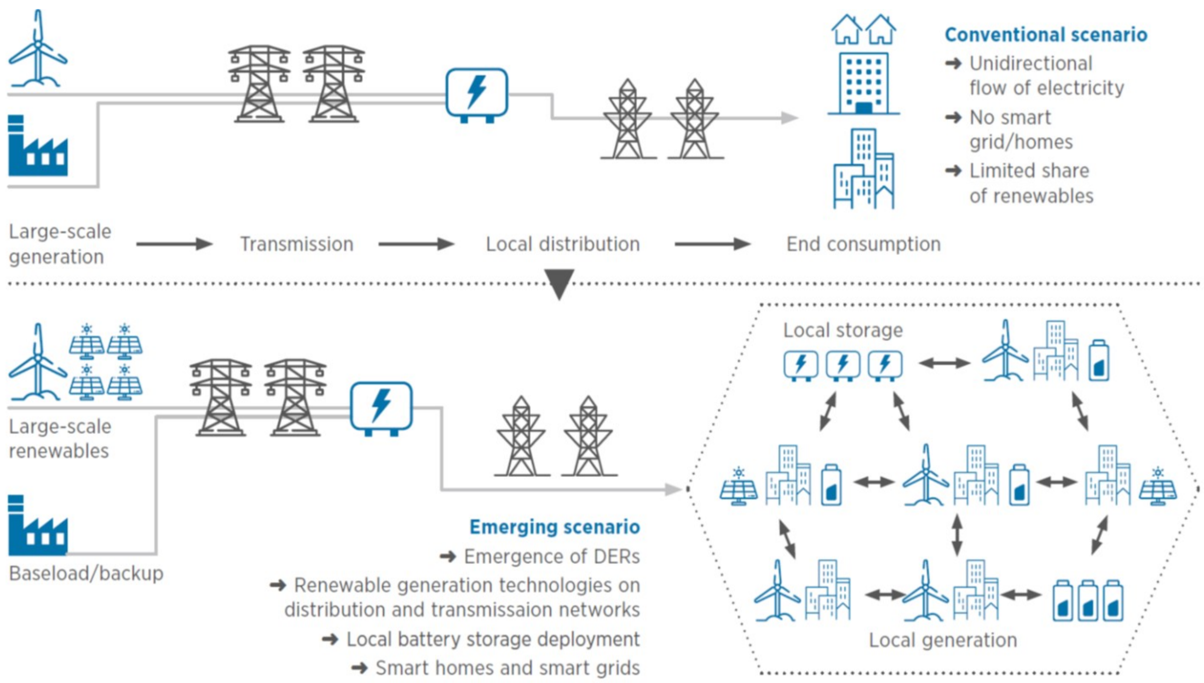



Figure 2: A high-level illustration of the system-wide transformation from the historical system structure to that of a high-VRE / high-DER future[8]

[7] As Kristov notes, the main bifurcation is increasingly between the bulk system which is mostly supply only, and the distribution system which is a hybrid of demand, supply and various new asset types.
[8] IRENA System Operation Collection 2020

### *Transformation accelerated by societal, technological and commercial forces*

These physics-based transformations are being accelerated by a range of societal forces and business model innovations that show no sign of slowing down. These include:

+ wider societal and consumer trends that value empowerment, autonomy, deep-customisation and environmental concerns;
+ digitalisation, platform and shared technologies are redefining how consumers engage with all sectors of the economy, including energy;
+ business model and technology innovations continue to expand the impact and adoption of non-traditional and customer-centric energy solutions;
+ established industry and regulatory change mechanisms risk being significantly outpaced by transformational and even disruptive forces;
+ concerns about social equity, fairness and the ability of all citizens to affordably share in the benefits of an evolving power system continue to grow; and,
+ deepening complexity, ideological 'balkanisation' and expanding technological optionality drive increased potential for stakeholder confusion, conflict and political impasse.

## 1.2 An Increasingly Dynamic & Complex Power System

AEMO together with Australia's transmission and distribution network operators are now faced with the challenge of managing a power system that is quickly becoming exponentially more dynamic. This is driven by the dual impacts of:

+ our expanding fleet of highly-variable, utility-scale wind and solar generation connected to our transmission networks; and,
+ the increasing variability in net load due to the deep and growing penetration of highly-variable, rooftop solar PV connected to our distribution networks.

The system impact of these dual drivers is further exacerbated by the limited visibility and controllability of Australia's expanding DER fleet which includes various types of flexible resources and demand management. As the scale of the DER fleet continues to expand, this lack of visibility and controllability risks becoming particularly problematic for Australia's overall power system operations.

***Advanced coordination and greater flexibility become critical***

Ultimately, Australia's growing portfolio of variable generation sources, whether centralised or distributed, means that deep demand-side flexibility is becoming one of the critical tools for managing the system.

In such a context, new levels of coordinated demand-side flexibility become key for supporting supply/demand balance, operational stability, and the long-run economic efficiency of the entire power system.

Most fundamentally, however, this will require considered and holistic approaches to the operational coordination of the entire system, which will ultimately span the traditional transmission – distribution interface.[9] Rather than presenting an 'either/or' dichotomy between the role of markets or controls, advanced operational coordination mechanisms always support 'market-control' alignment at each layer of a high-VRE / high-DER power system (including in a vertically disaggregated industry structure).

**Operational Coordination**

Structured mechanisms for coordinating from hundreds to tens of millions of energy resources operating in a power system. In increasingly heterogenous and dynamic power systems, modern approaches to Operational Coordination require close 'market-control' alignment across each layer of the power system. This requires both technological control and economic incentivisation elements to be tightly-coupled to function in a mutually-reinforcing manner that incentivises system stability and efficiency services across a range of time scales (days to milliseconds).

[9] The methodologies outlined in this report for navigating the structural or architectural complexity of the transforming power system will significantly enhance the objective, cyber-physical basis upon which the detail of evolving Roles & Responsibilities ('who-does-what') can be most constructively addressed.

***Architectural considerations are essential for assurance of scalability and resilience***

As noted earlier, legacy power systems were already recognised as massively complex cyber-physical-economic systems. As we move forward over the next decade and beyond, the expanding number of energy resources and endpoints and the complexity of operational coordination will continue to increase by orders of magnitude. Some of the key cyber-physical characteristics that are already well recognised include:

+ increasingly fast-changing dynamics at all levels of the power system (including bulk power, transmission and distribution system and customer devices);
+ the transition from slow data sampling to fast streaming data;
+ the transition from hundreds of generation sources to tens of millions of end-points;
+ vast increases in data rates generated by the power system and end-points; and,
+ decreasing tolerance for latency.

Interoperability standards, digital market platforms and dynamic operating envelopes are all expected to play key roles in supporting Australia's future power systems. However, in a context of such wide-ranging system change, where the wider system architecture considerations are not systematically examined, a range of hidden constraints will likely manifest only post-trial phase. Costly scaling issues that typically arise where architecture has not been comprehensively considered may include latency cascading, computational constraints and time wall effects, and cyber-security vulnerabilities which, in turn, reduce system reliability, resilience and efficiency. These issues are difficult to address once they emerge.

From the standpoint of the highly centralised, twentieth century power system, this can seem overwhelming and even unduly complex. In this context, it is especially important to recall that the underlying forces reshaping our power systems are no longer under the full control of system operators, network businesses or even traditional governance mechanisms.

As Daniel Westerman (AEMO's CEO) has noted about Australia's power system transformation:

> *"It is a stunning democratisation of power.*
>
> *"It's a transformation: turning historically passive electricity consumers into active generators.*
>
> *"And a capital transfer, too. Power infrastructure investment decisions that were once the preserve of our nation's boardrooms are now being made around the kitchen tables in our towns and suburbs."* [10]

Like it or not, this is the expanding systemic complexity we now have to deal with. To do so will require additional tools and methodologies and the upskilling of a multi-stakeholder 'community of practice'. Better equipping diverse stakeholders to collectively navigate this complexity and work more effectively toward enhanced system and customer outcomes will be essential for timely progress and the social license for change.

[10] https://aemo.com.au/en/newsroom/news-updates/the-view-from-the-control-room

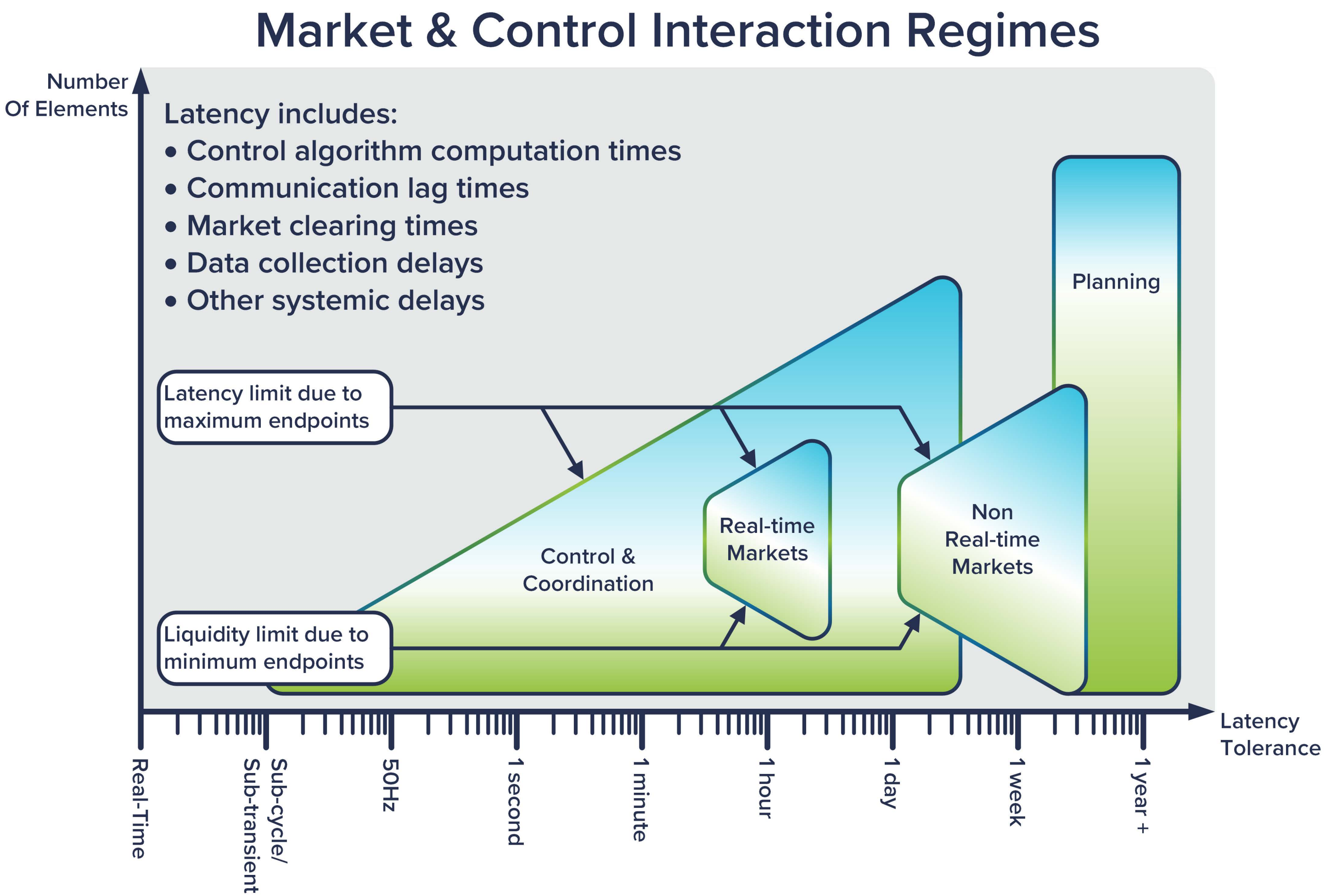



Figure 3: A high-VRE / high-DER power system requires advanced operational coordination mechanisms that support 'market-control' alignment and complementarity. [11]

[1] Source: Adapted from Pacific Northwest National Laboratory

## 1.3 Project Objective

As highlighted above and stated in AEMO's Renewable Integration Study and NEM Engineering Framework reports, the NEM is tracking into uncharted territory globally.

Further, AEMO's new CEO, Daniel Westerman, publicly stated in August 2021 that by 2025 our power systems must be capable of operating securely and reliably during operational periods where 100% of instantaneous demand is served by VRE.

**Power System Architecture – Project Objective**

Based upon an international and Australian analytical review, identify and recommend an integrated and adaptive combination of action research methodologies and activities that, over an 18-month project duration, will:

+ Enhance and accelerate Australia's capacity to navigate the complex structural and operational shifts that are inherent in the large-scale transformation of Australia's GW-scale power systems;
+ Provide a robust methodological basis for establishing a diverse and informed multi-stakeholder 'community of practice' that is better equipped to collaborate on the wide range of trade-off decisions essential to enhanced system and customer outcomes;
+ Significantly strengthen multi-stakeholder engagement, process coherence and transparency as a basis for greater trust and enhanced social license for change.

# 2. THE RELEVANCE OF POWER SYSTEM ARCHITECTURE

A key rationale for this Action Research Plan is that Australia's power systems are experiencing a once-in-a-century scale of transformational change. The types of shifts described above would have been almost inconceivable to the architects of the early 20th century power system. They are structural in character and are now emerging over months and years rather than decades – and well within the operational lifespans of the assets being impacted.

In a comparatively slower-change context, a focus on power system 'architecture' or 'structure' might have seemed abstract or academic. In today's context, there are few topics that are more urgent, practical or pragmatic. This is because the underlying structure of any complex system always has a disproportionate influence on what that system can efficiently and reliably perform. Where the structure is well aligned with the system's current or future purpose, all the components will function effectively together, and the system will be more scalable and extensible. Where the historical structure is misaligned with the requirements increasingly expected of the system, technology integration expenditure expands, investments are stranded and the system progressively becomes less reliable and efficient.

## 2.1 Modern Power Systems as a 'Network of Structures'

As noted above, a modern power system is a massively complex 'Network of Structures' that intersect, influence and dynamically interact with each other. When viewed from this whole-of-system perspective, it becomes clear that the power system combines the following six distinct but interconnected structures:

(a) Industry & Regulatory Structure (Entity-Relationships);

(b) Electricity Infrastructure (Power Flows);

(c) Operational Control Structure;

(d) Market Transaction Structure;

(e) Digital Infrastructure (Information/Data Exchange); and,

(f) Convergent Networks.

Particularly relevant to today's power system transformation, all of these structures progressively evolved over decades in the historical context of a highly centralised power system. They are subject to hidden and overt interactions, cross-couplings, constraints and dependencies. And, as they have emerged and evolved over time, few global jurisdictions have a single, current set of 'as built' documentation outlining precisely how all of the different structures actually function together!

While the 'system-of-systems' paradigm from software engineering is somewhat useful, being largely focused on components, it does not adequately represent the complex multi-structural properties constituting a modern power system.

The Network of Structures paradigm was developed by Pacific Northwest National Laboratory (PNNL) to support the structural analysis, mapping, and optimisation of the legacy, emerging and future architectures. This is critically important as the underlying structure of any complex system establishes its essential capabilities and limits. Therefore, the more rigorous structural analysis that the Network of Structures paradigm enables is a key to enabling the reliable and cost-efficient transformation of the power system.

It is also noteworthy that very few industry professionals have worked across several or all these six structures in detail. This exacerbates the challenge of ensuring whole-of-system perspective and underscores the value of formal architectural models and tools for supporting this.

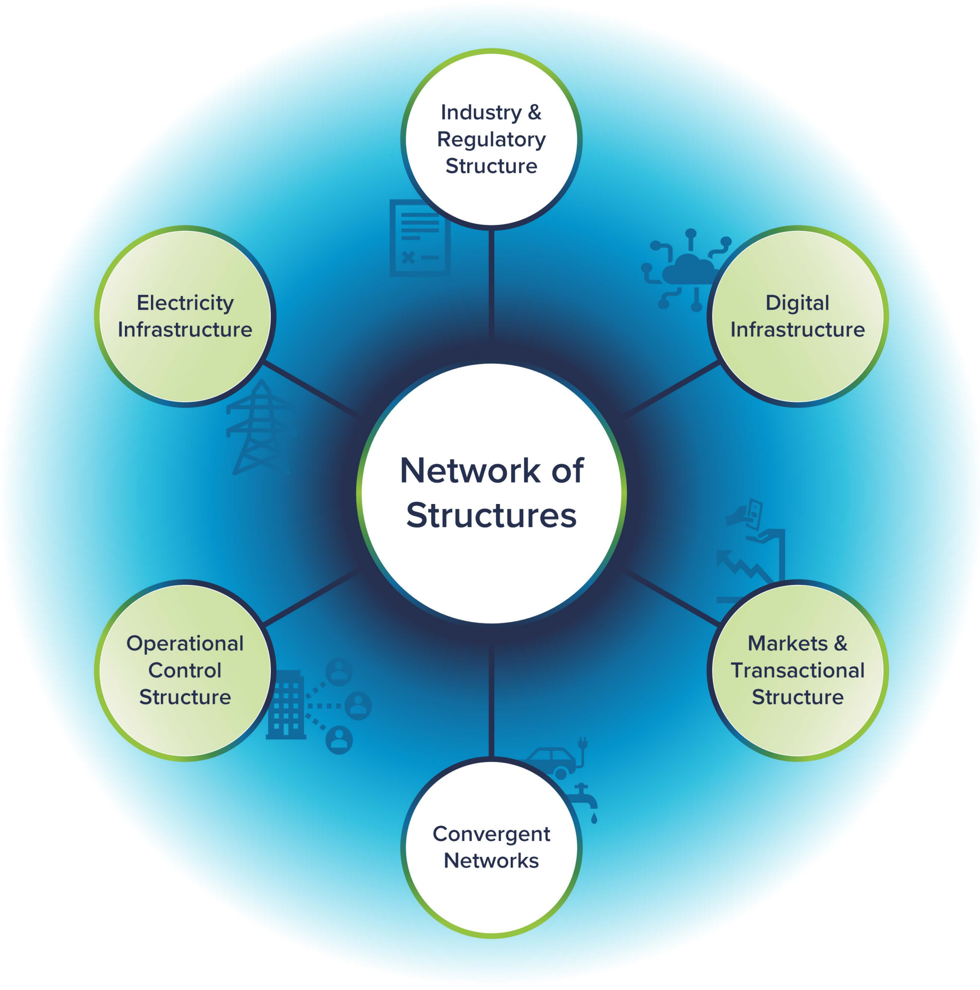



Figure 4: Modern power systems as a network of six distinct but interconnected and interdependent structures.[12]

[12] Adapted from Pacific Northwest National Laboratory

## 2.2 Key Rationale for employing Systems Architecture disciplines

The once-in-a-century nature of the transformation impacting power systems is driving renewed global consideration of how the underlying architecture of these legacy systems may also need to change. Following are five critical concepts that outline why this is the case.

1. **Complex power systems are becoming even more complex.** 20th century power systems were already defined as Ultra-large Scale complex systems. In the early 21st century, power systems are becoming vastly more complex as the number of energy resources and endpoints increase by orders of magnitude. At the same time, power system dynamics are rapidly increasing in speed as latency tolerance is decreasing.

2. **A system's architecture is foundational to its capability.** The structure or architecture of any complex system is critical to what that system can reliably and cost-effectively do. As indicated above, in the case of power systems, this is especially critical given the expanding range of functions required to enable the dynamic coordination of VRE, DER, EVs, flexible load, etc. at massive scale.

3. **Expectations of the power system are evolving.** Electricity system architecture in developed nations was designed in the context of a highly centralised, one-way delivery system. While recognising that the legacy architecture was not specifically designed for a decentralised and decarbonised grid, architectural tools focus on identifying the *minimal* structural changes to deliver the *maximum* system benefits.

4. **Additional methodologies and tools are required.** Architectural disciplines provide a unified foundation for interrogating the complex cyber-physical-economic 'Network of Structures' that make up the power system. This provides a level of insight and objectivity for making technology, market design, co-optimisation and regulatory decisions – and avoiding unintended consequences – that would be otherwise difficult if not impossible.

5. **Increased optionality and future-resilience are critical.** Most importantly, the effective application of architectural methodologies that deliver greater optionality rather than less are critical. They are solution-agnostic, imply no pre-determined policy, regulatory or other outcomes, and provide a robust and objective evidence-base for collectively making trade-off decisions about the future of the power system.

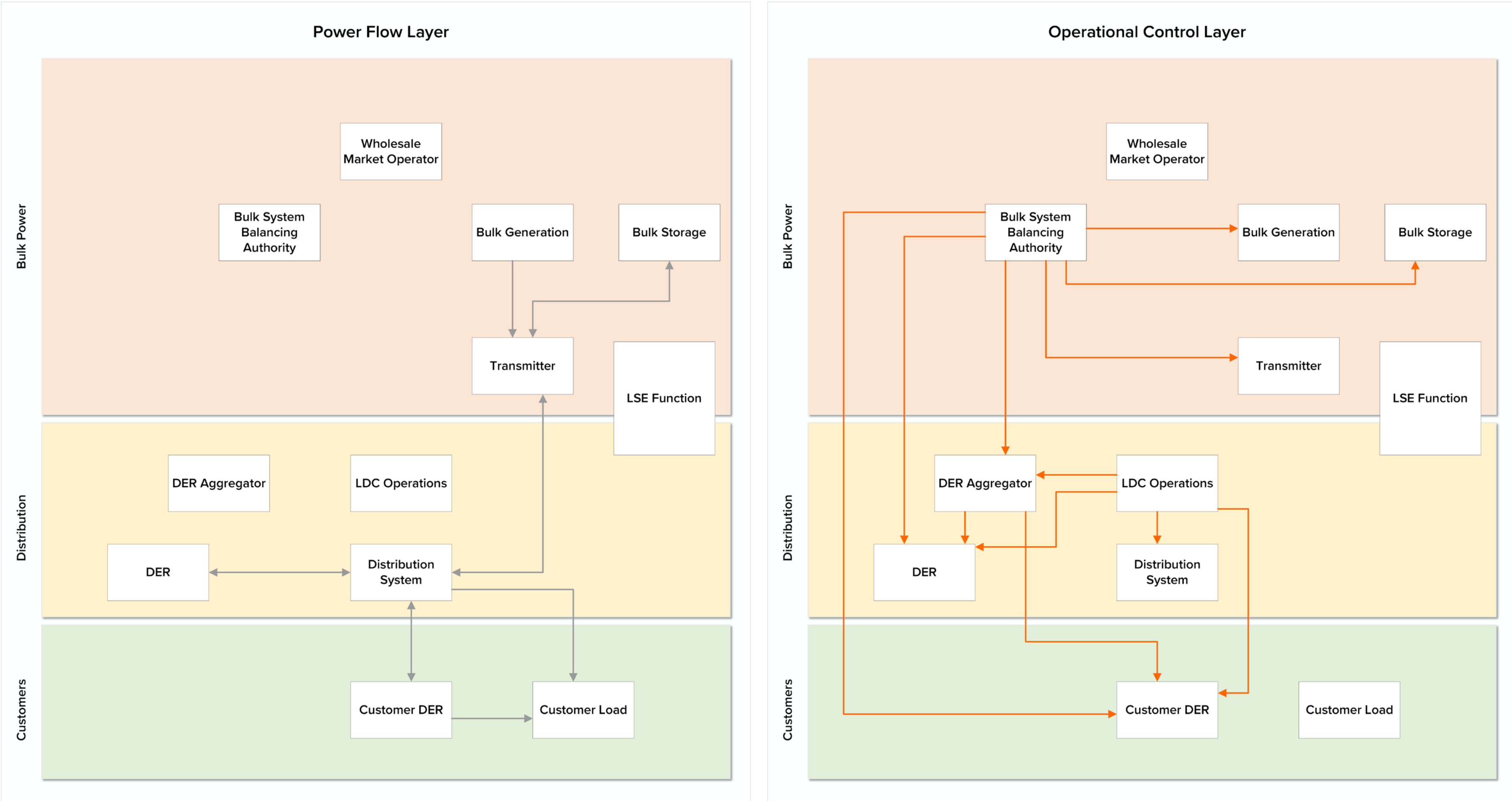



Figure 5(a): The four 'functional' layers / structures of the power system shown artificially as discrete systems[13]

[13] Development of a Transmission-Distribution Interoperability Framework, prepared by ICF for the Independent Electricity System Operator, Ontario, Canada (2020)

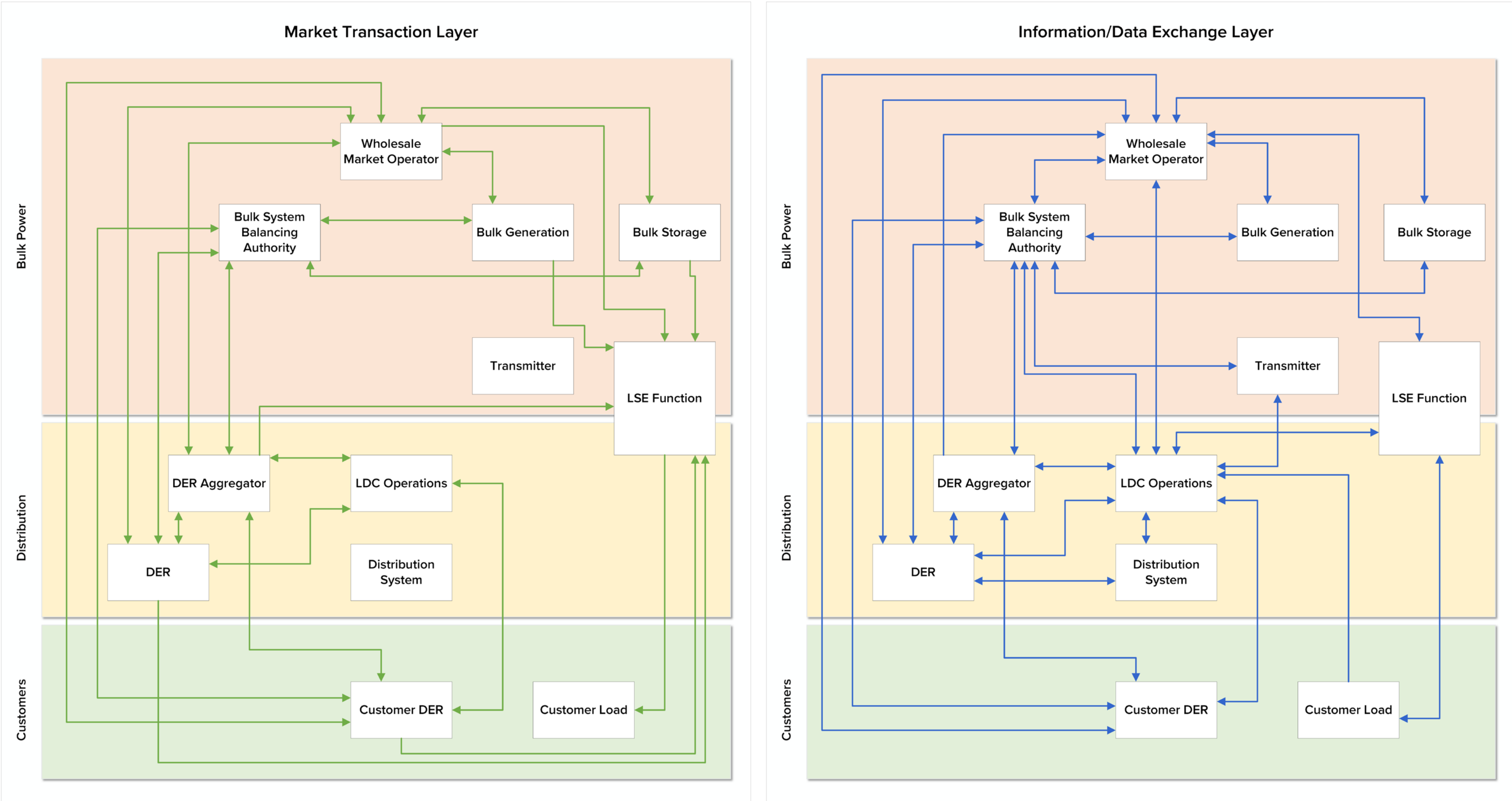



Figure 5(b): The four 'functional' layers / structures of the power system shown artificially as discrete systems[13]

[13] Development of a Transmission-Distribution Interoperability Framework, prepared by ICF for the Independent Electricity System Operator, Ontario, Canada (2020)

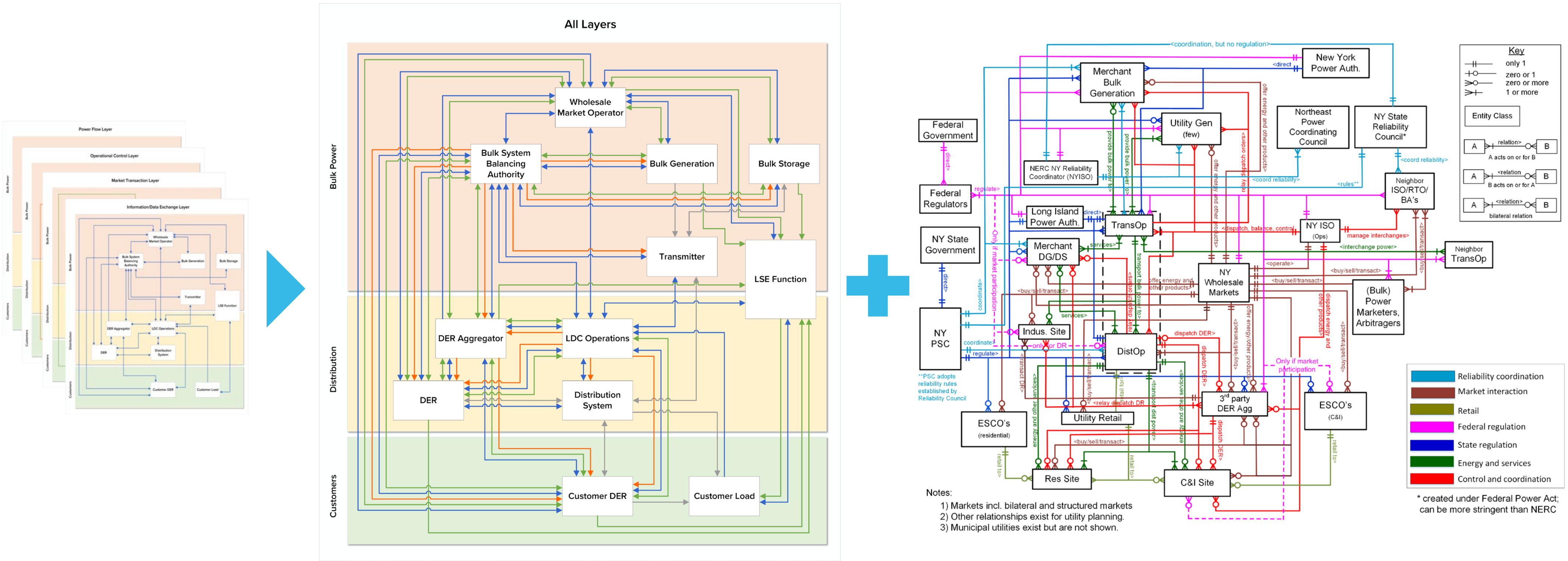



Figure 5(c): The four 'functional' layers / structures of the power system shown overlayed[13] as they are in practice together with an example regulatory and market structure model[14]

[13] Development of a Transmission-Distribution Interoperability Framework, prepared by ICF for the Independent Electricity System Operator, Ontario, Canada (2020) and [14] Pacific Northwest National Lab (2021)

Particularly relevant to the last point is the question of how very large and complex (ULS) systems undergo transformation.  For example, it is common to assume that complex systems in transition move from the legacy past to the emerging future state in a somewhat linear path. By contrast, Hodgson & Curry's[15] seminal work highlighted, that complex systems typically move through an intermediate transitional phase which can last for a decade or more.

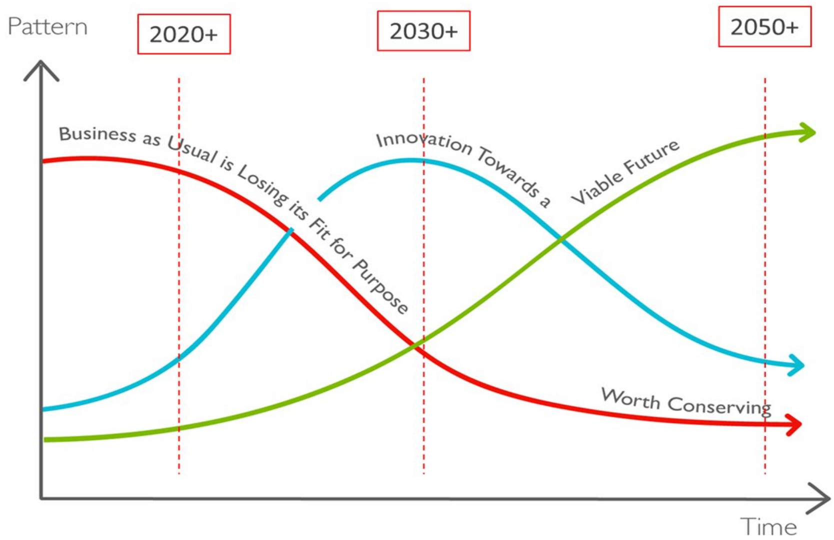


Figure 6:  Three horizons of complex system transformation. [16]

As Figure 6 above highlights, as the legacy state of a complex system gradually declines (red line), an extended transformative phase emerges (blue line) before the longer-term future state matures and finally settles into some form of equilibrium condition (green line).

This transformative phase typically involves new levels of ambiguity and imperfect knowledge; it reflects what the Oxford Scenario Planning Approach [17] refers to as a 'TUNA' operating context:

+ **T**urbulent;
+ **U**ncertain;
+ **N**ovel/Non-linear; and,
+ **A**mbiguous.

In this context, traditional linear and reductionistic modes of analysis and decision making become less reliable.  Given that such conditions can be expected to endure for a significant time as a system transforms, it becomes critical to build new organisational and stakeholder capacity for navigating TUNA conditions to ensure a robust basis for decision making that is future-resilient.

It is in this context that the PSA disciplines are especially valuable.  This is because they are designed to provide a robust and integrated set of tools for navigating complex and ambiguous transition.  They do so in a manner that expands optionality, identifies least-regrets choices, evaluates trade-offs and identifies the most future-resilient pathways.

[15] Seeing in Multiple Horizons: Connecting Futures to Strategy, Journal of Futures Studies (2008)

[16] Image: Adapted from https://www.h3uni.org/

[17] Strategic Reframing: The Oxford Scenario Planning Approach, Oxford University Press (2016)

## 2.3 Power System Architecture Defined

**Power Systems Architecture (PSA) is a generic term for an integrated set of disciplines that enable the strategic transformation of legacy power systems to better meet changing policy and customer expectations together with their physics-based implications[18].**

While many traditional models of change focus on discrete parts or components, the PSA discipline enables a holistic view of the entire power system over 5, 10 and 20-year time horizons. Recognising that the legacy power system is an extremely complex 'Network of Structures', the PSA disciplines uniquely provide:

a) **Whole-of-system insight** that enables diverse stakeholders to collaboratively interrogate and map current, emerging and future power system priorities, objectives and functions informed by a range of plausible future scenarios;

b) **Evidence-based tools** to navigate, analyse and shortlist key transformational options through the combined application of Systems Architecture, Network Theory, Control Theory and Software Engineering complemented by Energy Economics and Strategic Foresight disciplines; and;

c) **Future-resilient decision making** enabled by surfacing hidden structural constraints early that may otherwise drive future issues such as computational constraints, latency cascading and cyber-security vulnerabilities, which provides assurance that new investments are scalable and extensible under all plausible futures.

Most importantly, PSA expands rather than limits optionality. It enables architectural decision making based on agreed principles, objective methodologies and detailed structural analysis. It gives priority to extensive collaboration with diverse stakeholders and subject matter experts throughout to enhance trust, ensure high levels of alignment and support social license for change.

**Benefits of Addressing Architectural Issues**

Align the power system architecture with 21st century needs and new technologies will integrate more effectively, investments will be more future-resilient, the full value-stack of VRE / DER / EV services can be unlocked and monetised and the entire power system is enabled to be more reliable, resilient and cost-efficient for the long-term.

Fail to address power system architecture issues and VRE / DER / EV integration becomes increasingly complex and costly, investment stranding and duplication risks increase, scalability issues beyond technology trial volumes become more likely and the entire power system progressively becomes less resilient and less efficient.

[18] While developed with specific reference to Australian power systems, the Action Research Plan has been informed by numerous relevant projects and initiatives in the United States, United Kingdom, European Union and Australia. As different names are used in different jurisdictions for related activities, the term Power Systems Architecture (PSA) was selected as a generic descriptor for use in the Action Research Plan.

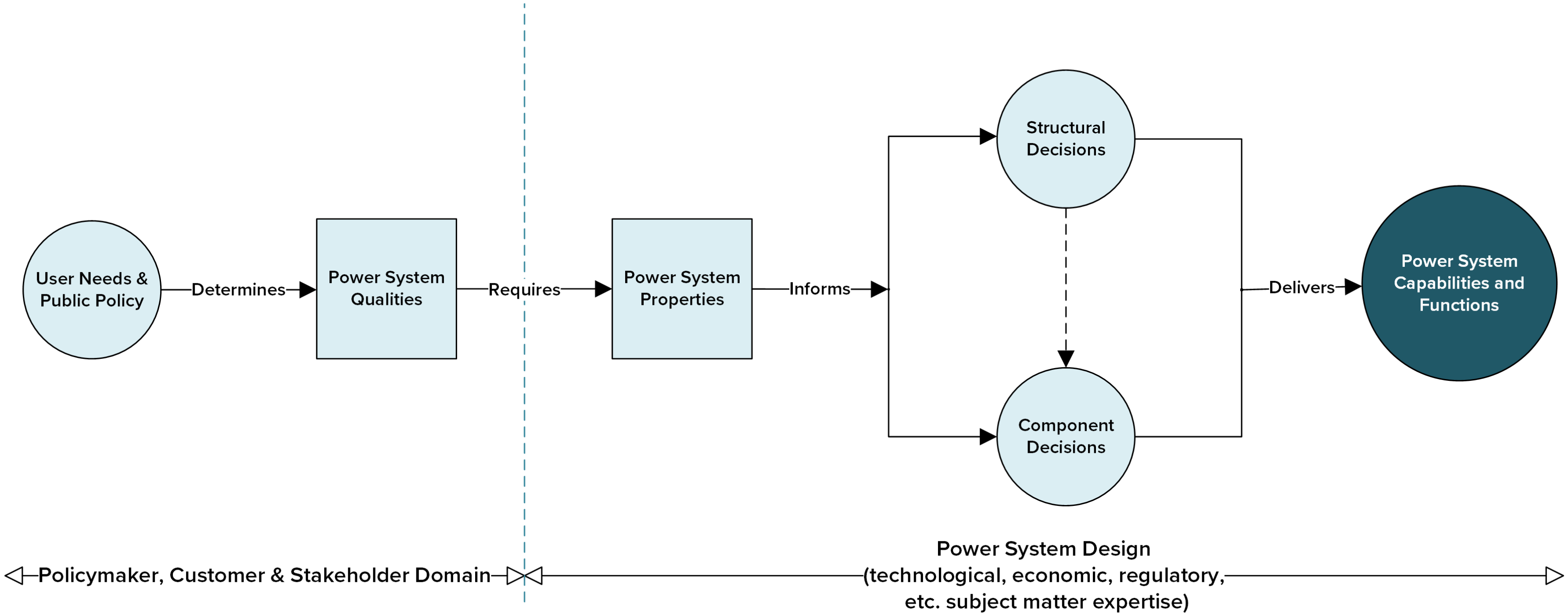



Figure 7: Power System Architecture provides a structure for multi-stakeholder navigation of whole-of-system transformation[19]

[19] Adapted from Pacific Northwest National Laboratory

## 2.4 Closely Aligned with the AEMO Engineering Framework

PSA is a set of disciplines that enable the navigation of complexity and ambiguity in a manner that expands whole-of-system and long-term perspective and upskills diverse stakeholder groups to enhance the quality of engagement. In doing so, it provides a valuable complement to (but does not replace) near and medium-term system and network planning.

As noted earlier, while many traditional models of change focus on discrete parts or elements of the power system, the PSA discipline enables a holistic view of the transforming system over 5, 10 and 20-year time horizons. As such, it strongly aligns with AEMO's Engineering Framework [19] and complements the Bridging the Gap (C) focus area as identified Figure 8 below.

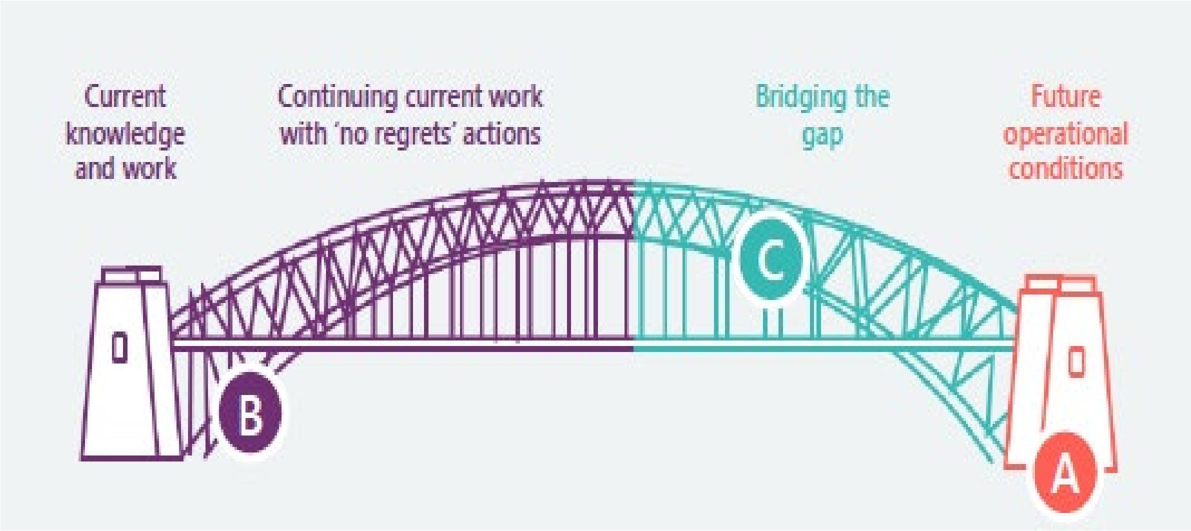



Figure 8: Power System Architecture strongly complements the Bridging the Gap (C) focus area identified in the NEM Engineering Framework. [20]

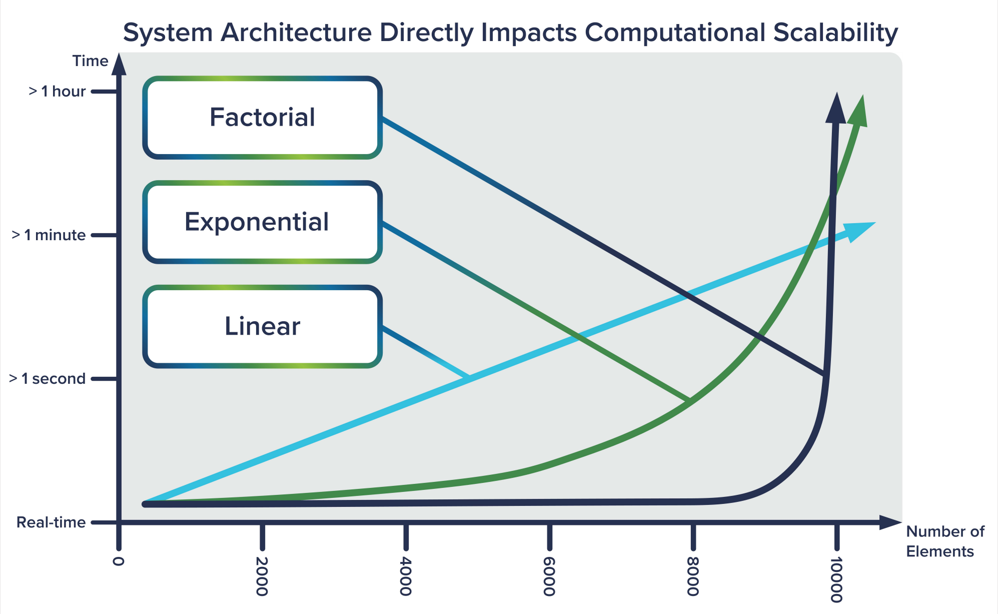
One of the key strengths of PSA is that expands rather than limits optionality. It enables decision making based on agreed principles, objective methodologies and detailed structural analysis. In a context of growing ambiguity, it provides a basis for more future-resilient decision making as it reveals hidden structural constraints that may otherwise drive future issues and therefore supports the shortlisting of investments are scalable and extensible.

[20] NEM Engineering Framework, AEMO (2021)

## Example: Power System Architecture, Markets & Operational Coordination[21]

As noted above, power systems are ultra-complex cyber-physical-economic systems. Today, however, the number of energy resources and endpoints, and the complexity of operational coordination across all layers of the power system, is increasing by orders of magnitude. Power system dynamics are also increasing in speed and decreasing in latency requirements by orders of magnitude.

In this transformational context, the architecture or structure of a complex system has a profoundly influential, and mathematically empirical, relationship to whether the system will be sufficiently scalable and extensible for future needs.




For example, electricity market functions have played a key role in the operational coordination of energy resources and Power systems. Traditionally the number of elements involved in electricity market solutions was in the thousands.

Now consider the implications of adding millions or tens of millions of DERs into the mix. Based on more traditional coordination architectures, it is likely that market optimisation engines will run into the computation 'time wall' at some point. In the case of the factorial (brown) curve, this can occur quite suddenly. As the curves grow, no amount of computing resources will be adequate to solve the optimisation problems in a reasonable time.

The relationship between the structured consideration of system architecture and technology trials is very practical: both are necessary. One without the other may result in innovations that function successfully as trials but prove uneconomic and fragile at scale.

[21] Adapted from Dr Jeffrey Taft, Pacific Northwest National Laboratory

# 3. PROJECT METHODOLOGY

The following development activities have occurred in developing the Action Research Plan.

## 3.1 Stakeholder Engagement & Input

### *International Expert Panel (IEP)*

A funded International Expert Panel was contracted and convened to provide globally-relevant and state-of-the art perspective on the disciplines relating to Power Systems Architecture in different parts of the world. The IEP consisted of:

+ Dr Jeffrey Taft, Pacific Northwest National Laboratory;
+ Dr Lorenzo Kristov, formerly of CAISO;
+ Paul De Martini, Newport Consulting; and,
+ Phil Lawton, Energy Systems Catapult.

At various points of the project, the IEP attended remote workshops and provided advice relevant to:

+ The original research questions proposed in Request for Proposal (RFP);
+ The structure and inclusions of Strategen's draft workplan and proposed report outline;
+ The list of global and Australian sources and projects proposed for review; and,
+ Particular aspects of various report drafts.

A universal observation of the IEP was that the some of the original RFP questions seemed to suggest that determining the 'right' or 'best' power system architecture was the outcome of the project. The IEP emphasised that identifying the optimal future architecture is always the product of a structured process based on core principles, objectives and methodologies underpinned by extensive stakeholder engagement throughout. As such, the Action Research Plan was configured to reflect this expert advice in a manner that addresses the core content outlined in the RFP scope

Other IEP feedback included:

+ An effective architecture project will build significant alignment across the sector and stakeholders
+ Wider architectural approach will address both DER control architecture and directly inform T-D interface design

+ Any architecture must be resilient to / recover from black start, cold start, islanding, computing and communications failure, cyber-attack, etc.

+ Perhaps consider the architectural features required in a 100% inverter-based system

+ 'Think big and think ahead' - must not be unduly constrained by historical paradigms. Needs to identify whether incremental approaches will work or are taking you up a 'blind alley'.

+ Need to enable insights from both 'bottom-up' and 'top-down' perspectives

+ Architecture must be considered with a detailed view of changing context, including:

  o commercial business models that are evolving around DER;

  o revenue requirements;

  o technological evolutions;

  o credible perspectives on plausible future customer preferences, behaviours and related potential services

Some interesting IEP quotes included:

+ "The current architecture is an accident of history"

+ "In any jurisdiction we've have worked, we have never yet found a complete industry and regulatory structure model in existence" (i.e. a single set of documents and artefacts that fully represent the entire 'as-built' network of structures that make up the power system).

### *Australian Stakeholder Panel (ASP)*

Several meetings of the Australian Stakeholder Panel were convened to ensure maximum participation across the nineteen nominees from diverse stakeholder organisations. This included representation from market bodies, customer advocates, networks, retailers, technology vendors and academia. The ASP recognises the critical importance of engaging on PSA frameworks with views and inputs from across our energy system.

The ASP was briefed on the focus on the project and provided a range of constructive feedback including:

- Ensure that customer perspectives and values are explicit
- This is critical to foster a shared view of the future to gain shared efficiencies
- Needs to span all interfaces: Customer / Distribution / Transmission / Generation
- Will help address the challenge of so many experts working in siloes
- Approach must have agility and not be unduly constrained by today's paradigms
- Should include a Counterfactual of what happens if architecture is unaddressed
- Needs to have a strong focus on EVs, Community Batteries and Hydrogen

Some interesting ASP quotes included:

- "Architecture is 'missing in action'. It's a much needed yet missing element in Australia's future system planning"
- "If we don't have a shared view of the future, many will end up in cul-de-sacs and dead-ends – and waste significant resources and time".
- "Architecture needs clarifying – many assume this refers only the IT paradigm"
- "Many trials underway are just assuming the OPEN Hybrid architecture as though it's been officially selected as the future solution"

## 3.2 Survey of Architecture Methodologies & Projects

A detailed review of international and Australian methodologies and projects was undertaken as follows. Consistent with the Project Objective as set out in section 1.3, the primary purpose of this review was to:

- Understand the diversity of approaches being applied to the consideration of System Architecture, T-D Interface and DER Control Architecture matters; and,
- Enable the identification and recommendation of an integrated and adaptive combination of methodologies and activities for application in Australia.

A detailed analysis of the following international and Australian projects and initiatives can be found in Part C of this document.

| International Projects and Initiatives | | |
|---|---|---|
| **Project / Initiative** | **Sponsor** | **Type** |
| **North America** | | |
| Grid Modernisation Laboratory Consortia (GMLC) | Pacific Northwest National Labs (PNNL) | Research |
| Development of a T-D Interoperability Framework | Independent System Operator Ontario (IESO) | White Paper |
| Modern Distribution Operation (DSPx) | US Department of Energy | |
| **United Kingdom** | | |
| Future Power System Architecture | Energy Systems Catapult & Institution of Engineering and Technology (IET) | National Reform Initiative |
| Open Networks | Energy Networks Association (UK) | Industry Collaboration |
| **Europe** | | |
| Universal Smart Energy Framework (USEF) | USEF Foundation (Alliander, Stedin, ABB, DNV GL, IBM, ICT, Essent) | Industry Collaboration |
| TSO-DSO Coordination for Acquiring Ancillary Services from Distribution Grids | International Smart Grid Action Network (ISGAN) | |

| Australian Projects and Initiatives | | |
|---|---|---|
| **Project / Initiative** | **Sponsoring Organisations** | **Type** |
| **AEMO Activities** | | |
| AEMO Engineering Framework | AEMO | Industry Collaboration |
| Integrated System Plan 2020 / 2022 | AEMO | Biennial Report |
| Coordination of DERs; Architecture Insights for Future Market Design | AEMO | Report |
| Minimum Operational Demand Thresholds in South Australia | AEMO | Report |
| AEMO VPP Trials | AEMO | Trials |
| **Research & Demonstration** | | |
| Indra Monash Smart Energy City | Monash University | Trial and Reports |
| Project EDGE | AEMO, Ausnet, Mondo | Trial |
| Dynamic Operating Envelopes Research | ANU | Research |
| State of DER Technology Integration | ARENA, FarrierSwier | Report |
| South Australian VPP Trial | Tesla, SAPN | Trial |
| **Government Activities** | | |
| Post-2025 Market Design Project | Energy Security Board, Energy Ministers | Government Reform Initiative |
| WA Energy Transformation | WA Government | Government Reform Initiative |
| **Other** | | |
| OpEN Energy Networks project | Energy Networks Australia, AEMO | Industry Collaboration |
| Interoperability Steering Committee | DEIP | Committee |
| Dynamic Limits project | Dynamic Limits, ARENA | Report and Modelling |

## 3.3 Analysis of Methodologies

Informed by the range of insights provided by both the (IEP and ASP) Stakeholder input and the survey of architecture methodologies and projects, the following has been undertaken:

+ **Comparative analysis:**
    - Key similarities of methodologies and approaches being applied across jurisdictions listed above
    - Material differences of the applied methodologies and approaches
+ **Gap analysis:**
    - Initiatives underway or planned that address specific needs;
    - Demonstrable and material gaps in their approach to system transformation; and,
    - Specific areas where Australia has relevant, unique and existing technology and solutions.
+ **Transferability analysis:**
    - Learnings that are transferable and non-transferrable to the NEM and SWIS; and,
    - The transferability of specific methodologies and approaches to Australia.
+ **Consideration of the following with reference to wider system architecture considerations and Research Plan design:**
    - Control architecture of DERs; and,
    - T-D Interface roles, responsibilities and data transfer requirements.

## 3.4 Analytical Observations

### *General Observations*

There is a significant amount of excellent work advancing in Australia and globally that can be learned from. There are also some cautionary notes worth stating as follows:

**Firstly, the term 'architecture' is used in various ways, some more appropriate than others.** With reference to power system transformation, is not uncommon for the term 'architecture' to be used with primarily reference to digital systems in general or Enterprise IT Architecture in particular. Sometimes it is used more generally to mean 'holistic', 'whole-system' or 'systemic'. However, to be consistent with established Systems Architecture disciplines, neither of these approaches are adequate or completely accurate. Given the complex multi-structure reality of a modern power system, any approach, methodology or toolkit that does not equip users to perform detailed analyses of all current structures, and the robust evaluation of plausible future structural options, is at best incomplete if not seriously deficient.[22]

**Secondly, several approaches place strongest emphasis on developing an extensive list of new functions that are expected to be required.** Such lists can be useful where they are informed by sound analysis of the key environmental drivers. However, their practical benefit may be diluted when seeking to implement the new functions. Without a robust approach to the underpinning structural analysis, enabling the range of new functions becomes inordinately complex and the risks of scalability and latency issues, unrealised benefits and stranded investments increase.

**Thirdly, many projects and initiatives are – not surprisingly – undertaken with primary reference to a specific regional (or localised) context.** In other words, while there will be many things that can be learned from these projects, there will generally be a need to recognise the very specific context that will have significant bearing on the project and therefore require consideration of what is transferable to the NEM or SWIS.

**Lastly, it is noteworthy that some initiatives have originated with a primary emphasis at the bulk power end of the system, while others have focused largely the distribution end of the system.** This naturally can tend to detract from a whole-of-system solutions capable of spanning the entire customer–retail–distribution–transmission–bulk generation value chain. This can ignore opportunities for resources to be brought to bear across the end-to-end system as well as missing challenges that could emerge through the unintended consequences of an inadequate approach to advanced operational coordination.

[22] This deficiency was found to be quite common in the case of power system initiatives and methodologies that include the term 'architecture' in their name. Given the disproportionate influence of the underlying structure or architecture on what any complex system can reliably perform, this is arguably a fatal omission if attempting to take a whole-of-system view of transformation. Any modern power system is a combination of inter-dependent complex structures that can be characterised as a 'Network of Structures'. As such, evidence-based due diligence requires detailed structural analyses of proposed alternative architectures, in terms of operational viability and scalability, as a credible basis for short-listing options and performing cost/benefit analyses (i.e. across at least the four functional layers of the inter-dependent network of structures that constitute the modern power system).

### *Key Differences in the Perceived Challenge*

A significant point of difference of the more ambitious and visionary initiatives reviewed is how they conceived of the nature of change impacting the power system.

For example, the rationale for the UK's Future Power System Architecture (FPSA) project was summed up as follows:

> *"The 'power system architecture' is the underlying structure of the electricity system – how its components and its participants are organised and interact. Major policy challenges, advanced technologies and emerging new business models will require transformative change to Britain's power system architecture by 2030."* [23]

In other words, as with the US Department of Energy's (US DoE) Grid Architecture and DSPx Modern Distribution System programs, the FPSA initiative conceived of the challenge confronting the power system as 'transformative' rather than incremental or integrative.

In Australia, we are now recognising that the NEM is tracking into entirely uncharted global territory. Historically, however, we have had no direct equivalent to these initiatives which, over the last 5 or more years, have focused on building the underpinning disciplines and tools for transformation. Until recently, the predominant 'theory of change' appears to have assumed that the accumulation of numerous near-term enhancements together with insights from diverse demonstration projects will be sufficient to the challenges ahead.

There is certainly no debate that Australia's power systems will continue to require a wide range of incremental enhancements and demonstration projects will continue to play an important role. However, as AEMO's Engineering Framework is now demonstrating, Australia's power system challenges also require more integrative or holistic approaches to building the capacity for transformation.

The Action Research Plan developed by this project draws upon international best practice to provide an integrative approach for accelerated national capacity building, the upskilling of a diverse community of practice and the holistic incorporation of nearer term enhancements and demonstration project insights.

[23] Future Power System Architecture, Main Report, Energy Systems Catapult (2016)

## 3.5 Recommended Approach

As outlined above, the Action Research Plan has been informed by a range of projects and initiatives in the United States, the United Kingdom and Australia. A key aim for this review was to identify and recommend an integrated and adaptive combination of methodologies and activities suitable for application in Australia.

In recognition of the observations noted above, the United States Department of Energy (US DOE) sponsored Grid Architecture program was identified as the most comprehensive and transferable methodological approach currently available. This is a function of being developed primarily under the Grid Modernisation Laboratory Consortia (GMLC) by Pacific Northwest National Laboratory with the objective of having transferable application across the fifty US states. This means that it spans a wide diversity of industry, market and regulatory structures, including vertically disaggregated industry structures somewhat similar to Australia's NEM such as the ERCOT region[23]. Importantly, it provides a comprehensive methodology for performing detailed structural analyses of the inter-dependent 'Network of Structures' that make up the power system. This is underpinned by mathematical methods drawn from optimisation theory, functional analysis, and graph theory. Collectively, the methodology provides specific and practical architectural principles and tools that enable evidence-based and future-resilient architectural decision making and cost/benefit analyses.

In addition, the US DOE's Modern Distribution Operation (DSPx) project, also part of the GMLC program, provides valuable and complementary content of relevance to Australia's 'high DER' transformation. As the name suggests, DSPx has a particular focus on fast-evolving distribution systems and how their ongoing modernisation may capitalise on new technologies and the proliferation of distributed resources within expanded integrated distribution planning frameworks.

Further, while more specific to its own policy and environmental context, the United Kingdom's Future Power System Architecture (FPSA) program also contains a significant depth of content that has been instructive in developing the Action Research Plan. This is particularly so in regard to its approach to function mapping and consideration of the transformational change mechanisms required to enable timely progress in the UK and similar economies.

Finally, a key activity in Strategen's development of the Action Research Plan provided in Part B has been the assimilation of relevant content from these best practice sources in a manner directly relevant to the Australian context and industry structure. In addition, Sections 5.2 – 5.4 provide an overview of key points of intersection with other G-PST Tasks together with Australian and global research collaboration opportunities.

[24] The Electric Reliability Council of Texas (ERCOT) is the Independent System Operator for Texas and manages the flow of electric power to 26 million customers.

# 4. ACTION RESEARCH PLAN

## 4.1 Key Purpose

As noted earlier, the key purpose of this project is to identify and recommend an integrated and adaptive combination of action research methodologies and activities that, over an 18-month project duration, will:

1. Enhance and accelerate Australia's capacity to navigate the complex structural and operational shifts that are inherent in the large-scale transformation of Australia's GW-scale power systems;

2. Provide a robust methodological basis for establishing a diverse and informed multi-stakeholder 'community of practice' that is better equipped to collaborate on the wide range of trade-off decisions essential to enhanced system and customer outcomes;

3. Significantly strengthen multi-stakeholder engagement, process coherence and transparency as a basis for greater trust and enhanced social license for change.

## 4.2 Delivery Structure

A modern GW-scale power system is a massively complex combination of distinct structures that dynamically interact with each other, many of which span structural and jurisdictional siloes. As emphasised by the International Expert Panel (IEP), the number of possible architectures is unlimited, but they are not all equally relevant for a particular context.

As such, the effective consideration of power system architectures will always be the product of a structured process informed by core principles and objectives. Based on robust methodologies and deep stakeholder engagement, the process must progressively identify and shortlist the options that are most future-resilient in the Australian context.

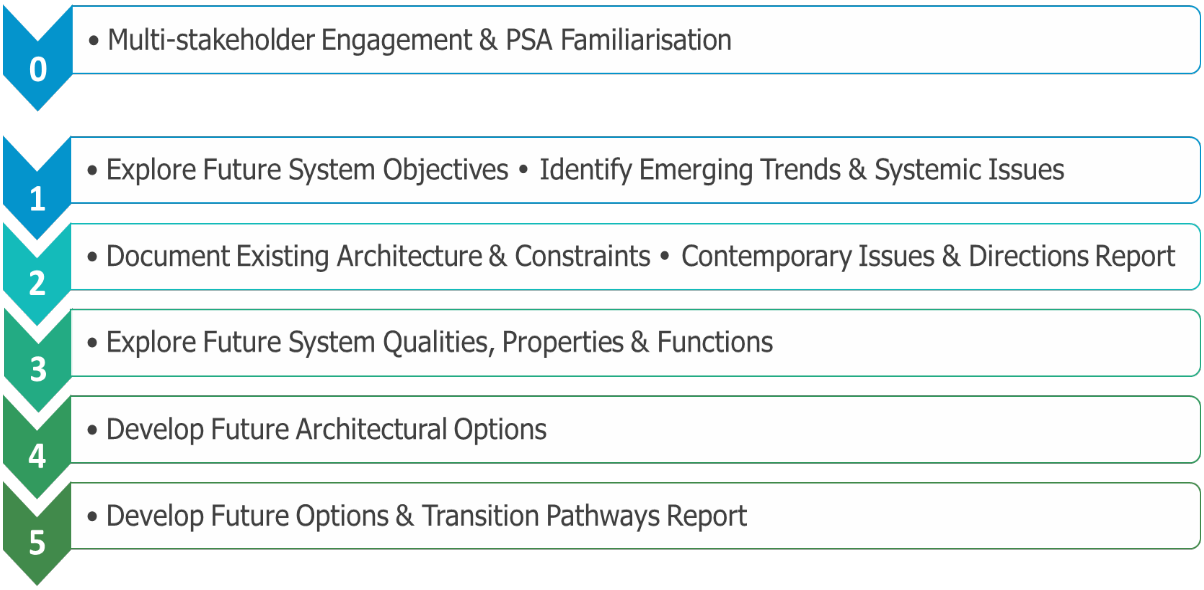



**Figure 9:** Five-phase Action Research Plan structure

Informed by the detailed analysis of the various methodologies and project experience outlined above, together with significant expert and stakeholder input, the above 5-phase Action Research Plan has been developed.  It is proposed that the 18-month project may be preceded by an initial 2 – 3 months of multi-stakeholder engagement and familiarisation with the PSA discipline and tools.

The full Action Research Plan is provided in Part B of this document.

## 4.3 Design Features

The Action Research Plan has been developed fully cognisant of both the need to effectively navigate complex transformation and the reality of how conflicted such change processes can be. As such, the plan is configured with the following combination of design features.

| Design Feature | Description |
|---|---|
| **Bias for informed action** | Given the pace and scale of change impacting the NEM and SWIS, time is of the essence and the project must have a bias for informed action. |
| **Brownfield starting point** | All project activities must be grounded in the practical realities that Australia has complex existing 'brown field' systems as the starting point. (Architecture pathways must recognise this). |
| **Leading disciplines** | Global best-in-class disciplines will be employed to identify critical gaps in theory, technology, organisation and process and provide an objective basis from which to collectively navigate complex and sometimes contested matters. |
| **Apolitical** | To facilitate a creative and apolitical positioning the project may be framed as exploratory under the sponsorship of CSIRO and the support of AEMO and a range of stakeholders. |
| **Future-conscious** | Recognising the transformational forces impacting global power systems, processes will stretch participants to frame matters from a 'future-back' perspective that expands creativity and mitigates confirmation bias. |
| **Whole-of-system** | Given the nature of the transformation, the project must apply a whole-system view of the entire power system spanning customer–retail–distribution–transmission–bulk generation. |
| **Community of practice** | The project will upskill a diverse range of stakeholders to establish a sizable community of 'architectural practice' capable of navigating complex matters and contributing to key trade-off decisions that must be made. |
| **Australian project team** | The dedicated project team would consist of Australian research and industry staff. |
| **Global expertise** | A funded panel of international experts would be sought to provide strategic advice and targeted services as necessary. |
| **Content development** | While significant stakeholder engagement will be essential, the bulk of new content that is the basis for meaningful stakeholder engagement will be the responsibility of a small, dedicated project team. |
| **Future-resilient options** | Prioritise the structured identification of options that enhance solution scalability and extensibility and support collective decision-making that is more future-resilient. |
| **Implementation-ready** | Consistent with the project's bias for action, all outputs will be structured in a manner that supports timely implementation through practically achievable transitional steps. |

## 4.4 Action Research Timeline

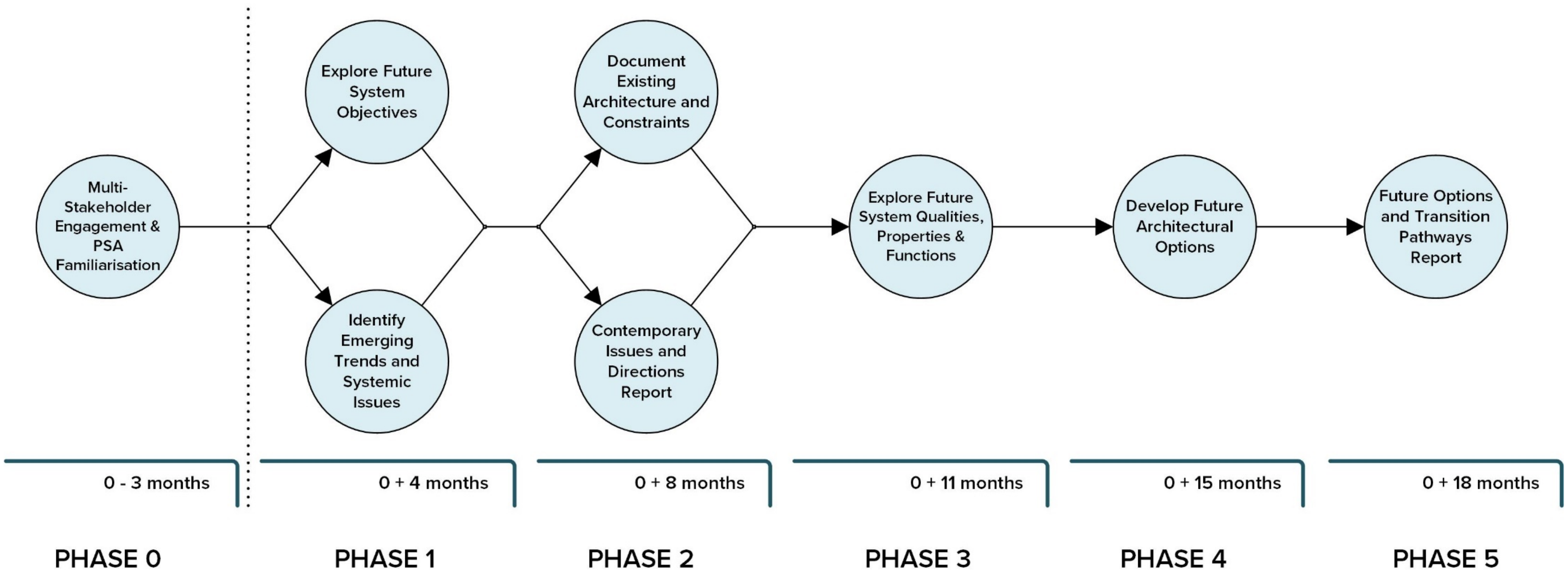



**Figure 10:** Five-phase Action Research Plan timeline

## 4.5 Key Report Outputs

As an Action Research process, the project design places very significant emphasis on key activities that enable collaborative learning, problem solving and evidence-based trade-offs. Nevertheless, it is also critical that key outputs are developed which provide content and decision traceably and these key deliverables are outlined below.

| Deliverable | Complete |
|---|---|
| **PHASE 1a: Explore Future System Objectives** | |
| + Future System Objectives Report<br>o Customer & Societal Objectives<br>o Industry & Sectoral Objectives<br>o Environmental & System Resilience Objectives | 0 + 4 mth |
| **PHASE 1b: Identify Emerging Trends & Systemic Issues** | |
| + Emerging Trends Report<br>o Customer Preferences<br>o Generation & Load<br>o New System Characteristics<br>o Network Convergence<br>o Business Models, Markets & Tariffs<br>+ Systemic Issues Report<br>o Physics-based Issues<br>o Computational & Control Issues<br>+ Organisational & Structural Issues | 0 + 4 mth |
| **PHASE 2a: Document Existing Architectural Structures & Constraints** | |
| + Current-state Structures Report<br>o Entity-Relationship (E-R) Mapping<br>o Individual Functional Layer Mapping<br>o Composite E-R & Functional Layer Mapping<br>o Constraints Analysis Report | 0 + 8 mth |

| | |
|---|---|
| **PHASE 2b: Contemporary Issues & Directions Report** | |
| + Directions Report:<br>o Architectural models with key strengths in the Australian context<br>o DER market model scalability insights provided by architectural analysis<br>o DER control architecture insights provided by architectural analysis<br>o Dynamic Operating Envelope generation scalability insights provided by architectural analysis<br>o Transmission-Distribution interface considerations informed by architectural analysis | 0 + 8 mth |
| **PHASE 3: Explore Future System Qualities, Properties & Functions** | |
| + Qualities, Properties & Functions Report<br>o Future System Qualities<br>o Future System Properties<br>o Future System Functions<br>+ Qualities, Properties & Functions Relationship Mapping | 0 + 11 mth |
| **PHASE 4: Develop Future Architectural Options** | |
| + Future Structural Options Report<br>o Entity-Relationship (E-R) Mapping x 2 – 4 options<br>o Individual Functional Layer Mapping x 2 – 4 options<br>o Composite E-R & Functional Layer Mapping x 2 – 4 options<br>+ Constraints Analysis Report | 0 + 15 mth |
| **PHASE 5: Future Options & Transition Pathways Report** | |
| + Final Report:<br>o Project Overview<br>o Current-state Architecture<br>o Contemporary Issues & Directions<br>o Future System Objectives<br>o Emerging Trends & Systemic Issues<br>o Future System Qualities, Properties & Functions<br>o Future Structural Options<br>o Operational Effectiveness/Risks<br>o Implementation & Transition Requirements/Costs<br>o Recommendations for Consideration | 0 + 18 mth |

# 5. EXECUTION FOR ENHANCED ALIGNMENT & SOCIAL LICENSE

This project is designed to function as vehicle for supporting alignment across the sector and enhancing the social license for informed change.  This is supported by its Design Features as set out in section 4.3 and particularly its whole-of-system perspective and focus on advanced stakeholder participation.

## 5.1 Advanced Stakeholder Participation is a Key Success Factor

As with other influential projects led by the Strategen team members, including the CSIRO Future Grid Forum (2012) and CSIRO/ENA Electricity Network Transformation Roadmap (2017) projects, pro-active stakeholder participation is absolutely critical to success.  In fact, this is almost always a key differentiator between the projects that have successfully fostered trust and enabled timely progress, and those that have not.

A key goal of the proposed Action Research Plan is to help expand the sector-wide expertise necessary to ensure Australia's power system can efficiently meet the opportunities and challenges of the 21st century. As such, the collaborative model will actively engage and upskill a wide cross-section of subject matter experts and diverse stakeholder representatives.  This will foster a sizable 'community of practice' that includes:

+ Residential and SME customers
+ Large Commercial & Industrial customers
+ Regulatory & Market bodies
+ Governments: Federal & State
+ Electricity Generation sector
+ Transmission & Distribution Network sector
+ Energy Retail sector
+ Clean Energy & Energy Storage sector
+ DER Providers & Aggregation sector
+ Electric Vehicle sector
+ Platform Technology sector
+ Research & Academia sector
+ Research & Trials grant/funding entities
+ Finance sector

As other global jurisdictions are recognising, this requires a highly collaborative process that involves informed stakeholders, a systemic approach and a robust, objective methodology.

It is ultimately a societal undertaking that cannot be achieved by any single organisation.  As such, successful execution will require:

+ An objective, science-based approach;
+ Balanced multi-stakeholder representation;
+ Engagement at IAP2 – Involve / Collaborate levels; and
+ Representative input and decision-making aimed at the highest practicable level of consensus.

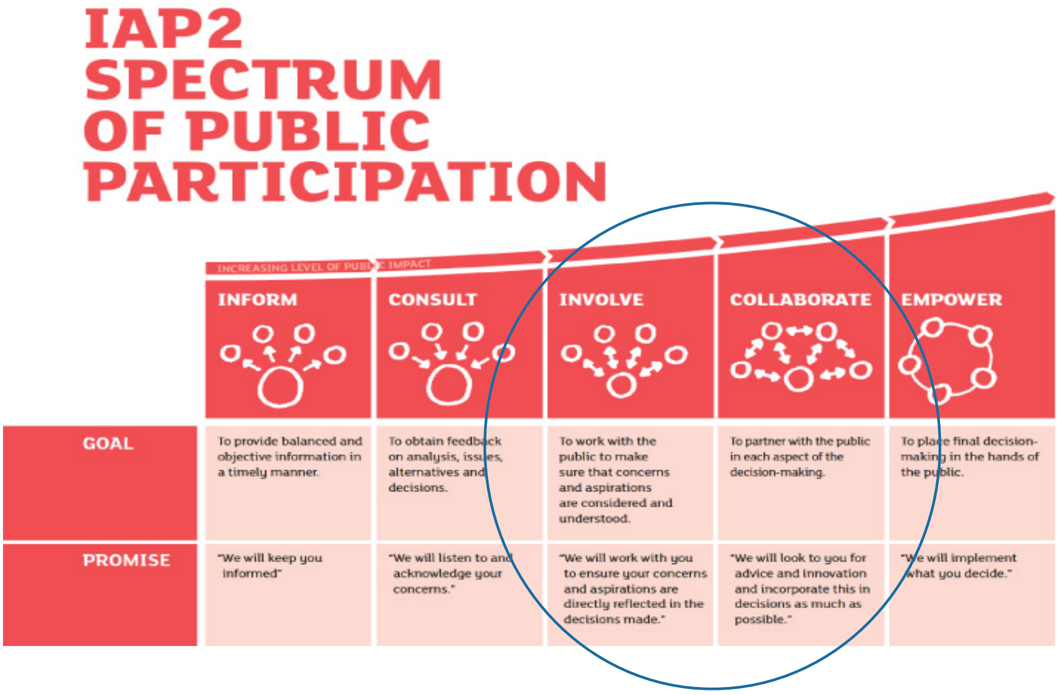



Figure 11: Stakeholder collaboration design focused at IAP2 Involve / Collaborate

**Key Stakeholder Participation Objectives**

Australia's power systems exist to serve customers and society as a whole.  As such, both subject matter experts and diverse stakeholder representatives are key to informing and enabling Australia's complex power system transformation.  The proposed Action Research Plan is, therefore, designed to enhance and accelerate our collective capacity to constructively navigate the transformational shifts ahead.  It does so by:

+ Providing a robust methodological basis for establishing a diverse and informed multi-stakeholder 'community of practice' that is well equipped to collaborate on the wide range of trade-off decisions essential to enhanced system and customer outcomes; and,

+ Significantly strengthening multi-stakeholder participation, process coherence and transparency as a basis for greater trust and enhanced social license for change.

## 5.2 Alignment with other G-PST Tasks

| G-PST Task | Potential Areas for Collaboration |
|---|---|
| **Task 3 – Control Room of the Future** | |
| **Research Entity:**<br>Electric Power Research Institute (EPRI)<br>**Key Contact:**<br>Mr Adrian Kelly | + Architectural provisions to ensure sufficient data flows for network visibility is available to control room operators, including across the transmission-distribution interface and with consideration of existing control schemes.<br>+ Architectural provisions to ensure sufficient control capabilities for demand-side and IBR based assets to maximise system flexibility available to operators.<br>+ Relevance of architectural tools, principles and artefacts to operator training and understanding.<br>+ Adapting architecture to enable pre-emptive system disturbance detection by making relevant diagnostic data available to operators.<br>+ Interfaces between digital architectures with various control room software required to operate system in real-time, near real-time and in 'auto pilot'.<br>+ Communication requirements of any architecture needed to support system operator monitoring and control – including consideration of reliability, latency, bandwidth and cyber-security. |
| **Task 8 – Distributed Energy Resources** | |
| **Research Entity:**<br>University of Melbourne<br>**Key Contact:**<br>Prof Luis (Nando) Ocho | + Architectural implications for minimum data flows needed to ensure the System Operator has sufficient visibility to maintain stability with high-penetration of DER across different time scales.<br>+ Understanding architectural best practice to promote cyber-security and therefore protect network and customer data and assets from attack.<br>+ Architectural provisions needed for cost-effective, sufficiently granular, and computationally achievable DER Control and Orchestration.<br>+ DER standards and implications for architecture.<br>+ Forecasting of expected DER uptake and heterogeneity over time and implications for future-proofing architectures.<br>+ Potential advantageous organisational and regulatory structural changes required to maximise participation of DER, including in ancillary services markets.<br>+ Architectural provisions for distribution-level markets. |

## 5.3 Australian Research Collaboration

<table>
<tr><th>Research Entity</th><th>Potential Collaborative Areas</th></tr>
<tr><td colspan="2">Australian National University</td></tr>
<tr><td>Research Team:<br>Battery Storage and Grid Integration Program<br>Key Contact:<br>Dr Lachlan Blackhall</td><td>+ Assessing the advantages of different architectural models for LV networks as they relate to:<br>o DER Control on the LV network, including Dynamic Operating Envelopes.<br>o DER Orchestration - maximising and coordinating capacity available to DER to participate in markets<br>o DER Optimisation – co-optimising of the above in line with local and system priorities.<br>+ Scalability and extensibility of different architectures as they relate to the above and to computational and communications constraints.<br>+ Unique architectural considerations of increasing penetration of storage throughout the power system.</td></tr>
<tr><td colspan="2">CSIRO</td></tr>
<tr><td>Research Team:<br>Energy Systems Research Program<br>Key Contacts:<br>Dr John Ward<br>Mr Paul Graham</td><td>+ Interaction of architecture with parallel evolution of standards for interoperability and power electronics.<br>+ Extent to which other energy vectors, including hydrogen, should influence architectural decisions.<br>+ Emerging and future intelligent control possibilities, including automatic grid reconfiguration, intelligent aggregation, smart consumer devices, and their implications for future-proofed architectures.</td></tr>
<tr><td colspan="2">Monash University</td></tr>
<tr><td>Research Teams:<br>Monash Energy Institute<br>RACE for 2030 - Networks Program<br>Key Contacts:<br>Prof Ariel Liebman<br>Mr Scott Ferraro</td><td>+ Transferable precinct-scale insights into architectural, design and coordination considerations across functional layers to GW-scale power systems, with particular emphasis on transactional layer and localised peer-to-peer sharing options.<br>+ Identifying emerging trends, particularly as they relate to future technology innovations (for example vehicle-to-grid and building-to-grid), customer behaviours and preferences, and business models.<br>+ Input into the impact of different architectural models to LV network visibility and optimising DER hosting capacity.</td></tr>
</table>

| University of Queensland | |
|---|---|
| **Research Team:**<br>Centre for Energy Futures<br>**Key Contacts:**<br>Dr Archie Chapman<br>Prof Stephen Wilson | + Identifying customer and societal objectives that may effect priorities for potential architectures through the lens of values, motivations, and socio-political and institutional dimensions of power systems<br>+ International approaches and perspectives to power system architecture, such as China.<br>+ Architectural impacts on the alternate optimisation techniques, such as the application of artificial intelligence, game theory, optimisation and machine learning to solve large-scale and dynamic allocation, scheduling and queuing. |

## 5.4 International Research Collaboration

| Research Entity | Potential Collaborative Areas |
|---|---|
| **Energy Systems Catapult** | |
| **Research Team:**<br>Future Power Systems<br>Future Markets<br>**Key Contact:**<br>Mr Phil Lawton<br>Mr George Day | + Methodology for identifying of future system objectives and the system and emerging trends underlying them from a whole-of-system perspective.<br>+ Barriers to implementation of functionality required to achieve future system objectives.<br>+ Lessons learnt in developing agile, holistic and inclusive enabling frameworks to support future options and transition pathways. |
| **MIT / Dartmouth College** | |
| **Research Team:**<br>Laboratory for Intelligent Integrated Networks of Engineering Systems<br>**Key Contact:**<br>Dr Amro Farid | + Reference Architectures for power systems that interact with other energy vectors such as the American Multimodal Energy System.<br>+ Insights from the quantification of power system architectures resilience using Hetero-Functional Graph Theory for Resilience Analysis.<br>+ Architectural considerations for distributed predictive control systems to achieve synergistic techno-economic performance. |

<table>
<tr><th colspan="2">Pacific Northwest National Laboratory</th></tr>
<tr><td>Research Team:<br><br>Grid Architecture<br><br>Key Contact:<br><br>Dr Jeffrey Taft<br><br>Dr Ron Melton</td><td>+ Methodology for understanding and documenting ‘as-built’ industry structure across four functional layers. Converging findings into suite of artefacts, such as E-R diagrams, for further interrogation.<br><br>+ Identifying physics-based, computational, control, and organisational and structural issues and their impact on plausible future scenarios.<br><br>+ Mapping the efficacy of different power system architectures in meeting future objectives for the system.</td></tr>
</table>

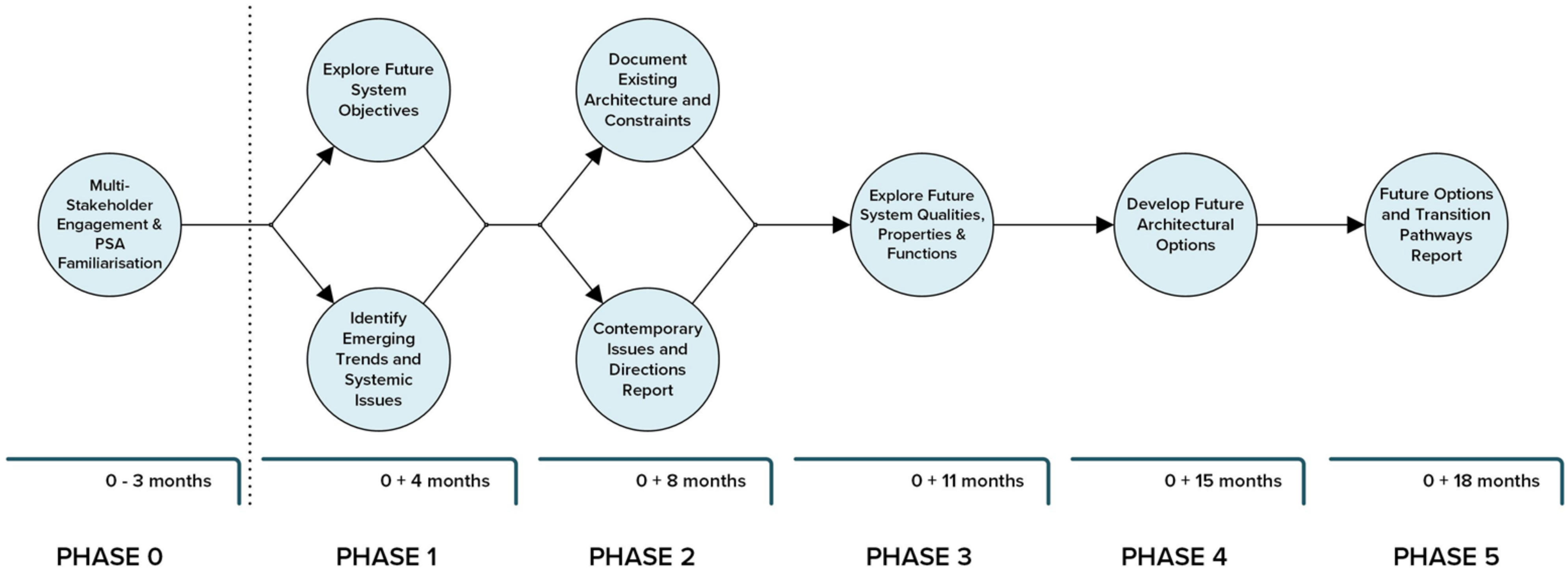
PART B

# Action Research Plan

## **PART B:** Action Research Plan

0. Multi-stakeholder Engagement & PSA Familiarisation
1. Explore Future System Objectives • Identify Emerging Trends & Systemic Issues
2. Document Existing Architecture & Constraints • Contemporary Issues & Directions Report
3. Explore Future System Qualities, Properties & Functions
4. Develop Future Architectural Options
5. Develop Future Options & Transition Pathways Report

# Action Research Indicative Timeline



<table>
<tr><th colspan="2">PHASE 1a: Explore Future System Objectives</th></tr>
<tr><th>Research Questions</th><th>Research Activities / Example Focus Areas</th></tr>
<tr><td colspan="2">Future System Objectives</td></tr>
<tr><td>Including but not limited to the examples listed:<br>1. What objectives may plausibly play a key role in shaping power system priorities to 2035 and beyond?<br>2. What least regret objectives would provide optionality for different policy settings?<br><br>* Groupings are indicative only and topics may map across customer, societal, industry and sectoral groupings.</td><td>Customer & Societal Objectives*<br>a) Safety & Reliability: Provide energy in a consistently safe and reliable manner, ensuring the number and duration of outages are minimised and customers are kept informed of issues.<br>b) Affordability: Provide residential, commercial and industrial customers with cost-effective access to existing electricity services and related emerging offerings.<br>c) Emissions Reduction: Reduce carbon emissions by meeting new generation needs with renewable energy sources, enabling VRE and DER integration, etc.<br>d) Customisation: Energy services built around individuals to reflect their unique circumstances, empowering people to easily manage their own energy use and costs.<br>e) Energy Justice: Support more equitable access to new technologies and/or the opportunity to participate in community energy resource offerings.<br>f) DER Enablement: Ensure the power system can integrate significant volumes of DER with negligible requirement to impose export constraints.<br>g) DER Service Remuneration: Provide incentives and mechanisms to actively expand the volume of energy and system services procured from customer-owned DER.<br>h) Electrification: Enable the electrification of transportation, building services and the industrial sector to accelerate the substitution of fossil fuels.</td></tr>
</table>

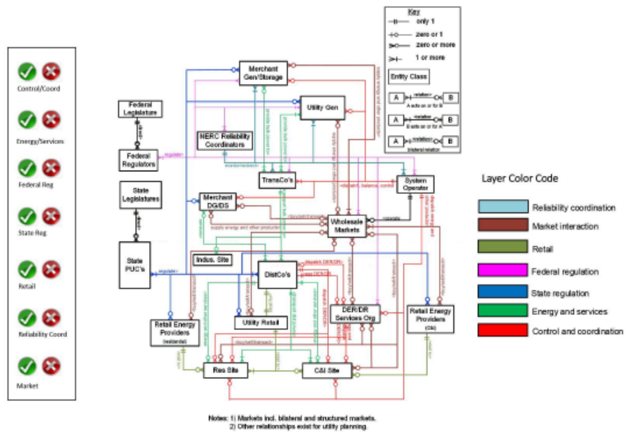
| Research Questions | Research Activities / Example Focus Areas |
|---|---|
| **Future System Objectives (Cont')** | |
| | **Industry & Sectoral Objectives***<br>a) Operational Reliability: Operate the power system within thermal, voltage and stability limits to withstand sudden disturbance or unanticipated failure of elements and maintain service provision within accepted standards.<br>b) Operational Excellence: Enhance customer service and optimal utilisation of power system assets and resources to minimise total system costs.<br>c) System Resilience: Withstand power system stress events without suffering operational compromise or minimise compromise via managed degradation.<br>d) Cyber-physical Security: Apply cyber and physical security requirements commensurate with the adverse impact that loss, compromise, or misuse of systems, physical and resource assets could have on the reliable operation of the distribution grid.<br>e) The Grid as a Platform: The power system is configured as a secure open access platform that allows for varied and constantly evolving applications to seamlessly interface with the platform.<br>f) A Robust Marketplace: The power system is functions as marketplace that allows innovative products and services to arise organically and be delivered seamlessly to customers by the entities of their choosing.<br>g) Hydrogen Export Platform: 50% or more of the energy managed through the power system is utilised for the production and international export of green hydrogen. |

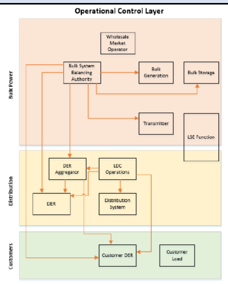
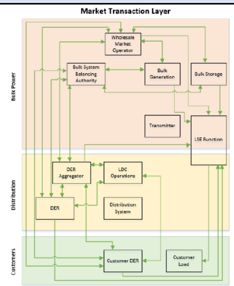
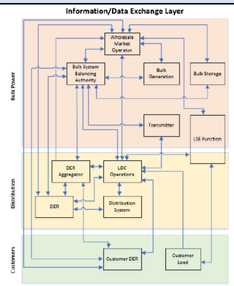
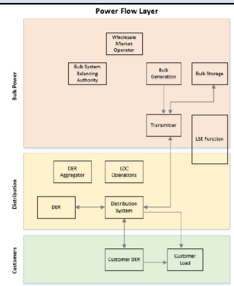
| PHASE 1b: Identify Emerging Trends & Systemic Issues | |
|---|---|
| **Research Questions** | **Research Activities / Example Focus Areas** |
| **Emerging Trends** | |
| Examine a diverse range of credible Australian and international studies and scenario planning focused on the 2030-2050 electricity systems futures.<br>Including but not limited to the examples provided:<br>1. What are the plausible emerging trends that Australia's GW-scale power systems must be resilient to in 2035?<br>2. What are the range of impacts arising from these emerging trends in 2035?<br>3. What emerging trends should be considered statistically most impactful in one or several plausible scenarios for the NEM / SWIS in 2035? | **Customer Preferences**<br>a) Increasing aspiration for sense of energy autonomy<br>b) Declining proportion of customers totally dependance on the power system for all electricity supply<br>c) (Alternative) Enhanced levels of grid engagement by customers through structured incentives to invest in relevant DER/DM and the remuneration of system services.<br>d) Preferences for shared energy resources including community batteries and solar farms.<br>e) Demand for a diversity of innovating energy services for all socio-economic groups.<br>f) Expanding adoption of energy storage, electric and hydrogen-based transport.<br>g) Demand for deeper and faster decarbonisation of the power system.<br>h) Growing demand and opportunities for localised peer-to-peer energy sharing options. |
| | **Generation & Load**<br>a) Increasingly heterogeneous generation fleet.<br>b) Significant fleets of generation located on either side of the T-D interface.<br>c) Increasing overall proportion of Inverter Based Resources (IBR).<br>d) Growth potential of renewable hydrogen production and accelerated power system decarbonisation.<br>e) Increasing frequency of minimum and negative system load.<br>f) Increasing volumes and types of energy storage. Increasing load flexibility and responsiveness.<br>g) Increasingly extreme evening ramp. |

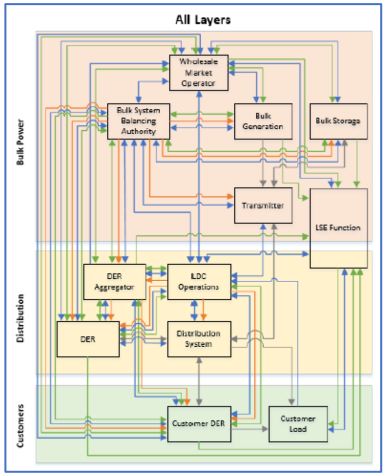
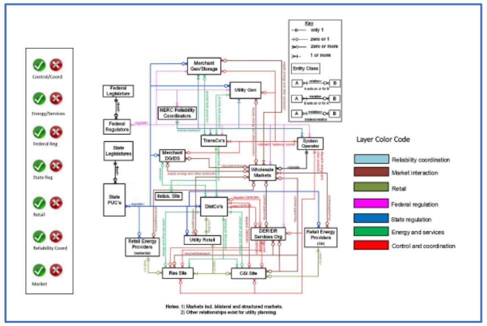
| Research Questions | Research Activities / Example Focus Areas |
|---|---|
| **Emerging Trends (Cont')** | |
| | **New System Characteristics**<br>a) Distribution Network Service Providers (DNSPs) transitioning toward a range of Distribution System Operator (DSO) models with significant structural implications.<br>b) Vastly increasing number of endpoints that must be managed, sensed, and/or controlled.<br>c) Large-scale data collection driving expanding roles for machine learning and automation.<br>d) Rapid growth in computational requirements as endpoint volume expands.<br>e) Increasing priority on physical and cyber security of the power system.<br>f) Increasing focus on resilience, including alternative approaches to resilience and power quality. |
| | **Network Convergence**<br>a) Continued convergence of information and communication technologies with power system<br>b) Increasing vehicle-to-grid convergence<br>c) Increasing building-to-grid convergence<br>d) Gas-electricity convergence (including hydrogen) |
| | **Business Models, Markets & Tariffs**<br>a) System cost impacts from changing customer engagement / grid dependance (as above). |

| Research Questions | Research Activities / Example Focus Areas |
| --- | --- |
| | b) More dynamic tariff and market platform options emerging in parallel with broad ‘all you can eat’ pricing options.<br>c) The viability of traditional volume-based business models under extreme pressure.<br>d) Increasing availability of zero marginal cost generation. |
| **Systemic Issues** | |
| Including but not limited to the examples provided:<br>1. What are emerging systemic issues that Australia’s GW-scale power systems must be resilient to in 2035?<br>2. What are the range of impacts arising from these systemic issues in 2035?<br>3. What emerging systemic issues should be considered statistically most impactful in one or several plausible scenarios for the NEM / SWIS in 2035? | **Physics-based Issues**<br>a) System dynamics are increasing in speed and decreasing in latency requirements by orders of magnitude.<br>b) Significant loss of system rotational inertia due to replacement of traditional generation with VRE.<br>c) Increasing volumes and variety of data due to diversity of device types and increasing observability<br>d) Proliferation of DER is hiding real demand and introducing apparent load volatility.<br>e) Loads are no longer passive and becoming less forecastable. |
| | **Computational & Control Issues**<br>a) Vastly increasing number of endpoints that exceed traditional power system controls.<br>b) Ability of system operator to identify communication and computational issues in real-time<br>c) Increasing complexity of control problems and application of optimisation methods to solve them.<br>d) Increasing complexity of control coordination across all layers of the power delivery chain.<br>e) Hidden feedbacks and cross-coupling embedded in existing system architecture.<br>f) Computational constraints and cyber-security vulnerabilities imposed by legacy system architecture.<br>g) Distribution grid visibility is poor and grid state definition limited. |

| | |
|---|---|
| | **Organisational & Structural Issues**<br>a) No agreed and complete 'single source of truth' mapping all interfaces between key entities interacting with the 'as built' power system.<br>b) Unresolved questions about future system structures, roles and responsibilities and no existing mechanism for the detailed and collective consideration of future needs and options.<br>c) Inadequate modelling platform development to interrogate potential architectural, roles and responsibilities options and outcomes.<br>d) T&D planning, operations, and regulation continues to occur in a fragmented or siloed manner. |

<table>
<tr><th colspan="2">PHASE 2a: Document Existing Architectural Structures & Constraints</th></tr>
<tr><th>Research Questions</th><th>Research Activities / Example Focus Areas</th></tr>
<tr><td colspan="2">Industry Structure Analysis</td></tr>
<tr><td>1. How are the entity relationships and interfaces structured in the NEM and SWIS across the following?<br>a) Control and dispatch interfaces;<br>b) Energy and ancillary services interfaces;<br>c) Regulatory interfaces;<br>d) Markets and transaction interfaces; and,<br>e) Retail interfaces.</td><td>Entity-Relationship (E-R) Mapping<br><br>Develop comprehensive mapping of the existing 'as-built' industry structure showing how all relevant entities interrelate across the several segments or layers that make up the NEM and SWIS.<br><br>The resulting Entity-Relations (E-R) Diagrams will provide unique new perspective on both the NEM and SWIS, capturing all structural elements, the full range of entities involved, their interactions, relationships, and functions. They will provide individual and aggregated views of the various layers of entity relationships that have evolved, including:<br>a) Control and dispatch relationships / interfaces;<br>b) Energy and ancillary services relationships / interfaces;<br>c) Regulatory relationships / interfaces;<br>d) Markets and transaction relationships / interfaces; and,<br>e) Retail relationships / interfaces.<br>

<br>
This is a necessary first step in any Power Systems Architecture project as a modern grid is an ultra-complex Network of Structures that has evolved and adapted over several decades.<br><br>It is commonly found that no single set of documentation exists that provides comprehensive and agreed mapping of all entities, relationships and interfaces as they actually exist and currently function.</td></tr>
</table>

| Research Questions | Research Activities / Example Focus Areas |
|---|---|
| **Industry Structure Analysis (Cont')** | |
| | While the E-R Diagrams will be developed by the project team, the activity requires very significant engagement, workshopping, and content iteration with diverse stakeholders to ensure comprehensive and accurate mapping. It will typically be found that a wide range of different perspectives, even within individual organisations, will need to be harmonised on how the many interfaces actually function.<br><br>Due to the complexity involved, the E-R Diagrams would be developed with multilayered modelling that allows individual layers to be hidden or revealed. This supports structural analysis by providing different views on both individual layers and how various relationship layers interrelate. |
| **Functional Layer Analysis** | |
| 1. What is the current or 'as built' structure of each of the four functional layers of the NEM and SWIS?<br><br>a) Operational Control Layer;<br><br>b) Market Transaction Layer;<br><br>c) Information/Data Exchange Layer; and,<br><br>d) Power Flow Layer. |        <br><br>**Individual Functional Layers**<br><br>In addition to the E-R Diagrams developed above, undertake detailed mapping of the following four functional layers of the NEM and SWIS as they currently exist.<br><br>a) Operational Control Layer;<br><br>b) Market Transaction Layer;<br><br>c) Information/Data Exchange Layer; and,<br><br>d) Power Flow Layer. |

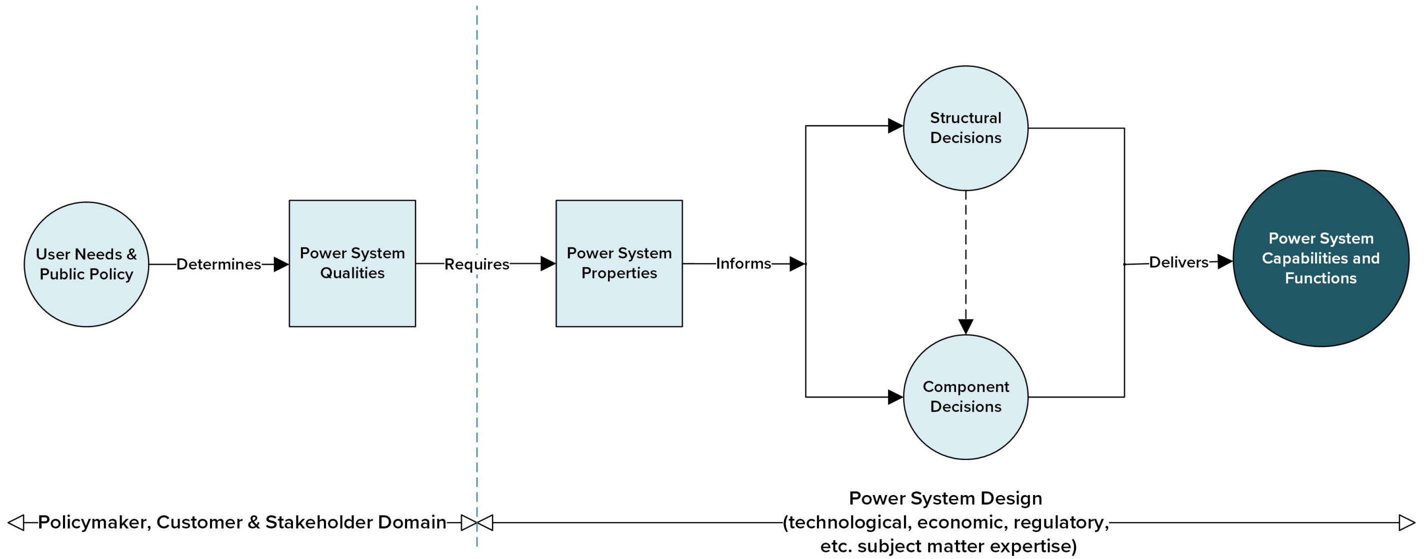
| Research Questions | Research Activities / Example Focus Areas |
|---|---|
| **Constraints Analysis** | |
| 1. What structural constraints are revealed when the four functional layers and E-R mapping is overlaid?<br>2. What structural constraints are to be considered firm in the remainder of this project? | **Composite E-R & Functional Layer Mapping**<br>A final step in this first phase is to overlay and evaluate both the E-R and individual functional layer mapping to:<br>a) Identify and correct inaccuracies;<br>b) Analyse specific structural constraints that are revealed; and,<br>c) Identify structural changes that can result in relief of these constraints.    |

| PHASE 2b: Contemporary Issues and Directions Report | |
|---|---|
| **Research Questions** | **Research Activities / Focus Areas** |
| **Australia-specific Questions** | |
| 1. In the Australian context, which architectural models may have particular advantages? | What architectural models can be empirically demonstrated to provide:<br>a) Sufficient scalability to accommodate the number of end-points that the power system of 2035 and 2050 will plausibly need to manage and coordinate?<br>b) The most resilient and efficient structure for managing a power system operating with between 75% and 100% wind and solar penetration?<br>c) The structure that best enables transition from one structure or model at modest levels of DER to one more suitable for very high levels of DER when that is required.<br>d) Superior outcomes in terms of cyber-security and interoperability characteristics which are both impacted by data flow structures which depends on an architecture's coordination framework. |
| 2. What critical insights may be derived using architectural analysis that are not readily available through current trials? | What insights may be derived using architectural analysis that would not be available under trial conditions alone for the following:<br>a) Assessment of the capacity and scalability of market models including the Hybrid and Two-Step-Tier models? This would include but not be limited to market/aggregator/local control latency, computational capacity, operational coordination functions and associated data flows when deployed at scale (i.e. beyond trial conditions).<br>b) Assessment of the veracity and inherent limits of different approaches to calculating and propagating Dynamic Operating Envelopes? This would include but not be limited to understanding the limits of the approach with respect to stability including the possibility of chaotic behavior, bifurcations into wild instability, oscillations, and so forth when deployed at scale (i.e. beyond trial conditions).<br>c) Modeling and simulation at scale should also be used to help assess the above matters to identify potential issues that may occur at full scale deployment. |

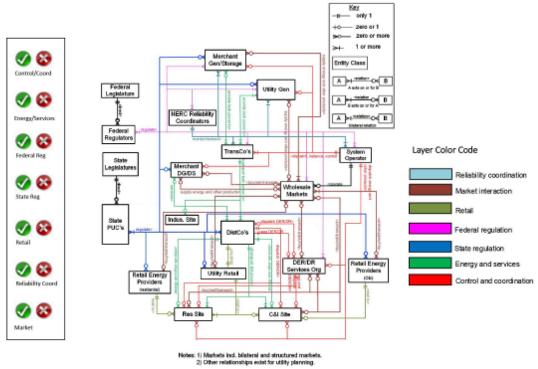
| Research Questions | Research Activities / Focus Areas |
|---|---|
| | For example, GridLAB-D would support scaled up modeling and simulation of distribution systems and used with co-simulation tools, can be coordinated with market simulations or other bulk-power system simulations to provide a large-scale result. |
| **Australia-specific Questions (Cont')** | |
| 3. What critical insights may be derived using architectural analysis concerning Transmission-Distribution interface design? | With regard to Transmission-Distribution Interface design:<br>a) What insights may be derived using architectural analysis of T-D Interface design characteristics relevant to market models including the Hybrid and Two-Step-Tier models?<br>b) What quantification tools can be applied to assess what and how limitations should be coordinated across Transmission-Distribution interface?<br>c) Would the SmartNet simulator provide a useful tool for comparing benefits of coordination schemes approaches in Australia? |
| 4. What critical insights may be derived using architectural analysis concerning the operational coordination of DER? | Employing architectural analysis, what insights might be gained concerning the operational coordination of DER, particularly what functions are best coordinated:<br>a) By controls vs financial incentives; and,<br>b) By tariffs vs market platforms.<br>c) Consideration of potential combinations of the above approaches |

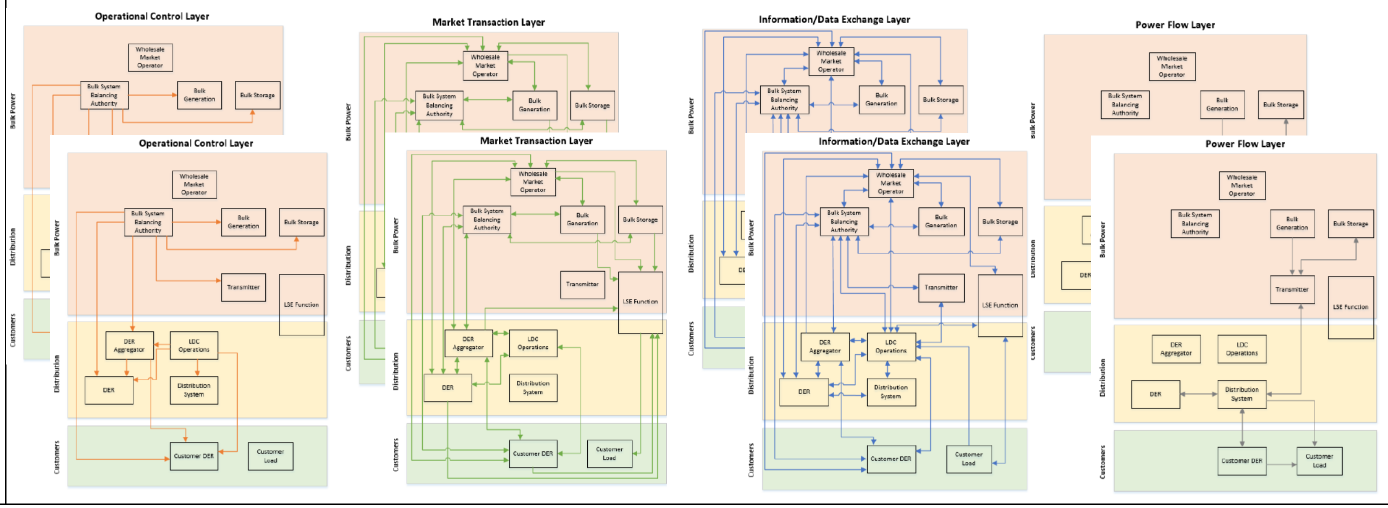
| Research Questions | Research Activities / Focus Areas |
|---|---|
| 5. What critical insights may be derived using architectural analysis concerning alternative approaches to DOE generation? | Recent work has proposed state estimation techniques and constraint engines to define operating envelopes. What insights may be derived using architectural analysis concerning:<br>a) Likely implementation challenges with these approaches, including, transparency and verifiability to and by other actors in the system?<br>b) Alternate approaches based on subsidiated real-time measurement and open processes? |
| 6. What critical insights may be derive using architectural analysis concerning DER control strategies? | a) How might architectural principles inform how communications may be best structured to manage data volume and routing from DER from edge devices to all relevant parties?<br>b) How might architectural considerations of scalability, subsidiarity, latency cascading, tier bypassing, and hidden coupling (partial knowledge) help mitigate against costly yet brittle implementations? |

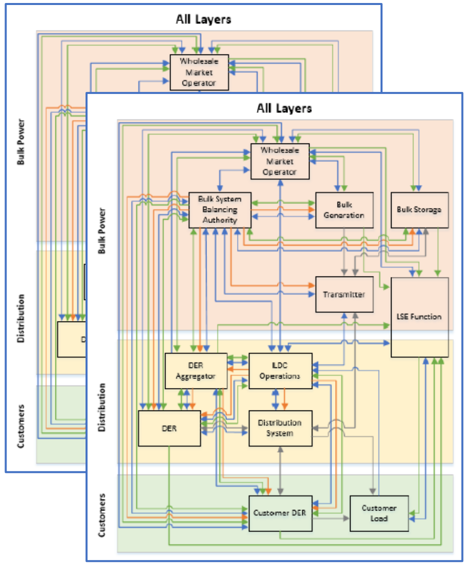
| PHASE 3: Explore Future System Qualities, Properties & Functions | |
|---|---|
| **Research Questions** | **Research Activities / Focus Areas** |
| **Future System Qualities** | |
| Informed by the Future System Objectives identified in Phase 2a:<br>1. What are the key System Qualities desired by a representative sample of policy makers, end-users and relevant stakeholders?<br>2. What are the weightings assigned to the System Qualities? | System Qualities are the high-level, desired characteristics of the entire power system from the industry 'outsider' perspective of policy makers, end-users and relevant stakeholders and phrased in solution-agnostic terms. Some examples may include affordability, autonomy, customisation, optionality, predictability, reliability, safety, simplicity and sustainability.<br>Generally, the number of System Qualities selected for a power system should be small, ideally weighted by priority and as a set of qualities, sufficiently comprehensive in nature. In the architecting process, it is helpful to distinguish the System Qualities from the System Properties to assist with more precise cause-and-effect reasoning and enable de-scoping where necessary. |

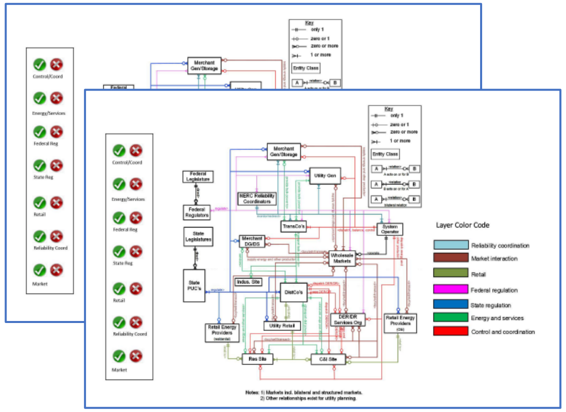


<table>
<tr><th>Research Questions</th><th>Research Activities / Focus Areas</th></tr>
<tr><td colspan="2">Future System Properties</td></tr>
<tr><td>Informed by the System Qualities above:<br>1. What System Properties are required to enable the System Qualities?<br>2. What are the relationships between System Qualities and System Properties (i.e. requires mapping)?<br>3. What are the weightings assigned to the System Properties?</td><td>System Properties are the high-level range of characteristics of the entire power system from the industry ‘insider’ perspective of power system architects, developers and operators, and phrased in solution-agnostic terms. Some examples may include adaptability, configurability, efficiency, extensibility, flexibility, interoperability, resiliency, scalability, stability and traceability.<br><br>In the architecting process, the necessary System Properties are directly informed by the shortlist of System Qualities desired by policy makers, end-users and relevant stakeholders. The System Properties themselves then inform the structural and component decisions that constitute the system and ultimately enable delivery of the required System Functions.</td></tr>
<tr><td colspan="2">Future System Functions</td></tr>
<tr><td>Informed by above System Properties:<br>1. What System Functions are required to enable the System Properties?<br>2. What are the relationships between System Properties and the System Functions (i.e. requires mapping)?</td><td>System Functions are the specific and detailed capabilities, processes, behaviours and operational results of the power system that fulfil key requirements. Following are random examples of System Functions only:<br>(a) Forecast energy resources at all voltage levels;<br>(b) Identify constraints and plan for credible events;<br>(c) Generate and issue dynamic operating envelopes;<br>(d) Provide a spot market for inertia;<br>(e) Enable customers multiple trading relationships;<br>(f) Procure network services through a local market;<br>(g) Manage microgrid islanding and grid-synchronisation;<br>(h) Provide peer-to-peer energy trading.<br><br>In the architecting process, System Functions emerge as the product of the structural and component decisions made. These are in turn informed by the System Properties and System Qualities decisions.</td></tr>
</table>

| PHASE 4: Develop Future Architectural Options | |
|---|---|
| **Research Questions** | **Research Activities / Focus Areas** |
| **Future Industry Structure Analysis** | |
| Informed by the Future System Quality, Property & Function analysis above:<br>1. What are plausible alternative entity relationships and interfaces across the following?<br>a) Control and dispatch interfaces;<br>b) Energy and ancillary services interfaces;<br>c) Regulatory interfaces;<br>d) Markets and transaction interfaces; and,<br>e) Retail interfaces. | **Future Entity-Relationship (E-R) Mapping**<br>Engage with relevant stakeholders to develop 2 – 4 x alternative Entity-Relationship maps. This is meant to be a creative and expansive process that provides optionality and is not looking to select any one at this point. Conducted through iterative loops, it will provide stakeholders with new perspective on the alternative models for:<br>a) Control and dispatch relationships / interfaces;<br>b) Energy and ancillary services relationships / interfaces;<br>c) Regulatory relationships / interfaces;<br>d) Markets and transaction relationships / interfaces; and,<br>e) Retail relationships / interfaces.<br><br>While the E-R Diagrams will be developed by the project team, the activity requires very significant engagement, workshopping, and content iteration with diverse stakeholders to ensure comprehensive and accurate mapping. Due to the complexity involved, the E-R Diagrams will be developed with multilayered modelling that allows individual layers to be hidden or revealed. This supports structural analysis by providing different views on both individual layers and how various relationship layers interrelate. |

| Research Questions | Research Activities / Example Focus Areas |
|---|---|
| **Future Functional Layer Analysis** | |
| Informed by the Future System Quality, Property & Function analysis above:<br>1. What are plausible alternative functional layer configurations across the following?<br>a) Operational Control Layer;<br>b) Market Transaction Layer;<br>c) Information/Data Exchange Layer; and,<br>d) Power Flow Layer. | **Future Individual Functional Layers**<br>Engage with relevant stakeholders to develop 2 – 4 x alternative configurations for the following.<br>a) Operational Control Layer;<br>b) Market Transaction Layer;<br>c) Information/Data Exchange Layer; and,<br>d) Power Flow Layer.<br> |

<table>
<tr><th>Research Questions</th><th>Research Activities / Example Focus Areas</th></tr>
<tr><td colspan="2">Constraints Analysis</td></tr>
<tr><td>Informed by the above:<br><br>1. What structural constraints are revealed when the 2- 4 Composite Structures are analysed?</td><td>Composite E-R & Functional Layer Mapping<br><br>A final step is to overlay and evaluate the 2 – 4 alternative configurations of the E-R and individual functional layer mapping to:<br><br>a) Identify and correct inaccuracies;<br><br>b) Analyse specific structural constraints that are revealed; and,<br><br>c) Identify structural changes that can result in relief of these constraints.<br><br>


</td></tr>
</table>

| PHASE 5: Future Options & Transition Pathways | |
|---|---|
| **Research Questions** | **Research Activities / Focus Areas** |
| **Operational Effectiveness/Risks** | |
| Evaluating the 2 – 4 composite options:<br>1. What are the operational effectiveness issues and risks relevant to each of the options?<br>2. What other issues should be considered, including:<br>o Future-resilience;<br>o Operational resilience<br>o Cyber-security | a) Assess Structures based on Architectural Considerations<br>b) Clarify & Assess Role Assignments<br>o Responsibility/role matching<br>o Assignments cannot just be arbitrary<br>c) Identify & Assess Control Paths<br>o Physical Controls<br>o Economic Signals<br>d) Competing or conflicting objectives<br>o For example, Local independent optimization vs. global coordination<br>e) Identify & Assess Information Flows<br>o Gaps<br>o Feedback loops<br>o Latencies<br>f) Transition Pathway Mapping<br>o Roadmap development<br>o Critical Path identification |

PART C

# Survey of Architecture Methodologies & Relevant Projects

## Australian Project Scan

The Action Research Plan has been informed by a range of projects and initiatives in the United States, the United Kingdom and Australia. A key aim was to review a wide range of initiatives to identify and recommend an integrated and adaptive combination of methodologies and activities suitable for application in Australia.

The following section provides a detailed analysis of a range of projects and initiatives underway or recently completed in Australia that have relevance to the above objective.

| Australian Projects and Initiatives | | |
|---|---|---|
| **Project / Initiative** | **Sponsoring Organisations** | **Type** |
| **AEMO Activities** | | |
| NEM Engineering Framework | AEMO | Industry Collaboration |
| Integrated System Plan 2020 / 2022 | AEMO | Biennial Report |
| Coordination of DERs; Architecture Insights for Future Market Design | AEMO | Report |
| Minimum Operational Demand Thresholds in South Australia | AEMO | Report |
| AEMO VPP Trials | AEMO | Trials |
| **Research & Demonstration** | | |
| Indra Monash Smart Energy City | Monash University | Trial and Reports |
| Project EDGE | AEMO, Ausnet, Mondo | Trial |
| Dynamic Operating Envelopes Research | ANU | Research |
| State of DER Technology Integration | ARENA, FarrierSwier | Report |
| South Australian VPP Trial | Tesla, SAPN | Trial |
| **Government Activities** | | |
| Post-2025 Market Design Project | Energy Security Board | Government Reform Initiative |
| WA Energy Transformation | WA Government | Government Reform Initiative |

| Other | | |
|---|---|---|
| OpEN Energy Networks project | Energy Networks Australia, AEMO | Industry Collaboration |
| Interoperability Steering Committee | DEIP | Committee |
| Dynamic Limits project | Dynamic Limits, ARENA | Report and Modelling |

| Project / Initiative Details | |
|---|---|
| **Name** | NEM Engineering Framework |
| **Lead Organisation** | AEMO |
| **Partner Organisations** | Significant industry engagement |
| **Budget** | Unknown |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

AEMO's Renewable Integration Study (RIS) Stage 1 report, and the AEMC's System Services Consultation Paper called for a more holistic engineering framework – a map to help all stakeholders stay informed and to structure industry discussions around the prioritisation of future work, so the most urgent issues are addressed first.

The NEM Engineering Frameworks seeks to provide this whole of system framework, based on the technical needs of the system, so together we can prioritise actions that support the interests of consumers, participants, and investors during this rapid re-engineering of the power system.

The framework will explore the range of plausible future NEM operating scenarios, and the sequence of preparatory actions that would be needed for each. It will focus on what is needed to support the changing system over a rolling three- to four-year window and seek to bridge the gap between today's urgent operational needs and the longer-term decision-making covered by the Integrated System Plan (ISP).

The 10 focus areas are spread across three broad themes:

- Attributes are the fundamental technical elements of power system operation that are needed to ensure reliability and security
    - Resource Adequacy
    - Frequency Management
    - Voltage Control
    - System Strength
    - System Restoration
- Operability is the ability to manage the power system within security and reliability standards. It includes the data, tools, training, analytical capability and market mechanisms to support operation.
    - Control Room and Support
    - System Analysis

- Integration is the process of adapting both the existing system and the innovative ways in which parties are interacting with the power system, so the system will continue to meet consumer expectations.
    - Resilience
    - Performance Standards
    - Distributed Energy Resources

In summary, the framework is being developed to:

1. Help stakeholders stay informed of the changing needs of the power system and the current work underway to meet these needs
2. Provide transparency on emerging priorities for technical, regulatory, and market reforms to support these changing system needs
3. Identify where technical analysis and insights are needed to support current and emerging reform processes and where AEMO has prioritised technical projects to support the changing system
4. Show how all these moving pieces fit together, and how stakeholders can engage on a variety of topics

**Key Objectives**

- Facilitate a discussion to identify possible future operational conditions for the NEM power system
- Consolidate a common view of the current work underway across industry to adapt the power system and existing avenues for engagement
- Collaborate on identifying where increased industry focus is needed to bridge the gap between current work and future operational conditions

**Key Deliverables**

- December 2020: Information pack published
- February 2021: Industry virtual workshop
- March 2021: Engineering Framework: March 2021 report
- April 2021: Open online discussion session
- April-June 2021: Targeted stakeholder discussions
- From June 2021: Periodic open forums
- Second half 2021: Engineering Framework: Update report
- December 2021: Engineering Framework – Interim Roadmap

| How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements. | |
|---|---|
| **Power System Architecture** | The framework's ten focus areas are broadly similar to the UK's Future Power System Architecture suite of 35 functions. The resilience focus areas under the integration theme mentions the importance of interactions between sectors and the need for 'whole-of-system' coordination and planning, from energy to end use sectors, such as building, transport and industry – also referred to as "societal integration", though no reference to architecture. Likewise, performance standards identify architectural principles, such as expanding range of actors in the system, need for interoperability, operational complexity and increasing data flows and computation requirements. DER integration acknowledges the need for optimized consumer participation, a larger and more diverse supply mix with complex interactions and the need for greater coordination. All the above are relevant to the problem domain that power system architecture addresses. |
| **Regulatory Innovation** | Not considered. |
| **Market innovation** | Not considered. |
| **T-D Interface** | Not considered. |
| **DER Control Architecture innovation** | A sequence of steps is proposed for better integrating DER integration with the broader power system. These are high-level enablers and do not delve into specific control schemes. For example, data and information that enables DER visibility and predictability for informed consumer, planning and operational decisions is acknowledged. |
| **Roles & Responsibilities** | The NEM Engineering Framework outlines roles and responsibilities in relation to other ongoing industry processes and the development of the framework. AEMO is looking for stakeholder input on roles and responsibilities as they relate to priority actions to support future operational conditions. |
| **Architectural Methodologies / Models applied in the design of the Project / Initiative** | |
| None used. | |
| **Key Reference Documents** | |
| 2020-12 Introductory Pack,<br>2021-03 NEM Engineering Framework March 2021 Report | |

| Project / Initiative Details | |
|---|---|
| **Name** | 2020 Integrated System Plan (ISP) |
| **Lead Organisation** | AEMO |
| **Partner Organisations** | None |
| **Budget** | Unknown |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

AEMO publishes the Integrated System Plan (ISP) pursuant to its functions under section 49(2) of the National Electricity Law (which defines AEMO's functions as National Transmission Planner) and its broader functions under the National Electricity Rules to maintain and improve power system security.

The ISP is a whole-of-system plan to maximise net market benefits and deliver low-cost, secure and reliable energy through a complex and comprehensive range of plausible energy futures. It identifies the optimal development path for the National Electricity Market (NEM), consisting of ISP projects and development opportunities, as well as necessary regulatory and market reforms.

AEMO developed the ISP using cost-benefit analysis, least-regret scenario modelling and detailed engineering analysis, covering five scenarios, four discrete market event sensitivities and two additional sensitivities with materially different inputs.

This analysis identified the least system cost investments needed for Australia's future energy system. These are distributed energy resources (DER), variable renewable energy (VRE), supporting dispatchable resources and power system services. Significant market and regulatory reforms will be needed to bring the right resources into the system in a timely fashion.

The analysis also identified targeted augmentations of the NEM transmission grid and considered sets of investments that together with the non-grid developments could be considered candidate development paths for the ISP. The combined supply and network investments proposed in the 2020 ISP are expected to deliver $11 billion in net benefits to the National Electricity Market (NEM).

**Key Objectives**

The ISP guiding objective is to meet power system needs while optimising net market benefits. Its planning horizon is the next two decades, to 2040.

The ISP aims to:

- widely consult on ISP assumptions, scenarios and sensitivities that span all plausible operating environments.
- efficiently achieve power system needs through transformational change, in the long-term interests of the consumers of electricity.
- serve the regulatory purpose of identifying actionable and future ISP projects, as well as the broader purposes of informing market participants, investors, policy decision makers and consumers.

| **Key Deliverables** | |
|---|---|
| The key deliverables are covered under five parts:<br>• A dynamic, whole-of-system roadmap<br>• Deep consultation and modelling for the ISP<br>• ISP development opportunities for an optimal energy system<br>• Network investments for an optimal energy system<br>• The optimal development path | |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
| **Power System Architecture** | The consultation process resulted in the Forecasting and Planning Scenarios, Inputs and Assumptions Report (August 2019) which provided the inputs for the modelling.<br>The following are features of the future state under which the PSA is forest to operate:<br>• Distributed energy generation capacity is expected to double or even triple.<br>• Over 26 GW of new grid-scale renewables is needed<br>• 6-19 GW of new dispatchable resources are needed in support.<br>• Power system services are critical to the secure operation of the power system<br>The ISP provides cost benefit analysis, scenario and sensitivity modelling to identify strategic projects which have a high likelihood of supporting additional renewable generation and grid resilience under a variety of future environments. In its role as a National Transmission Planner, the AEMO foresees the need for the following types of network investments to achieve the above outcomes:<br>• Transmission interconnectors (including Marinus HVDC link)<br>• Efficiently located Renewable Energy Zones (incorporating storage)<br>• Utility-scale pumped hydro (Snowy 2.0), large-scale battery energy storage systems, new flexible gas generators, distributed batteries, VPP and other demand side participation (DSP).<br>The recommendations of the ISP are likely to be important and highly influential upon the future state of the NEM and therefore the inputs, scenarios, future state, markets and investment measures contemplated should be accommodated within the selected grid architecture model.<br>The ISP also provides guidance as to the capability gaps which exist in the current market. |

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| **Regulatory Innovation** | The ISP doesn’t contain recommendation for regulatory change however notes that regulatory support will be crucial to encourage investment in supporting technology (e.g. power system services to provide system inertia and replace dispatchable generation).<br><br>The ISP roadmap considers in each of its scenarios the effect Government regulation and policy (e.g. RE targets, DER and EV incentives) may have on a variety of inputs and its impact on the future operating environment. |
| **Market innovation** | The ISP does not propose changes or development of market but refers to other projects whose focus is upon development of markets (e.g. Open Energy Networks, DER Integration Market Design Initiative, Wholesale Demand Response rule changes).<br><br>The ISP notes the importance of innovation leading to changes in market design in wholesale energy and supporting the evolution of consumer DER markets:<br><br>• Market design is crucial for both regulated and private investment to deliver the least-cost outcome for consumers. Without adequate changes to market design, currently being considered by the Energy Security Board (ESB), it is unlikely that the existing market mechanisms will deliver the optimal outcomes reported here. Without improved markets, consumers will ultimately have to pay higher prices for these sub- optimal outcomes.<br>• Market design needs to reward the increasing value of flexibility and dispatchability in complementing and firming variable generation.<br>• Assuming effective market design, $11 billion in net market benefits would be available to consumers through reduced power bills.<br><br>The report supports the hypothesis that market innovation will be an important enabler of the ISP key objectives and the Market layer will need to be integrally connected to lower layers of PSA (Power Topology, Data & Information, Control and Coordination). |
| **T-D Interface** | The ISP refers to the Open Energy Networks project which considers different frameworks for the monitoring and control of DER. The ISP does not make specific recommendations. |
| **DER Control Architecture innovation** | Not considered. |
| **Roles & Responsibilities** | Not considered. |

| Architectural Methodologies / Models applied in the design of the Project / Initiative |
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| The ISP seeks to achieve its NEO objective by identifying a portfolio of least risk bulk transmission network investment and supporting generation services. Implicit in this methodology is an assumption that all other inputs and components are not controlled or directly influenced. Under this planning method, distribution investment and DER are not modelled as controllable inputs but through environmental scenarios and sensitivities.<br><br>This method can be characterized as identifying future state(s) which are largely driven by political, environmental and macro-economic factors. The enabling of future state plans for transmission and system level projects largely assumes independent transmission and distribution investment processes. |
| **Key Reference Documents** |
| 2020-07 AEMO - 2020 Integrated System Plan.pdf |

| Project / Initiative Details | |
|---|---|
| **Name** | Coordination of DERs; International System Architecture Insights for Future Market Design |
| **Lead Organisation** | AEMO |
| **Partner Organisations** | Newport Consulting; Strategen Consulting; Energeia; Hawaiian Electric |
| **Budget** | Unknown |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

In 2018, AEMO commissioned an expert report that summarises the international experiences and provides analysis to assist AEMO in exploring future system architectures for the orchestration of DER.

Effective integration of large scale DER into the power system as well as utilization of DER services for wholesale markets and distribution network services will require operational and market coordination between AEMO and distribution network operators. This involves developing effective system architecture, including market designs, and operational structures (including controls) to execute DER coordination reliably, otherwise customer value may be negatively impacted. This analysis raises the need for early identification and action of long-lead time matters and the potential need for interim measures to be implemented by AEMO under the current regulatory regime.

To this end, this report developed by the Newport Consortium of leading experts on DER coordination architectures summarises international experiences to-date and employs comparative analysis to assist AEMO in exploring options for future system architectures for the coordination of DER.

**Key Objectives**

- The report outlines architectural approaches that are being explored by international jurisdictions to coordinate high penetrations of high DER across Transmission and Distribution levels of electricity systems.
- An assessment of the identified coordination architectures is provided including assessment summary level identification of potential issues and considerations, including potential bottlenecks, distribution operational bypasses, scalability, information flow paths, roles and responsibilities, and other issues that become apparent from examination of the architecture.

**Key Report Findings:**

- There is general acknowledgement across jurisdictions of the need for distribution-transmission coordination, rather than purely transmission level coordination. This is due to existing or anticipated scale of DER integration and utilisation in wholesale markets and/or for distribution network services and the potential for uncoordinated operational impacts at either distribution or transmission.

- There is growing international recognition of the role of System Architecture in the design considerations for DER participation in wholesale and/or distributed markets. Of particular focus is on addressing issues such as observability, tier bypassing and hidden coupling along with the potential to address these issues through layered decomposition.

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| <ul><li>At the time of publication, none of the leading international efforts had progressed to detailed design or implementation of DER coordination architectures including dispatch optimisation and the specific roles and responsibilities of a DSO were still being evaluated.</li></ul>Based on the Newport Consortium's key findings, it reached the following conclusions of relevance to Australia's DER coordination efforts:<ul><li>DER coordination will need to involve distributor network operators as key actors in both operational information and control architectures irrespective of whether they become DSOs. From a wholesale market perspective, this could be analogous to the TSO-TO roles and responsibilities in several international locations. Failure to address this need will inherently lead to more issues around transmission and distribution conflicts and worse system and network security or economic outcomes.</li><li>Aside from wholesale market participation considerations, there is an issue of what role the DO plays regarding distribution network services.</li><li>If any future architecture involves a DSO type role and set of responsibilities, as currently envisioned internationally, the question arises as to whether an independent DSO is needed. At the time of publication, this was an unresolved issue under active discussion in the UK, Europe, and the United States (nationally).</li><li>Key elements for a best practice DER coordination architecture include:<ul><li>Developing clear objectives and identifying required capabilities for the TSO and DO.</li><li>Development of a DER coordination architecture, including identifying and defining the roles and responsibilities for TSO, DO, and DER aggregators</li><li>Wholesale – distribution network services markets coordination, and operational information and control architectures</li><li>DER connection, registration, and measurement requirements and communication protocols</li><li>Coordinated demonstrations to test and verify implementation of architectural elements described above and address industry knowledge gaps</li><li>Cost-effectiveness assessments to evaluate the net benefit of various options for customers, society, or other specific objectives</li></ul></li></ul> | |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
| **Power System Architecture** | Identifies both need for expanded role of DNSP to DSO and need for increased coordination between Transmission System Operators (TSOs) and Distribution Operators (DOs or DSOs). A Reference Architectural Framework is outlined in the report.<br><br>In outlining the spectrum of Conceptual Models of DER coordination the Report notes that it is unlikely that either a full conceptual Total TSO or Total DSO would be employed in any location. Rather future architectures will likely be a variation of the Hybrid model oriented to be either more TSO-centric or DSO-centric in terms of primary DER coordination responsibility. |

Newport Consortium - International Review of DER Coordination
**31 May 2018 • Report for AEMO**

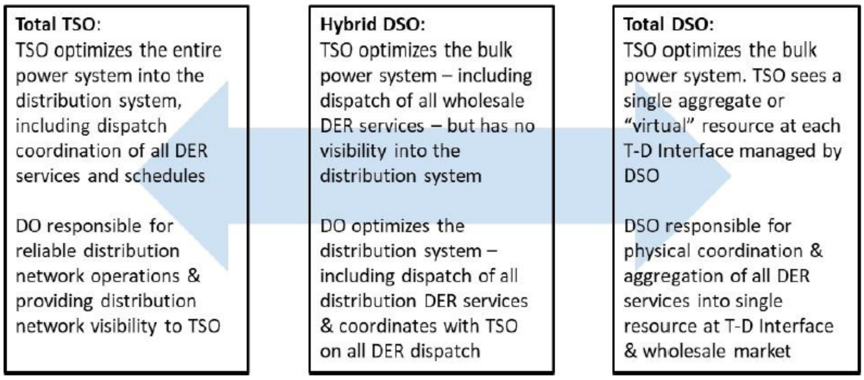


*Figure ES - 1 Spectrum of Conceptual Models of DER Coordination*

The report notes that several future approaches under discussion internationally are based on the Hybrid DSO model and would seem to be attempts to 'have it both ways'. However, the report notes, that this introduces additional complexity in both power system coordination structures and roles and responsibilities. While this may be manageable at lower levels of DER, market and network services participation but increasingly experience scalability issues as DER participation grows.

Therefore, the report authors anticipate that while some initiatives may begin with an Hybrid DSO type approach, it is likely they will ultimately need to evolve toward either a Total TSO centralised structure or a more layered Total DSO structure. This evolution will depend on if and how the hybrid structural coordination challenges involving market coordination, information flows, and controls can be satisfactorily resolved.

The Report outlines Key Coordination Architecture Principles:

- Layered decomposition solves large-scale optimization problems by decomposing the problem multiple times into sub-problems that work in combination to solve the original problem.
- Avoiding Tier bypassing: Creation of information flow or instruction /dispatch /control paths that skip around a tier of the power system hierarchy, thus opening the possibility for creating operational problems. To be avoided.
- Avoiding Hidden Coupling: Two or more controls with partial views of grid state operating separately according to individual goals and constraints to be avoided. Such as simultaneous, but conflicting signals from both the DO and TO.
- Managing Cascading latency issues: The arrangement for connecting DER via a DER supplier and then an aggregator to get to the DSO introduces the possibility of some cascading latency issues. Because of the layering and use of the DSO approach, scalability is good and cyber vulnerability of the bulk energy system due to DER connectivity is small.

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| | • **Observability:** Function related to operational visibility of the distribution network and integrated DER. Sufficient sensing and data collection can help to assemble an adequate view of system behaviour for control and grid management purposes, thus providing desirable snapshots of grid state. The data can also be utilized to validate planning models.<br>• **Scalability:** Ability of system's processes and technology design to work well for very large quantities of DER resources. Coordination architecture can enhance or detract from this desired capability.<br>• **Cyber security vulnerability:** While this topic has many dimensions, the principle here is to reduce cyber vulnerability through architectural structure. Structure can expose bulk energy systems to more or less vulnerability depending on data flow structure, which depends on coordination framework. To be minimized. |
| **Regulatory Innovation** | Not considered. |
| **Market innovation** | Not considered. |
| **T-D Interface** | An important architectural issue is the need to coordinate and optimise significant amounts of DER for participation in both wholesale markets and distribution network services, while simultaneously respecting/mitigating transmission and distribution level constraints. |
| **DER Control Architecture innovation** | In the near-term, jurisdictions are responding to distribution level constraints via connection standards limiting exports, or market rules limiting aggregation to nodes, i.e. distribution connection points, where connection policies ensure constraints will not arise.<br>Markets are considering both maximum and minimum thresholds for DER aggregation. Maximum size for a single aggregator is considered as potential mitigation to address market power and/or non-performance beyond the existing prudential requirements to participate in the wholesale market or provision of distribution network services. Also, several markets have been lowering the minimum DER participation level for wholesale markets, which is trending towards 100 kW to increase the number of DER that may participate directly (100kW or greater) or through aggregations of at least 100kW. |
| **Roles & Responsibilities** | The Report provides a description of how different international jurisdictions are approaching Roles and Responsibilities for coordination of DERs and provides a comparative analysis of how different approaches might related to Australia grid transformation.<br>Unavoidable choices about longer-term centralised or layered structures is an early architectural decision that has a profound impact on many downstream decisions relating to Roles & Responsibilities. |

| Architectural Methodologies / Models applied in the design of the Project / Initiative |
| --- |
| The architectural analyses in this report was undertaken by examining structural diagrams identified in documentation gathered or conceptually developed for each assessed location. These diagrams and related documentation were assessed to identify potential issues and considerations, including potential bottlenecks, loops, bypasses, feedbacks, scalability, intended and unintended information flow paths, role/responsibility match or mismatch, and other issues that become apparent from examination of the structure and/or descriptions. The report outlines a discussion of the coordination architecture is provided for each location as well as a comparative discussion.<br><br>Coordination diagrams are diagrams that derive from industry structure, control structure, and market functions like dispatch. Each diagram shows the relevant entities (derived from industry structure definition). Lines of operational coordination flow connect the boxes representing entity classes. Operational flows involve all the relevant information needed to coordinate the market functions and network operational functions typically in real time (T) up to T minus 45 (T-45) days for certain operational engineering and maintenance coordination activities. Flow may be unidirectional or bi-directional, depending on the nature of the coordination relationship.<br><br>Many aspects of this work align with the Grid Architecture methodology developed under the Grid Modernization Laboratory Consortia (GMLC) sponsored by the US Department of Energy. |
| **Key Reference Documents** |
| May 2018. Coordination of DERs; International System Architecture Insights for Future Market Design<br><br>https://www.aemo.com.au/-/media/Files/Electricity/NEM/DER/2019/OEN/Newport-Intl-Review-of-DER-Coordination-for-AEMO-final-report.pdf |

| Project / Initiative Details | |
|---|---|
| **Name** | Minimum operational demand thresholds in South Australia |
| **Lead Organisation** | AEMO |
| **Partner Organisations** | SA Government, SAPN |
| **Budget** | Unknown |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

The Government of South Australia has requested advice from AEMO on the risks of electricity supply disruption associated with reducing minimum operational demand levels in South Australia's network, which is contained within this technical report.  This technical report presents findings to date, covering the development of new dynamic models that capture the behaviour of load and distributed PV during system disturbances, and initial analysis of impacts on power system security. Dispatch studies were also undertaken to explore the minimum load required for operation of South Australia in an islanded operational state.

**Key Objectives**

Provide the Government of South Australia with advice on minimum demand operating thresholds that the South Australian network can operate at in a secure and reliable state, and potential conditions that, when coupled with minimum demand, would put South Australia at a risk of the supply of electricity being disrupted to all or part of the South Australian community.

**Key Deliverables**

- Technical Report on Minimum Demand Thresholds

| How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements. | |
|---|---|
| **Power System Architecture** | Architectural changes are not considered in detail. The implementation time horizons for recommended mitigation for system security challenges are Spring 2020 and 2020 to 2023. |
| **Regulatory Innovation** | SAPN explored introducing flexible export capability as part of their regulatory determination for 2020-2025, with implementation expected in 2023. |
| **Market innovation** | No considered. |
| **T-D Interface** | The technical report notes that "enduring policy framework for successful integration of DER" are required. The Markets and Frameworks workstream is developing a two-way energy market, the concept for which was developed in consultation with DNSPs through an initiative called Open Energy Networks. This aims towards a future market and power system where distributed assets participate actively. |

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| **DER Control Architecture innovation** | As solving for minimum demand is primarily in view, the need for control architecture is noted for active management and curtailment of distribution system connected distributed. Demand-response market mechanism is proposed to encourage customer load, but specific architectural mechanism is unclear. |
| **Roles & Responsibilities** | Refers to ongoing trials and demonstrations projects as the next step in determining future roles in a two-way energy market. |
| **Architectural Methodologies / Models applied in the design of the Project / Initiative** | |
| None used. | |
| **Key Reference Documents** | |
| 2020-05 AEMO - Minimum Operational Demand Thresholds in South Australia | |

| Project / Initiative Details | |
|---|---|
| **Name** | AEMO Virtual Power Plant Demonstrations |
| **Lead Organisation** | AEMO |
| **Partner Organisations** | ARENA<br>Intelia Pty Ltd<br>The Customer Experience Specialists |
| **Budget** | ARENA funding $2.46M, total project cost unknown |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

The VPP Demonstrations explore the capability of aggregated DER to deliver contingency FCAS and develop AEMO's understanding of how VPPs respond to energy market price signals. It is anticipated that coordinating DER through VPPs can benefit both:

- Consumers owning VPP assets who earn value from delivering grid services, such as reliability and emergency reserve trader (RERT), FCAS, or energy. The value received by consumers depends on the business model offered to them by VPP operators.
- All other electricity consumers who benefit from a more efficient power system, as more resources respond to market price signals rather than operating independently.

The project will operate over 18 months (unless extended) and is co-funded by ARENA. VPP participants who can provide DER FCAS services (dispatchable generation and controllable load) were invited to join the trial. Seven VPP participants were reported in the third Knowledge Sharing Report and the AEMO has since announced trial participation is now capped.

Participants can register in the trial either directly as Market Ancillary Service Providers (MASP) or via their Retailer as Market Customers and are required to provide operational and availability data for their VPP and individual sites or DER directly to AEMO. Operational data is provided in five-minute intervals with high resolution sampling required for frequency and power measurement. Control and monitoring data is exchanged via an API interface developed for the trial. The trial is technology neutral and can accommodate storage and loads with variable or switchable control. Participants are rewarded through market payments (either directly or via their FRMP) for provision of FCAS.

**Key Objectives**

- Understand whether VPPs can reliably control and coordinate a portfolio of resources to stack value streams relating to FCAS, energy, and possible network support services.
- Develop systems that provide AEMO with operational visibility of VPPs to understand their impact on power system security, local power quality, and how they interact with the market.
- Assess current regulatory arrangements affecting participation of VPPs in energy and FCAS markets, and inform new or amended arrangements where appropriate.
- Provide insights on how to improve consumers' experience of VPPs in future.
- Understand what cyber security measures VPPs currently implement, and whether VPP cyber security capabilities should be augmented in future.

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| **Key Deliverables**<br>The key deliverables are to publish Knowledge Sharing Reports (three available at time of writing) and Consumer insights Reports (one available at time of writing) across the following topic areas:<br>• VPP capability for market participation<br>• Operational visibility<br>• Market dynamics and planning<br>• Local power quality<br>• Consumer insights<br>• Cyber security | |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
| **Power System Architecture** | Not considered. |
| **Regulatory Innovation** | As a precursor to the VPP demonstration, AEMO submitted the interim Rule Change Proposal *Integrating Energy Storage Systems into the NEM* to expedite the participation of DER in FCAS markets in the National Electricity Market (NEM) in the short term. It sets out AEMO's approach to approving the classification of a load which has DER behind the connection point as an ancillary services load under the current National Electricity Rules (NER) and Market Ancillary Services Specifications (MASS). Future adoption of this rule would enable the mass participation of DER (storage, EVs, and controllable loads) to provide FCAS and in doing so provide additional value stream for DER owners. |
| **Market innovation** | The VPP trial has demonstrated significant effects which are beneficial to the market:<br>• Storage systems are also responding to energy prices by changing behaviour from self-consumption only (FCAS participation is autonomous)<br>• If extrapolated out, charging of a very large VPP to very low or negative energy prices could lessen the duration of the negative spot price period, as well as lessen the magnitude of the negative price event and contribute to reduced curtailment of variable renewable energy, and the need for ramping large thermal units.<br>• High revenues can be earned based on dispatch pricing during contingency FCAS events.<br>The trial has also exposed problems with:<br>• Verifying FCAS response due to VPPs "value stacking" FCAS and energy trading.<br>• VPPs responding differently to market signals. As VPPs scale in size, and in the absence of a scheduling obligation, different behaviours in response to market price signals will make it more difficult for AEMO to forecast the supply demand balance accurately and operate the power system efficiently and securely. |

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| **T-D Interface** | Not considered. |
| **DER Control Architecture innovation** | This trial uses an AEMO developed API to exchange control and monitoring data between the AEMO and trial participants. All APIs are published and are accessible via public internet.<br><br>The trial reports have indicated issues with the efficiency of device registration, time taken to effect API integration and unreliability of communications when utilizing household internet.<br><br>As there is no direct DNSP involvement, the demonstration control system is consistent with either the single Integrated Platform (SIP) or Hybrid frameworks described in the ENA Open Networks Project. |
| **Roles & Responsibilities** | Not considered. |
| **Architectural Methodologies / Models applied in the design of the Project / Initiative** | |
| The project is limited to trial of a specific VPP control function and system and doesn't apply architectural methodologies in its design. | |
| **Key Reference Documents** | |
| 201907 - NEM Virtual Power Plant (VPP) Demonstrations Program Final Design<br><br>Other reference documents:<br><br>VPP Knowledge Sharing Stage 1 Report<br><br>VPP Knowledge Sharing Stage 2 Report<br><br>VPP Knowledge Sharing Stage 3 Report<br><br>VPP Consumer Insights Interim Report | |

| Project / Initiative Details | |
|---|---|
| **Name** | Indra Monash Smart Energy City |
| **Lead Organisation** | Monash University |
| **Partner Organisations** | Indra, ARENA |
| **Budget** | Capex Costs: \$6.1 million + ARENA funding of \$2.9 million<br>Opex Costs: \$2 million per annum |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

The Smart Energy City project intends on demonstrating how a grid-interactive 100 per cent renewable-powered net zero emissions city could operate reliably, and the value it could provide to customers and the broader electricity network.

A Smart Energy Framework has been developed as a design and implementation method for the introduction of Smart Energy Management to precinct scale microgrids. The three framework layers (DER Integration, Active Grid Management and Smart Energy Management) have been applied in the Smart Energy City project to enable Monash to manage and orchestrate the energy generation, storage and two-way power flows in the microgrid, including the interface with the broader electricity network, both from an energy and power quality perspective. The strategy for aggregating the microgrid's available flexibility is based on an internal market approach where each DER will act as an independent customer that will, where it chooses to, offer and commit to providing their available flexibility as a commercial service to the transactive energy market (TEM). The TEM will then be able to apply this internal market functionality to aggregate the microgrid's available flexibility. The TEM will complete the application of the Smart Energy Framework in delivering a smart energy platform for the Monash Microgrid. It will demonstrate how smart energy management enables a precinct-scale microgrid to provide aggregated flexibility services through the creation of internal competitive markets that ensure

The Indra Monash Smart Energy City (SEC) project team is also in parallel working towards developing a platform or 'living-lab' to facilitate research on key industry challenges.  This incorporates end-user behavioural sciences, transacting value at the distribution level, DER integration, microgrid services and commercial, and regulatory and operating models.

**Key Objectives**

The Smart Energy City project seeks to:

- Inform the development of standards, guidelines and regulations for technology platforms to support microgrid operation
- Support potential microgrid operators to participate in the energy market and bid into ancillary market services
- Enhance competition for demand response services, potentially leading to more cost-effective network support and investment
- Support the safe production, storage and consumption of DER

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| <ul><li>Provide a research and teaching platform to develop new solutions and train the next generation of energy industry professionals.</li><li>Create a platform that enables the testing of future markets, technologies, regulations, and user behaviours in a real-world environment.</li></ul> | |
| **Key Deliverables**<ul><li>A Grid-interactive Microgrid on the Clayton Campus</li><li>Reports<ul><li>Smart Energy City – Introductory Report</li><li>Microgrid Use Cases Summary</li></ul></li><li>ARENA Knowledge Sharing Deliverables</li><li>Academic Journal Articles</li></ul> | |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
| **Power System Architecture** | At the microgrid level, the SEC have developed a Smart Energy Framework, informed by principles of scalability and replicability, which drives the design and deployment of the platform, aligned with the microgrid's desired capabilities and objectives. The three layers are DER Integration, Active Grid Management and Smart Energy Management (including the Transactive Energy Market functions). Each layer has subcomponents. This overarching structure was established early in the project life cycle, before detailed implementation. |
| **Regulatory Innovation** | Monash published a paper with regulatory recommendations to enable greater uptake of local electricity supply systems, including microgrids, across Victoria. |
| **Market innovation** | In later works, detailed economic and control schemes research papers that enable the operation of distribution-level markets were published, including P2P trading, community-based trading, and hybrid markets. |
| **T-D Interface** | As a grid-interactive microgrid with a singled connection point to the grid, the SEC program provides relevant insights into coordination of a sub-network control hierarchy and objectives interacting with a parent-network and its objectives, which in many instances won't align. |
| **DER Control Architecture innovation** | Indra have deployed a proprietary active grid management system.<br><br>In the chosen architecture for DER control, each DER asset is connected to the Active Grid Management layer via a smart gateway node to collect, monitor, analyse and manage the data. Node #1, Indra's Edge Platform and iSPEED, Indra's Real-Time Data bus make the DERs visible and controllable by the Active Grid Management and Smart Energy Management layers. |

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| | The project is also considering adopting standards, such as IEEE 2030.5, Universal Smart Energy Framework (USEF), Industrial Data Space (IDS), Open ADR, and Open FMB, to provide services that are able to build on common functional and technical representations of DERs and promote interoperability with vendor. |
| **Roles & Responsibilities** | Not considered. |

| **Architectural Methodologies / Models applied in the design of the Project / Initiative** |
|---|
| Implicitly – Layered Decomposition |

| **Key Reference Documents** |
|---|
| 1907 – Smart Energy City Introductory Report<br>1905 – Victorian Market Assessment for Microgrid Electricity Market Operators<br>2106 – Two-stage mechanism design for energy trading of strategic agents in energy communities |

| Project / Initiative Details | |
|---|---|
| **Name** | Project EDGE |
| **Lead Organisation** | AEMO |
| **Partner Organisations** | AusNet; Mondo Power |
| **Budget** | Unknown |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

Project Energy Demand and Generation Exchange ('Project EDGE') aims to develop and test the concept of a DER Marketplace for DER services. Project EDGE is being undertaken by AEMO In partnership with AusNet and Mondo with funding from ARENA.

The proof of concept DER Marketplace in EDGE aims to optimally facilitate DER participating at scale in the wholesale markets while also delivering local network support services. The small-scale off-market trial is designed to demonstrate the following four key functions:

- Data exchange – providing a secure, efficient and scalable way for data exchange between Project EDGE participants
- Wholesale integration of DER – trailing how aggregated DER might participate with progressive sophistication in the NEM wholesale dispatch process and operate within distribution network limits.
- Deliver of local network services using aggregated DER to meet requirements set by the distribution network service provider (DNSP) – providing DER owners and aggregators the opportunity to deliver new value streams.
- Understanding and defining the customer value proposition that market aggregators can offer their customer by developing and testing incentives for DER owners (customers) that promote active market participation.

**Key Objectives**

Project EDGE Objectives are:

1. Demonstrate how DER fleets could participate in existing and future wholesale energy markets at scale.

2. Demonstrate different ways to consider distribution network limits in the wholesale dispatch process.

3. Demonstrate how to facilitate standardised, scalable and competitive trade of local network services.

4. Demonstrate how data should be exchanged efficiently and securely between interested parties to support delivery of distributed energy services.

5. Develop a proof of concept, integrated software platform to facilitate delivery of objectives 1-4 in an efficient and scalable way.

6. Develop a detailed understanding of roles and specific responsibilities that each industry actor should play.

7. Conduct comprehensive cost benefit analysis to provide an evidence base for future regulatory decision making.

8. Conduct a customer focused social science study to understand customer opinions on the complexities of DER integration.

9. Deliver best practice stakeholder engagement throughout the project with a commitment to knowledge sharing.

10. Deliver recommendations, supported with evidence, on how and when the concepts demonstrated should be implemented operationally.

**Key Deliverables**

Project EDGE was initiated late in 2020 and will run for multiple years and will deliver reports and insights that could cover:

- Existing knowledge and information from Market operators and DSOs that informed the project
- Approach to development of platform/systems/capability for each party
- Interoperability and communications between market participants and impacts on interfacing stakeholders (such as original equipment manufacturers).
- Projected outcomes should the DER marketplace be upscaled
- Insights on requirements for regulatory or operational arrangements affecting market participation of VPPs
- Information to support broader industry learnings and impacts on industry
- Market Operator insights:
    - Explanation of how the market operator platform will remain neutral for prospective participants
    - Defined and documented Marketplace design including interactions and interdependencies between project participants
    - Description of the Marketplace trial capabilities, including system operations, market operation and aggregation platforms
    - Interaction between local and wholesale bids within a constrained distribution grid
    - Analysis on regulatory impacts and changes (e.g. regulatory changes needed to enable full access to DER capability and incentivize DER ownership)
    - Assessment of the potential impact on the NEM system operations to facilitate DER market participation
    - Assessment of the replicability of the market design in other locations and jurisdictions (e.g  the WEM)
- DSO insights:
    - Approach and findings in relation to operating envelope model(s) tested
    - Definitions approaches and findings of DER services tested
    - Data collection, access, storage, sharing, validation, usage, integration, privacy and cybersecurity
- Aggregator insights:
    - Use of monitoring and management systems to provide real-time data and control capability
    - Findings on coordination with market participants to structure and submit market bids into the wholesale market, develop forecasts, manage dispatch and compliance of DER to dispatch instructions.

| How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements. | |
|---|---|
| **Power System Architecture** | Project EDGE explores the Open Energy Network (OpEN) Hybrid model. The key to enabling this trial is a proof-of-concept marketplace platform to enable data transfers between project participants.<br><br>An operating envelope (OE) design is a key consideration in terms of data exchange and information provided by the DNSP to the Market Platform. The level that the OE is applied will be a key consideration of the project trials. OEs will start off as simple approaches and gradually increase in sophistication to more dynamic signals incorporating increasingly dynamic and granular data sources reflecting the state of the local network.<br><br>The project currently seeks to test efficient and scalable approaches to data exchange. The Local Services Exchange (MarketPlace) is not a 'market' for local services, but rather a 'marketplace' in which services are still traded in bilateral contracts between DSOs and aggregators - it is just that the contracts are standardised (with degrees of freedom) |
| **Regulatory Innovation** | The trial results will provide lessons in terms of how Regulatory frameworks and subsequent Regulatory Reset Determinations might need to facilitate new investments to support future Marketplace operation at scale. |
| **Market innovation** | The MarketPlace Platform will enable the exploration of complex market interactions and data exchanges to occur. |
| **T-D Interface** | The MarketPlace Platform will consider both Distribution constraints (as provided by DSO) and binding Transmission Constraints (as identified by AEMO) in dispatch of DERs for both wholesale and local services. The project will explore how Distribution level constraints should be considered in wholesale dispatch. |
| **DER Control Architecture innovation** | Aggregators are responsible for all DER operation on behalf of customers who voluntarily participate in the project. Customer experience is a key consideration of the project design. |
| **Roles & Responsibilities** | A trial objective is to explore how market participant roles will transition over time. The Project broadly outlines the following roles and transitions:<br>• DNSPs transition to DSOs (key role appears to be providing data to platform to advise of constraints or to seek local services to address local conditions)<br>• AEMO runs NEM Dispatch – including incorporating OEs as provided by DNSPs and considering binding constraints at transmission level<br>• Aggregators utilize customer-owned DER<br>DNSPs as DSOs remain accountable for local network operation using OEs and dynamic connection agreements.<br><br>The platform is intended to be implemented in a manner that facilitates highly automated, efficient and scalable operation of the Marketplace. |

| Architectural Methodologies / Models applied in the design of the Project / Initiative |
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| Project EDGE builds on AEMO and ENA’s work in Open Energy Networks (OpEN) to explore a Hybrid model approach to DER integration and architecture. Project EDGE is designed to provide an opportunity to test and deploy different practical demonstration approaches to a hybrid framework.<br><br>The Hybrid model framework enables multiple operation models to be tested (due to the flexible design approach in interactions between the DNSP, market operator, and aggregators as enabled through the program’s data exchange platform. The proposed operating models range from relatively simple through to more complex which should provide valuable comparable evidence for future market design insights.<br><br>Key principles in the design are simplicity and standardisation. |
| **Key Reference Documents** |
| 2021: Project Lessons Learned Report and Launch Webinar: https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/der-demonstrations/project-edge |

| Project / Initiative Details | |
|---|---|
| **Name** | Dynamic Operating Envelopes – evolve Project |
| **Lead Organisation** | Australian National University (ANU) |
| **Partner Organisations** | In partnership with ZepBen (ARENA Funded) |
| **Budget** | Unknown |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

Research conducted by the Battery Storage and Grid Integration Program at the Australian National University, has identified numerous advantages for using dynamic operating envelopes to support DER integration. For example, they can:

1. Enable greater hosting capacity for solar PV, battery storage and electric vehicles
2. Reduce network congestion, thereby avoiding costly network upgrades
3. Increase network utilisation, thereby reducing prices for all network consumers
4. Support new business models for DER aggregation and participation in markets for energy and ancillary services
5. Be simple to implement across a variety of different DER assets. This can reduce the compliance costs of DER integration broadly

Implementing dynamic operating envelopes requires significant technical and technological development. Such development is the focus of the *evolve* Project.

In particular, the project team are working on methods for calculating and communicating dynamic operating envelopes, including the implementation of standards-based communication approaches. The recent ARENA knowledge sharing report delves further into the calculation and use of dynamic operating envelopes.

**Key Objectives**

- Develop test and explore the application of Dynamic Operating Envelopes as a tool for managing growing populations of DERs.
- Operating envelopes effectively represent the translation of physical and operational voltage and thermal constraints into nodal real and reactive limits for each participating node within a given distribution network segment.
- Operating envelope benefits - There are several benefits of operating envelopes at the current maturity levels of DER deployed within the electricity system:
    1. Operating envelopes can address multiple use cases including challenges currently being faced in both electricity distribution networks and at the whole of system level.
    2. Operating envelopes promise to be simple to implement across a variety of different DER assets, and do not require the use of sophisticated local control and optimisation systems. This has the potential to increase adoption and compliance from the variety of DER assets installed in Australian distribution networks.
    3. Operating envelopes can be deployed progressively into different segments of a distribution network as they are needed.

| | |
|---|---|
| One of the direct benefits from the adoption of operating envelopes is the broad uplift in capabilities for distribution networks to be able to calculate and publish the available network capacity. This requires an uplift in network visibility, including in capturing network topology and electrical characteristics. | |
| **Key Deliverables**<br>• Operating envelopes are being implemented within the evolve framework, an open-source technology framework which is deployed into cloud infrastructure and integrated with both DNSP and aggregator systems.<br>• The calculation and publication of operating envelopes are implemented as a series of software modules and algorithms within the evolve framework. | |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
| **Power System Architecture** | Not directly considered. |
| **Regulatory Innovation** | Evolve does not make Regulatory recommendations but lessons learned through the development of Dynamic Operating Envelopes may necessitate or inform potential regulatory changes or support future investments required to support expanded capability. The equitable and fair allocation of hosting capacity is flagged as a key issue that will require careful consideration, with the principle that DER should be allowed to operate to the maximum possible extent within identified constraints. |
| **Market innovation** | Evolve includes working with Aggregators and Distribution networks to establish open communication protocols to share information on hosting capacity and dynamic operating envelopes. |
| **T-D Interface** | While the evolve project is focused on the development of operating envelopes to ensure that physical and operational network limits are not breached, there is emerging interest in the use of operating envelopes to help maintain system security limits during periods of high solar generation.<br><br>The reduction in minimum demand for both SA and WA will require solutions that may include solar curtailment, something that could be accomplished using operating envelopes. In this instance, the signal for operating envelopes could be published using the same mechanisms described within evolve but the source of information to define the operational security constraint would be sourced from AEMO systems. To accommodate this use case an additional data integration would therefore be needed with AEMO. |
| **DER Control Architecture innovation** | It is important to realise that as dynamic operating envelopes represent a form of active network management, they can only be utilised for DER assets or connection points that are able to respond to external signals. At the nexus of many of the capabilities described in previous sections are the DER assets themselves and the systems that monitor, optimise and control these DER assets. While many of these local control systems are proprietary, they play a vital role in not only providing network visibility but also operationally enacting the operating envelopes. |

| Architectural Methodologies / Models applied in the design of the Project / Initiative |
| --- |
| None used. |
| **Key Reference Documents** |
| https://arena.gov.au/assets/2020/09/on-the-calculation-and-use-of-dynamic-operating-envelopes.pdf<br>https://arena.gov.au/knowledge-innovation/distributed-energy-integration-program/dynamic-operating-envelopes-workstream/ |

| Project / Initiative Details | |
|---|---|
| **Name** | The State of DER Technology Integration Report |
| **Lead Organisation** | ARENA |
| **Partner Organisations** | GridWise Energy Solutions and farrierswier |
| **Budget** | unknown |
| **Project / Initiative Overview, Objectives & Deliverables** | |

**Project Overview**

Through consultation with leading organisations and subject matter experts across Australia, this report has sought to identify and categorise the different capabilities needed to achieve distributed energy resources (DER) technology integration in Australian electricity markets.

A functional framework was developed that defines the requirements for DER technology integration and provides a common framework through which various stakeholders can assess technology integration progress and challenges.

A baseline maturity assessment was also conducted that provides a mid-2020 view of how 45 recent and current ARENA and non-ARENA funded projects will collectively advance maturity for each required functional area upon their completion.

This report informs stakeholders of the contributions made towards DER technology integration by the assessed projects. The functional framework and maturity assessment have been designed to enable future application to track progress towards effective DER integration across Australia.

The technology integration focus of this functional framework does not examine the social and economic work of solving efficient cost optimisation, market design regulatory change, and consumer protections that are also required for DER integration. It is hoped that this baseline maturity assessment and future progress tracking using the functional framework will help stakeholders see how and where DER integration is being impeded by the pace of change in those important complementary reforms.

**Key Objectives**

- The report seeks to synthesise existing work (particularly focussed upon technology related issues) and explain how it fits together in a manner that is accessible for people wanting an overarching view of the current state of DER technology integration, including both technical and non-technical stakeholders.
- The report's scope is limited to technology issues related to DER integration. It includes technology related to DER devices themselves as well as the systems of parties that need to interact with DER devices (e.g. AEMO, network businesses, aggregators and other energy service providers) and the communications systems and protocols required to facilitate that interaction.
- It also includes the data necessary to enable effective operation of DER and its integration into the broader energy system and markets. Standards related to DER technology and data are also an important part of this project.

**Key Deliverables**

Working with the leaders of the 45 sampled projects and a Technical Reference Group (TRG), applied a three-step process to assess how these projects will collectively mature each required functional area:

1. Develop functional framework
2. Identify projects
3. Maturity assessment

Provided an assessment against a rating scheme identifying function maturity as Commercialisation, Deployment or Standards Development, Trial Stage or Research Stage.

The DER capabilities functional framework identifies the following integration topics and functional areas:

- Devices - What capabilities can DER assets provide to benefit the power system?
    - Ability to withstand disturbances
    - Grid support
    - Protection and control
- Communications and interoperability – How do DER assets communication and interoperate with each other and broader systems?
    - Interoperability between devices and between devices and systems
    - Integration of DER within AEMO’s and distributor’s systems
    - Cyber Security
- Understanding DER behaviour – What data, modelling and analysis is needed to understand DER behaviour and maximise the benefits of DER?
    - DER visibility
    - DER modelling
    - Network hosting capacity
    - Buk power system security and reliability
    - Distribution system reliability and power quality
- Services – What market and network services can DER deliver?
    - Integration with wholesale energy and system security services markets
    - Provision of localized network services

| How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements. | |
|---|---|
| **Power System Architecture** | Not considered |
| **Regulatory Innovation** | As noted within the report, the functional framework and DER maturity assessment method does not address broader customer, market design, regulatory or policy questions. |
| **Market innovation** | As noted within the report, the functional framework and DER maturity assessment method does not address broader customer, market design, regulatory or policy questions. |
| **T-D Interface** | The maturity assessment of the T-D interface is not directly described however the maturity of some structures between the T-D interface are loosely assessed within the Communications and Interoperability and Services integration topics. |
| **DER Control Architecture innovation** | The functional framework and DER maturity assessment method is used to assess the current maturity of functions, many of which are desirable qualities or attributes of control architecture, such as:<br>• DER visibility (trial stage 25D and 9ID projects)<br>• Integration of DER within AEMO's and distributors' system (trial stage 23D and 6ID projects)<br>• Interoperability between devices and between devices and systems (trial stage 23D and 5ID projects)<br>• Cyber security (research stage 2D and 15ID projects)<br>The report finds functions necessary for control architecture are generally less mature than power system architecture functions. |
| **Roles & Responsibilities** | Not considered. |

| Architectural Methodologies / Models applied in the design of the Project / Initiative |
|---|
| Applied a framework to categorise projects into four integration topics and thirteen functional areas aligned under each topic. Conducted a technology maturity assessment against each functional area by consulting with project leaders and a technical review group. Note, the method does not address broader customer, market design, regulatory or policy questions. |

| Key Reference Documents |
|---|
| 2021-02 ARENA - The State of DER Technology Integration Report.pdf<br>More information on the methodology is published in the following annexures:<br>Annex A: Functional Framework<br>Annex B: Maturity Assessments and Methodology<br>Research and trials referred to: |

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|---|---|
| Realising Electric Vehicle-to-Grid Services (REVS) | ActewAGL Retail |
| AEMO Virtual Power Plant Demonstrations | AEMO |
| DEIP EV Grid Integration Standards Taskforce | AEMO |
| DER Impact on Bulk Power System Operations | AEMO |
| Renewable Integration Study – Distributed PV Stream | AEMO |
| Visibility of DER | AEMO |
| Updated Standards for Demand Response from Residential Loads | AEMO and Standards Australia |
| Updated Standards for DER Inverter Capability and Performance | AEMO and Standards Australia |
| AGL Virtual Power Plant | AGL |
| Consumer Energy Systems Providing Cost-effective Grid Support (CONSORT) | Australian National University |
| DER Integration API Technical Working Group | Australian National University |
| Distributed Energy Resources Hosting Capacity Study | CitiPower & Powercor |
| National Low-Voltage Feeder Taxonomy Study | CSIRO |
| Battery Storage System Performance Standard | DNV GL |
| Dynamic Limits DER Feasibility Study | Dynamic Limits |
| Open Energy Networks (OpEN) | OpEN ENA/AEMO |
| Enel X Demand Response Project | Enel X |
| EnergyAustralia Demand Response Program | EnergyAustralia |
| DER Integration and Automation Project | Evoenergy |
| Energy Under Control Demand Response | Flow Power |
| Decentralised Energy Exchange (deX) Program | GreenSync |
| Expanded Network Visibility Initiative (ENVI) | GridQube |
| Project Highgarden | Horizon Power |
| Indra Monash Smart Microgrid Project | Indra / Monash |
| Demonstration of Three Dynamic Grid-Side Technologies | Jemena |
| Yackandandah SWER Trial | Mondo |
| Intelligent Switchgear Project | NOJA Power |
| Demand Management and Modulation | Pooled Energy |
| DER Enablement Project | Renew |
| Advanced VPP Grid Integration | SA Power Networks |
| Closed-Loop Voltage Control Trial | SA Power Networks |
| Simply Energy Virtual Power Plant | Simply Energy |
| Enhanced Reliability through Short Time Resolution Data around Voltage Disturbances | Solar Analytics |
| DER Visibility and Monitoring Best Practice Guide | Solar Analytics as contact for industry working group |
| Advanced Planning of PV-Rich Distribution Networks Study | University of Melbourne |
| Addressing Barriers to Efficient Renewable Integration | UNSW |
| Digital Grid Futures Institute | University of New South Wales |
| Voltage Analysis of the LV Distribution Network in the Australian NEM | UNSW |
| Optimal DER Scheduling for Frequency Stability Study | University of Tasmania |
| Network Opportunity Maps | University of Technology Sydney |
| Networks Renewed | University of Technology Sydney |
| My Energy Marketplace | Wattwatchers |
| Western Power Community Batteries | Western Power |
| Townsville Community Scale Battery Storage Project | Yurika |
| Evolve DER Project | Zepben |

| Project / Initiative Details | |
|---|---|
| **Name** | Advanced VPP Grid Integration |
| **Lead Organisation** | SAPN |
| **Partner Organisations** | Tesla |
| **Budget** | $2.48M |

## Project / Initiative Overview, Objectives & Deliverables

### Project Overview

To trial setting of export limits dynamically, according to the local conditions of the network at a point in time. The benefit is that greater export capacity can be made available at times when the network assets are lightly loaded, increasing the opportunity of the VPP to be dispatched for market benefits.

SAPN and Tesla co-designed an Application Programming Interface (API) to enable the secure real-time exchange of data between Tesla and SAPN to control the export limit.

Dynamic export limits will be a key capability of a Distribution System Operator (DSO) in an energy system dominated by distributed generation, to increase hosting capacity and open up as much of the available distribution network capacity as possible for generation without compromising security of supply.

The project found that time-varying and locational export limits could enable DER to be hosted at higher levels of penetration, particularly distributed energy storage VPPs conducting arbitrage between solar and non-solar hours. The results support the view that a dynamic network capacity management approach can enable larger, more active DER and demand management systems to continue to operate under higher levels of DER penetration than would otherwise be possible with static limits.

### Key Objectives

The primary goal of the trial was to explore whether the amount of energy the VPP can export through the network can be increased by as much as two-fold at certain times through the use of dynamic, rather than fixed, export limits.

The project had the following specific objectives:

- Objective 1: Design and build DSO-VPP interface and operating model for dynamic operating envelopes
- Objective 2: Develop new hosting capacity forecasting system
- Objective 3: Test at scale in the real world
- Objective 4: Demonstrate capability to increase VPP access to network capacity
- Objective 5: Quantify the value

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| **Key Deliverables**<br>• SAPN and Tesla have co-designed an Application Programming Interface (API) that enables the secure real-time exchange of data between Tesla's and SA Power Networks' systems via the internet.<br>• SAPN has developed a model to estimate available hosting capacity for every LV area of the network. The model generates a rolling 24 hour forward forecast of available export capacity in five minute intervals for each area – the local 'dynamic operating envelope' for the network. | |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
| **Power System Architecture** | Not considered. |
| **Regulatory Innovation** | Not considered. |
| **Market innovation** | Not considered. |
| **T-D Interface** | Not considered. |
| **DER Control Architecture innovation** | The project utilises a bespoke API (based on the IEEE 2030.5 standard with specific alterations and simplifications) to enable SAPN to communicate Dynamic Operating Envelopes (DOE) to Tesla.<br>Tesla's VPP control system also communicates with the AEMO via API and can dispatch the VPP for FCAS (refer AEMO's ARENA-funded VPP demonstrations trial) or for wholesale market trading via their retail partner Energy Locals. |
| **Roles & Responsibilities** | Not considered. |
| **Architectural Methodologies / Models applied in the design of the Project / Initiative** | |
| Whilst AEMO's VPP demonstration and this trial are independent, the control architecture of the combined AEMO and SAPN/Tesla VPP trials is most like (but not the same as) the Independent DSO framework described in the Open Energy Networks project. In this arrangement the DNSP is communicating the DOE to the aggregator independently of the TSO which is communicating FCAS requirements. The IDSO (in this case Tesla) maintains a platform which consolidates this information for dispatching the DER. Tesla effectively has two functions, market platform operator and aggregator.<br>Other reports (e.g. SmartNet and OpEN) have found that the IDSO architecture is the most complex compared to other models and may incur ICT issues at scale. | |
| **Key Reference Documents** | |
| 202105 – Advanced VPN Grid Integration Final Report | |

| Project / Initiative Details | |
|---|---|
| **Name** | Post 2025 Market Design Project |
| **Lead Organisation** | Energy Security Board |
| **Partner Organisations** | AER, AEMC, AEMO and inputs from various consultants |
| **Budget** | 2021-22 Federal Budget - $34.3 million to continue implementing the energy market reform agenda currently in progress through the Energy Security Board's post-2025 electricity market review program |

## Project / Initiative Overview, Objectives & Deliverables

**Project Overview**

The Energy Security Board (ESB) was tasked by the former Council of Australian Governments Energy Council (COAG EC), to develop advice on reforms to the National Electricity Market (NEM) to meet the needs of the transition and beyond 2025, including the need for:

- Resource adequacy mechanisms: to provide the right signals which will drive investment in an efficient mix of new resources which will minimise costs and maintain reliability;
- Essential system services and ahead scheduling: to ensure that the essential services required (frequency, control, operating reserves, inertia and system strength) are available to maintain system security;
- Integration of distributed energy resources and flexible demand: to deliver benefits to customers through the integration of rooftop solar, battery storage, smart appliances and other resources into the system in an efficient way; and
- Transmission and access: to reconfigure the transmission system so that new renewable generation and large-scale storage can connect and be dispatched to meet customers' demand.

The ESB has recommended potential reform pathways to address these implications and promote a secure, reliable and efficient energy transition while maintaining affordability for customers. The proposed pathways build on the Directions paper published in January 2021. The ESB will make recommendations to Ministers in mid-2021.

**Key Objectives**

- **Resource adequacy mechanisms and aging thermal retirement:** facilitate the timely entry of new generation, storage and firming capacity, and an orderly retirement of aging thermal generation.
- **Essential system services and scheduling and ahead mechanisms:** availability of resources that provide essential system services and support investment in necessary capability to balance the highly variable dynamics of the changing generation mix, without AEMO intervention. AEMO also needs the right tools to manage the greater complexity and uncertainty to schedule these resources so they are available when they are needed.
- **DER integration and demand side participation:** enable the integration of DER (such as rooftop solar and distributed storage) and value flexible demand so they can provide services to networks, the wholesale market and other consumers
- **Transmission and access:** Objective the addition of transmission investments to enable the new generation and market arrangements and that new generation and storage locates and operates in ways that use transmission investment efficiently.

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| **Key Deliverables**<br>• Consultation Paper (September 2020)<br>• Directions Paper (December 2020)<br>• Options paper for Consultation (April 2021)<br>• Recommendations to Ministers (Mid-2021) | |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
| **Power System Architecture** | Identified as a necessary consideration but not addressed in detail. |
| **Regulatory Innovation** | The program proposes a wide-ranging suite of new and untried changes to the regulation of the NEM to meet the emerging needs of the system. Regulatory reform spans all workstreams. In the DER and demand-side workstream, the proposed trader-services approach to facilitate customer resources participating in markets is intended to be technology agnostic, and a framework that can support a range of business models to make it easier to provide services to customers. Innovating the regulatory regime itself was not considered. |
| **Market innovation** | Market Design is the central theme. New markets are envisaged for a range of essential system services, and to unlock value from DER by rewarding customers for their flexible demand. Primarily the focus is on integrating DER into the wholesale market through retailers or aggregators, with less focus on potential revenue streams for network services. |
| **T-D Interface** | Not considered. |
| **DER Control Architecture innovation** | Not considered. |
| **Roles & Responsibilities** | The program outlines traditional roles and how they have evolved into current roles. It indicates that further clarity on roles will be needed to better accommodate greater participation from DER and demand-side resources. |
| **Architectural Methodologies / Models applied in the design of the Project / Initiative** | |
| | |
| **Key Reference Documents** | |
| 21-04 – Post 2025 Market Design Options Part A<br>21-04 – Post 2025 Market Design Options Part B | |

| Project / Initiative Details | |
|---|---|
| **Name** | Distributed Energy Resources Roadmap |
| **Lead Organisation** | WA Govt Energy Transformation Taskforce |
| **Partner Organisations** | AEMO, Western Power, Synergy |
| **Budget** | Unknown |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

The purpose of the Roadmap is to identify an integrated set of actions for implementation from 2020 through to 2024 to achieve the Taskforce's three objectives and its vision of a future where DER is integral to a safe, reliable and efficient electricity system, and where the full capabilities of DER can provide benefits and value to all customers.

The Roadmap proposes 36 actions under fourteen functions grouped into four themes: Technology integration, Tariffs and investment signals, DER participation and Customer protection and engagement.

Key to these actions is the establishment of a DSO (by the DNSP, Western Power) and a DMO (by AEMO) with all DER dispatch enacted by VPPs managed by retailers or market aggregators. Dispatch of all registered, aggregated DER occurs via the DMO which leverages a single Market Platform for the coordination of market processes.

**Key Objectives**

The Energy Transformation Taskforce has developed this DER Roadmap of actions to meet the following objectives:

• allow customers to continue to utilise DER to manage their own energy bills;

• enable all electricity customers to share in the benefits from higher levels of DER; and

• integrate increasing volumes of DER into the SWIS without adversely affecting the security of the power system.

**Key Deliverables**

Delivery of the Strategy involves three work streams:

- develop a Roadmap for a transition to a decentralised, democratised, and highly data driven power system – the DER Roadmap,
- undertake comprehensive long-term modelling of the power system to assist Government policy and sector wide investment decisions, and
- make major modifications to the design and operation of the SWIS.

The roadmap entails delivery of 36 actions which are listed in section 3.3 of the report.

<table>
<tr><th colspan="2">How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.</th></tr>
<tr><td>Power System Architecture</td><td>A DER Orchestration Pilot (Project Symphony) includes the establishment of DSO, DMO and aggregator roles.<br><br>The project seeks to resolve the practical challenges of integrating DER as an ‘active’ participant in the market and provide input to refine the functions of relevant parties to enable DER to be orchestrated and managed in a coordinated manner as an essential input to operation of a DSO and DMO.<br><br>Symphony will test and identify test and use cases for DER including; Network use cases; market use cases; retailer/aggregator use cases; and will develop pilot prototypes of the platforms (such as DERMS) and systems needed to operationalise DER integration and deliver on DER orchestration capability.<br><br>Based on the ‘Hybrid’ model explored in the ENA/AEMO OpEN project Symphony will assess how Western Power (existing DNSP) could evolve to a DSO and how AEMO (System Operator in SWIS) could evolve to a DMO based on the assumption that these changes will incrementally extend existing capability and avoid the creation of new separate business units within these organisations.<br><br>Dispatch of all registered, aggregated DER occurs via the DMO which leverages a single Market Platform for the coordination of market processes.</td></tr>
<tr><td>Regulatory Innovation</td><td>Regulatory changes are being implemented to overcome restrictions on procurement of DER and storage:<br><br>The Electricity Networks Access Code 2004 does not provide a clear method for valuation of the benefits provided by DER to the network.<br><br>Where a market for storage services to Western Power does not emerge to resolve network needs where it is efficient, the existing regulatory framework does not readily facilitate the ownership and cost recovery of distribution batteries by Western Power.</td></tr>
<tr><td>Market innovation</td><td>In the SWIS the transmission and distribution networks are owned and managed by Western Power (TNSP and DNSP) with system operation (TSO) and wholesale energy market currently managed by AEMO.  Under the roadmap the DMO role will also be created and managed by AEMO.</td></tr>
</table>

| | |
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| **T-D Interface** | The creation of a DSO role for Western Power will require the establishment of an interface to exchange operational data and network constraints. Dynamic operating envelopes, data and information exchange between the DSO and TSO has not been specified and will likely arise from the DER Orchestration Pilot (*Project Symphony*). |
| **DER Control Architecture innovation** | The Roadmap description of participant roles and interrelationships is consistent with the Hybrid model proposed in the OpEN project. This may be one of the early implementations of this structure. Issues of tier bypassing, hidden coupling and control latency will need to be considered and have not been specifically addressed. |
| **Roles & Responsibilities** | A DER Orchestration Pilot (Project Symphony) will consider definitions and roles including a DSO and DMO function. Dispatch of all registered, aggregated DER occurs via the DMO which leverages a single Market Platform for the coordination of market processes. The Symphony pilot will explore a range of proposed functions under each of the outlined roles to be explored under the program. |

**Architectural Methodologies / Models applied in the design of the Project / Initiative**

The Roadmap, like the AEMO ISP roadmap, identifies an integrated set of actions (across four themes) to address gaps in regulation, tariffs, market and technology integration necessary to achieve a future vision. The DER coordination scheme is informed by work done in the OpEN project. The roadmap condenses considerations from a number of prior trials and projects (refer *Summary of Considerations for DER Roadmap* section of the roadmap appendix B). The DER structure does not arise from, nor is driven by, a specific architecture model, instead these will evolve from the various projects and trials which arise from the roadmap.

**Key Reference Documents**

2019-12 WA Energy Taskforce - DER_Roadmap

2021-04 DER Roadmap Progress Report

Appendix A – Regulatory Settings Summary

Appendix B – DER Project Stocktake

**Aug 2020. Issues Paper - DER Roadmap: DER Orchestration Roles and Responsibilities**

https://www.wa.gov.au/sites/default/files/2020-08/Issues%20Paper%20-%20DER%20Roadmap%20%20Distributed%20Energy%20Resources%20Orchestration%20Roles%20and%20Responsibilities.pdf

| Project / Initiative Details | |
|---|---|
| **Name** | Open Energy Networks (OpEN) |
| **Lead Organisation** | Energy Networks Australia & AEMO |
| **Partner Organisations** | None |
| **Budget** | Unknown |
| **Project / Initiative Overview, Objectives & Deliverables** | |

**Project Overview**

Beginning in early 2018 AEMO and Energy Networks Australia (ENA) partnered to explore frameworks to most effectively facilitate the entry of high-levels of DER into the Australian market.

The project sought to understand what roles a future Distribution System Operator (DSO) and AEMO should play in the emerging energy system to ensure that value is returned to all customers; both those connected at transmission and distribution level. Specifically, OpEN attempted to explore frameworks and approaches that could facilitate market access for all stakeholders (DER owners, aggregators, network operators, etc) while ensuring that technical network limits are not breached and ensuring the integrity and security of the network is preserved, maintaining a safe and reliable power supply for all.

Informing these considerations were the following key foundational principles:

1. Simplicity, transparency and adaptability of the system to new technologies

2. Supporting affordability whilst maintaining security and reliability of the energy system

3. Ensuring the optimal customer outcomes and value across short, medium and long-term horizons – both for those with and without their own DER

4. Minimising duplication of functionality where possible and utilising existing governance structures without limiting innovation

5. Promoting competition in the provision and aggregation of DER, technology neutrality and reducing barriers to entry across the National Energy Market (NEM) and Western Energy Market (WEM)

6. Promoting information transparency and price signals that encourage efficient investment and operational decisions

7. Lowest cost.

ENA and AEMO explored the high-level functionality required to bring about four potential DER optimisation frameworks. A Smart Grid Architecture model (SGAM) approach was used to create a functional specification of each framework, to build understanding of each framework and to allow a degree of comparison and analysis of the frameworks to begin exploring an optimal pathway towards a DSO transition.

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| **Key Objectives**<br>• A foundational objective was to identify both the system requirements that must be addressed in the formation of a two-way system and to obtain a better understanding from traditional and new market participants how, from a network and market operator perspective, can reduce barriers to entry into the system and best facilitate innovation and competition at the grid edge.<br>• The OpEN project sought to explore options that avoided issues associated with; uneconomic DER connection; uneconomic network augmentation to support DER growth; uncoordinated DER operation; technical management of network constraints; and unconstrained DER operation. |
| **Key Deliverables**<br>• The OpEN consultations initially outlined several 'strawman' frameworks that explored how responsibility for distribution level optimization and system level dispatch could be coordinated. The initial models included;<br>o Single Integrated Platform (SIP): AEMO central platform for optimising dispatch taking into account transmission and distribution network constraints;<br>o Two Step Tiered (TST): DNSPs optimising distribution level dispatch of DERs; and,<br>o Independent DSO (IDSO): An independent entity optimising distribution level dispatch of DERs.<br>• Qualitative stakeholder feedback on these three models suggested the need for a fourth 'Hybrid' model. The independent DSO was seen to be overly complex. The two-step tiered platform highlighted a perceived conflict of interest in the DNSP maintaining a technical operation role as well as a market clearing function.<br>• Based on this stakeholder feedback, a fourth Hybrid model was added that combined elements of the Single Integrated Platform and Two Step Tiered Platform as follows:<br>o Hybrid Model. A conceptual cross between the SIP and TST frameworks involving a two-sided marketplace comprised of wholesale and ancillary services that is organised and operated by AEMO. A central market platform acts as the key data exchange platform between market participants (including network operators) and collects bids and offers from energy resources, such as DER via aggregators/retailers, and makes them available to AEMO and the DSO for whole system co-optimisation.<br>• Managing the market and the system at the transmission and distribution level was considered too much for one organisation to manage via the SIP model. In the Hybrid model, the DNSP were considered as managing and communicating distribution network constraints albeit routed via the Hybrid platform managed by AEMO. The market platform operated by AEMO was conceived as optimising all DER bids for wholesale, Frequency Control Ancillary Services (FCAS), network services and other market services.<br>• The Smart Grid Architecture Model (SGAM) methodology was used to conceptually map the functionality required to support each of the four models and to allow for comparison and assessment of the different options. The approach taken broke the four frameworks down into 13 key functions and associated activities required to deliver key DER optimisation principles to answer three basic questions: 1) Who is communicating with whom; 2) What are they communicating; and, 3) How are they communicating and how often. As such, this approach had a primary focus on a limited subset of the Network of Structures that make up the power system. |

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| • The SGAM approach and consultations highlighted that a range of 'least regrets' priorities should be progressed in the immediate term as enablers or 'required capabilities' to support future DSO Frameworks. These included;<br>o DNSPs defining network visibility requirements and network export constraints;<br>o Defining communication requirements for operating envelopes; and,<br>o Establishing an industry guideline for operating envelopes for export limits.<br>This work has led to subsequent work across industry exploring dynamic operating envelopes and integration/communication approaches to share data across different industry parties. | |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
| **Power System Architecture** | OpEN applied the SGAM methodology to conceptually map functionality requirements across the four frameworks noted above. This was used as the basis of stakeholder workshops focused on the comparative differences of four frameworks. The resulting content was also used as the basis of the related Cost Benefit Analysis undertaken by Baringa.<br>SGAM was originated for the purpose of analysing discrete smart grid use cases. In OpEN, the approach taken was quite aligned with a common Enterprise IT methodology informed by a hybrid of TOGAF and SGAM. This approach provides useful insights but is limited by the absence of a comprehensive framework and methodology for detailed structural analysis of the power system as a whole and especially the deep interdependencies across the several overlapping structures distinguished by the Network of Structures model. |
| **Regulatory Innovation** | A preliminary assessment of functions to support functionality required for each framework provides high-level indication of likely regulatory impacts of different frameworks being implemented. The ENA OpEN Position Paper (May 2020) concludes that: "To effectively incorporate DER some reform of the rules and regulations governing the operation of the national electricity market will be required to support the transformation."<br>Options mooted for further consideration include:<br>• Strengthen incentive-based network regulation for better outcomes. This could include incentives targeted at optimizing hosting capacity, using DER where efficient and providing greater network visibility or network reinforcement where this enables realization of customer and market value through additional capacity. Consideration could also be given to greater focus on 'output focused revenues'. Current incentives are heavily focused on reducing costs whereas further changes could encourage new or improved services which produce more positive outcomes for consumers. |

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| | • Integrating DER into the Regulatory Determination Process. This could provide a greater focus on DER outcomes in future determinations. Reforms could potentially include; DER integration plans to encourage networks to present investment plans to improve hosting capacity; Revised capital and operational expenditure criteria; exploring potentially moving to alternative revenue assessment models (such as TOTEX) to ensure incentives are neutral between capital intensive and alternative solutions.<br>• Review Ring-Fencing arrangements. Changes could allow network businesses to provide more efficient solutions day to day while reducing regulatory burden and complexity. Some possible reforms suggested could include a threshold permission approach or wider class exemptions to improve the experience of current and future DER owners. (A review of the AER RingFencing Guideline is underway at the time of this status summary).<br>• Regulations for distribution level markets. New arrangements may be required to provide appropriate economic signals for customers with DER and other participants in the future. This will be pivotal in ensuring that efficient distribution-level markets can emerge providing greatest value for DER owners.<br>• Network Tariffs. Should have the ability to signal the cost of using network for DER and benefits of modifying behaviour. There are many options for what form this could take, including incentives, and could help to limit the need for future investment in infrastructure and lowering costs for all customers. (AEMC is currently consulting on Pricing and Access Pricing Reforms at the time of this summary). |
| **Market innovation** | Not considered. |
| **T-D Interface** | The OpEN project had a focus of exploring at a conceptual level how DER aggregation could or should be coordinated at the T-D interface. The four frameworks explored through OpEN each suggest different approaches to DER aggregation and coordination at the T-D interface. |
| **DER Control Architecture innovation** | Not considered. |
| **Roles & Responsibilities** | OpEN explores at length the possible future roles of distribution networks (potentially with an expanded role as the DSO), aggregators and AEMO as they system operator. The project explored a range of functions and functionalities that may be required to facilitate or enable different functional approaches to DER coordination. |

## Architectural Methodologies / Models applied in the design of the Project / Initiative

As noted above, OpEN applied the SGAM methodology which was developed by the Smart Grid Coordination Group11/Reference Architecture Working Group (SG-CG/RA) as part of the European Commission Mandate M/49012. As the name suggests, it was originated for the purpose of analysing discrete smart grid use cases and focuses on particular aspects of interoperability.

The approach taken in OpEN broke the four frameworks down into 13 key functions and associated activities required to deliver DER optimisation. SGAM was used to conceptually map functionality requirements across the four frameworks for stakeholder workshops that focused on the comparative differences of the four frameworks. The resulting content was also used as the basis of the related Cost Benefit Analysis undertaken by Baringa.

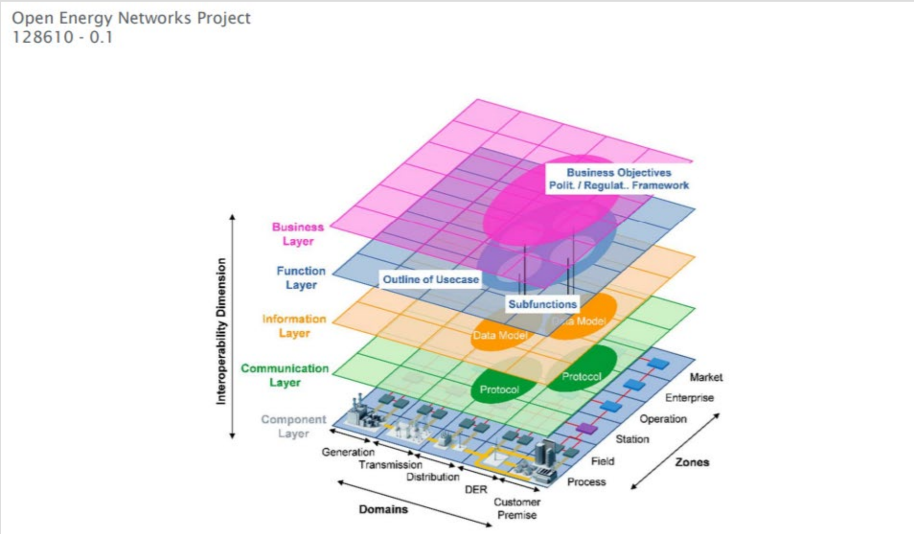


Figure 1: Smart Grid Architecture Model (SGAM) [21]

Overall, the approach taken was quite aligned with a common Enterprise IT methodology informed by a hybrid of TOGAF and SGAM. Three basic questions applied across the four frameworks were:

1. Who is communicating with whom?;
2. What are they communicating?; and,
3. How are they communicating and how often?

As articulated by EA Technology, this approach provided a "structured and coherent way to describe, visualize and interpret the DSO frameworks by capturing the interactions between different actors from a high-level business context down to the detail of what information is exchanged, using what communication methods, between physical components and equipment"[22]. As such, this approach primarily focused on only a limited subset of the Network of Structures that collectively make up and each dynamically influence the operation and coordination of the power system as a whole.

[21] "Smart Grid Reference Architecture," CEN-CENELEC-ETSI Smart Grid Coordination Group, Nov. 2012. https://ec.europa.eu/energy/sites/ener/files/documents/xpert_group1_reference_architecture.pdf as referenced by EA Technology https://www.energynetworks.com.au/resources/reports/ea-technology-open-energy-networks-project/

[22] Pg 29 EA Technology Open Energy Networks Project Report. https://www.energynetworks.com.au/resources/reports/ea-technology-open-energy-networks-project/

| Key Reference Documents |
| --- |
| June 2018. Open Energy Networks Consultation Paper.<br>https://www.energynetworks.com.au/resources/reports/open-energy-networks-consultation-paper/<br><br>Dec 2018. Open Energy Networks Consultation Response Paper.<br><br>https://www.energynetworks.com.au/resources/reports/open-energy-networks-consultations-response-paper/<br><br>July 2019. EA Technology. Supporting report for Open Energy Networks project.<br><br>https://www.energynetworks.com.au/resources/reports/ea-technology-open-energy-networks-project/<br><br>July 2019. Required Capabilities and recommended actions report.<br><br>https://www.energynetworks.com.au/assets/uploads/open_energy_networks_-_required_capabilities_and_recommended_actions_report_22_july_2019.pdf<br><br>May 2020. Open Energy Networks Project: Energy Networks Australia Position Paper.<br><br>https://www.energynetworks.com.au/resources/reports/2020-reports-and-publications/open-energy-networks-project-energy-networks-australia-position-paper/<br><br>May 2020. Assessment of Open Energy Networks Frameworks.<br><br>https://www.energynetworks.com.au/resources/reports/2020-reports-and-publications/assessment-of-open-energy-networks-frameworks/ |

| Project / Initiative Details | |
|---|---|
| **Name** | Distributed Energy Integration Program |
| **Lead Organisation** | A collaboration of thirteen government agencies, market authorities, industry and consumer associations led by a steering group. |
| **Partner Organisations** | ARENA, AEMO, AEMC, AER, Aust Energy Council, CEC, CEFC, Clean Energy Regulator, COAG Energy Council, CSIRO, ENA, Energy Consumers Australia and the Energy Security Board. |
| **Budget** | Unknown |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

The Distributed Energy Integration Program (DEIP) is a collaboration of government agencies, market authorities, industry and consumer associations aimed at maximising the value of Distributed Energy Resources (DER) for all energy users.

Led by a steering group, the forum is driven by the premise that exchanging information and collaborating on DER issues will more efficiently identify knowledge gaps and priorities, as well as accelerate reforms in the interest of customers.

DEIP's objective is to map a pathway to DER maturity through a process of research, industry consensus building, prioritisation and trial. DEIP define work packages for priority areas. The DEIP packages will:

- Identify and define a problem that needs collaboration
- Scope the work items to progress this (e.g. seek buy-in, resourcing, and governance)
- Leverage design thinking methods to facilitate brainstorming, convergence and consensus building within industry
- Supplement stakeholder consultation with studies and knowledge sharing

Outcomes typically include:

- A consensus document or report
- Reform recommendations (eg. Rule Change Requests)
- Informing an industry activity or trial (eg. DER orchestration pilots)
- Trials and demonstration projects
- Commitment to next steps and priorities identified in the process

**Key Objectives**

DEIP members have a shared interest in supporting evolution toward a distributed energy system that is secure, reliable, resilient, affordable and efficiently integrates and utilises customer's DER.

**Key Deliverables**

The priority work packages (from the Nov 2020 and Mar 2021 CEO Forums) are:

- Dynamic Operating Envelopes (2021) - The current state of operating envelopes (i.e. DER import and export limits) is binary and inefficient. There is significant latent value which can be unlocked through dynamic approaches.

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| • Interoperability (2021) - Without DER interoperability, system operators will be faced chaotic threats to power quality, reliability which will impact access by new customers.<br>• EV Grid Integration (2021) - Despite slow uptake, EVs are expected to become a significant future electricity asset. There is significant value in managing the impact of EVs in Australia before uptake.<br>• Access and Pricing (2020) - Explore alternative distribution network access, connections and pricing models for a high DER future – taking into account electricity system users' expectations<br>• DER Market Development (2020) – Using the Open Energy Networks models, run market place trials to test the theory in practice before wide-scale roll out. | |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
| **Power System Architecture** | Not considered. |
| **Regulatory Innovation** | DEIP work packages will inform regulatory innovation which may then be enacted by members of the program. Examples may include changes to regulation of networks, wholesale markets, investment planning, metering, connection and installation. |
| **Market innovation** | DEIP places a high priority on open markets to facilitate access by DER to energy markets. The DER Market Development work package will trial and refine models presented in the Open Energy Networks framework which may lead to innovation in the market and T-D interface. |
| **T-D Interface** | Not considered. |
| **DER Control Architecture innovation** | The support of a work package for Dynamic Operating Envelopes may result in recommendations affecting DER control architecture. |
| **Roles & Responsibilities** | The DEIP is innovative so far as it incorporates representatives (including Government, advocacy, regulatory, finance and research organisations) in the process of prioritising, defining and leading a broad range of DER projects which are likely to be highly influential in the Australian context. |
| **Architectural Methodologies / Models applied in the design of the Project / Initiative** | |
| The project is a collaboration of stakeholders and doesn't rely upon a specific architectural methodology, however, does refer to frameworks contained in:<br>• Open Energy Networks (DER control)<br>• ARENA The State of DER Technology Integration Report (integration functionality) | |
| **Key Reference Documents** | |
| 202103 - Distributed Energy Integration Program – CEO Forum Presentation | |

| Project / Initiative Details | |
|---|---|
| **Name** | The Role of Decentralised Control for Managing Network Constraints for DER on Regional, Rural and Remote Networks |
| **Lead Organisation** | Dynamic Limits |
| **Partner Organisations** | Essential Energy, SAGE Automation, Opto22, and UniSA. Funded by ARENA |
| **Budget** | $798k ($292k funded by ARENA) |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

A feasibility study on a proposed Decentralised Dynamic Limits Control Scheme (the DDL Control Scheme) for implementing dynamic control for DER to increase the hosting capacity of electricity networks with a particular focus on regional, rural and remote network sections. The work first outlines how a distribution feeder's thermal capacity constraints and voltage limits combine to create an operational window within which DER import and export is bound. It then explains the shortcomings of current approaches to managing DER, with a particular focus on Power Quality Response Modes as found in AS4777.2:2015.

With ENA and AEMO's OpEN Initiative and supporting reports as context, the project nominated 5 key principles that support the hypothesis that decentralised control of DER for the management of local network constraints can provide a range of benefits. They are:

1. DER Network Constraint Management must be prioritized above DER Orchestration
2. Subsidiarity – efficient and effective outcomes are best achieved when decisions are made at the lowest level possible of a hierarchy.
3. Customer Choice must be enhanced
4. Heterogeneity of Solutions – a constraint management scheme should support a variety of technologies.
5. Rural distribution networks have different economics and characteristics to urban networks which must be considered when developing control schemes.

With these principles in view, the project proposes a Decentralised Dynamic Limits (DDL) control scheme. This scheme is built on four key elements – network sensors, the Open Network Data Platform (ONDP), DER Controllers and Dynamic Limits Profiles (DLP). Following the OpEN's Initiative EA Technology Report framework, the scheme performs three tasks, it determines network constraints, defines operating envelopes (based on network constraints) and communicates the operating envelopes.

The project identified a number of benefits associated with the DDL Control Scheme, namely, overcoming the challenges of latency cascading, tier bypassing and hidden coupling; constraint monitoring at the point of constraint, rather than by applying network models; modular nature of the solution allowing for discrete implementation where needed or desired, as opposed to needing to be deployed across large parts of the network at once.; improved visibility of DER behaviour; transparency and verifiability, as network sensor provide actual constraints as opposed to network models producing theoretical state estimation; and the ability to manage the failure of any component of the scheme; automated reporting based on local intelligence; ability to monitor curtailment levels and hence report on compliance; and opportunities to assess and address customer equity. The study also examined

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| issues relevant to customers, safety, integration with existing SCADA and distribution management systems, cyber security, data management and integration with other existing and emerging actors.<br><br>A desktop feasibility study was developed and modelled for three scenarios. The final conclusions posit that DER installation size can be increased by three to five-fold under the typical rural supply scenarios modelled with only minimal curtailment of energy. | |
| **Key Objectives**<br><br>To test the hypothesis that the decentralized control of DER for the management of local network constraints can provide a range of benefits, especially where the distribution network is weakest and resource constrained (in terms of revenue per km of network managed). | |
| **Key Deliverables**<br><br>• A Final Report<br>• Desktop Feasibility Study based on modelling three different scenarios<br>• Stakeholder Engagement Activities | |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
| **Power System Architecture** | The project's supporting principles are a helpful example of architectural considerations. Of note is the priority on subsidiarity and importance place on a framework that supports heterogeneity of solutions.<br><br>The project also considered integration and interaction with other actors (and their associated systems and technologies) emerging business models, and highlighted the advantage of an open-source platform such as ONDP that manages the interface with each energy services aggregation platform, eliminating the need for multiple separate interfaces with each DER installation. |
| **Regulatory Innovation** | Not considered. |
| **Market innovation** | Not considered. |
| **T-D Interface** | Not considered. |
| **DER Control Architecture innovation** | This work tackles key challenges of DER Control Architecture, specifically those outlined in the Newport Consulting report developed as part of the OpEN process. The challenges addressed include:<br><br>• Tier Bypassing<br>• Latency Cascading<br>• Hidden Coupling<br><br>It also provides a worked example of coordinating DER constraint management with DER orchestration. |

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| **Roles & Responsibilities** | Not considered. |

| **Architectural Methodologies / Models applied in the design of the Project / Initiative** |
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| Subsidiarity<br><br>The project also considered integration and interaction with other actors (and their associated systems and technologies) emerging business models, and highlighted the advantage of an open-source platform such as ONDP that manages the interface with each energy services aggregation platform, eliminating the need for multiple separate interfaces with each DER installation. |

| **Key Reference Documents** |
|---|
| 2020-08 The Role of Decentralised Control for managing Network Constraints for DER on Regional, Rural, and Remote Networks. |

# International Project Scan

The Action Research Plan has been informed by a range of projects and initiatives in the United States, the United Kingdom and Australia.  A key aim was to review a wide range of initiatives to identify and recommend an integrated and adaptive combination of methodologies and activities suitable for application in Australia.

The following section provides a detailed analysis of a range of projects and initiatives underway or recently completed globally that have relevance to the above objective.

| International Projects and Initiatives | | |
|---|---|---|
| **Project / Initiative** | **Sponsor** | **Type** |
| **North America** | | |
| Grid Modernisation Laboratory Consortia (GMLC) | Pacific Northwest National Labs (PNNL) | Research |
| Development of a T-D Interoperability Framework | Independent System Operator Ontario (IESO) | White Paper |
| Modern Distribution Operation (DSPx) | US Department of Energy | |
| **United Kingdom** | | |
| Future Power System Architecture (FPSA) | Energy Systems Catapult & Institution of Engineering and Technology (IET) | National Reform Initiative |
| Open Networks | Energy Networks Association (UK) | Industry Collaboration |
| **Europe** | | |
| Universal Smart Energy Framework (USEF) | USEF Foundation (Alliander, Stedin, ABB, DNV GL, IBM, ICT, Essent) | Industry Collaboration |
| TSO-DSO Coordination for Acquiring Ancillary Services from Distribution Grids | International Smart Grid Action Network | |

| Project / Initiative Details | |
|---|---|
| **Name** | Grid Modernization Laboratory Consortium – Grid Architecture |
| **Lead Organisation** | United States Department of Energy |
| **Partner Organisations** | Pacific Northwest National Lab (PNNL), Electric Power Research Institute (EPRI), Smart Energy Power Alliance (SEPA), GWU Law, Utilities Technology Council (UTC), Omnetric Group, California ISO, MISO, SMUD, Great River Energy, and Enernex |
| **Budget** | $220 million (USD) over three years for parent program, $3 million (USD) for Grid Architecture |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

Grid Architecture is a comprehensive set of discipline expertise that has been developed by the US Department of Energy, Pacific Northwest National Lab, and the Grid Modernisation Laboratory Consortia. Matured over the last ten years, a comprehensive set of tools and methodologies are provided that are adaptable to any combination of industry, market and regulatory configurations and/or policy objectives.

The integrated discipline set has been developed through the combination of Systems Architecture, Network Theory, Control Theory and Software Engineering disciplines. It has a primary focus on the underlying structure of GW-scale power systems which are formally defined as Ultra-Large-Scale (ULS) complex systems. This is seen as critical as the structure or architecture of a complex system (as distinct from its components) has a disproportionate influence on what the system can efficiently and reliably perform.

Grid Architecture engages with each power system as a complex 'Network of Structures' and provides tools for analysing the inter-dependencies across the following distinct structures that intersect and dynamically interact with each other:

(a) Industry Structure

(b) Electricity Infrastructure;

(c) Operational Control Structure;

(d) Market Transaction Structure;

(e) Digital Infrastructure

(f) Coordination Framework; and,

(g) Convergent Networks.

Importantly, it is recognised that most of these seven structures have evolved progressively over decades in the context of a highly centralised power system. They are subject to hidden and overt interactions, cross-couplings, constraints and dependencies.

Ultimately, consistent with the established Systems Architecture engineering discipline, a key emphasis of Grid Architecture is that where underlying structure is well aligned with the system's current or emerging future purpose, all the elements will function effectively together, and the system will be more scalable and extensible. By contrast, however, where the structure is misaligned with current or future needs, technology integration becomes increasingly costly, investments are stranded, and full benefits realisation is placed at risk.

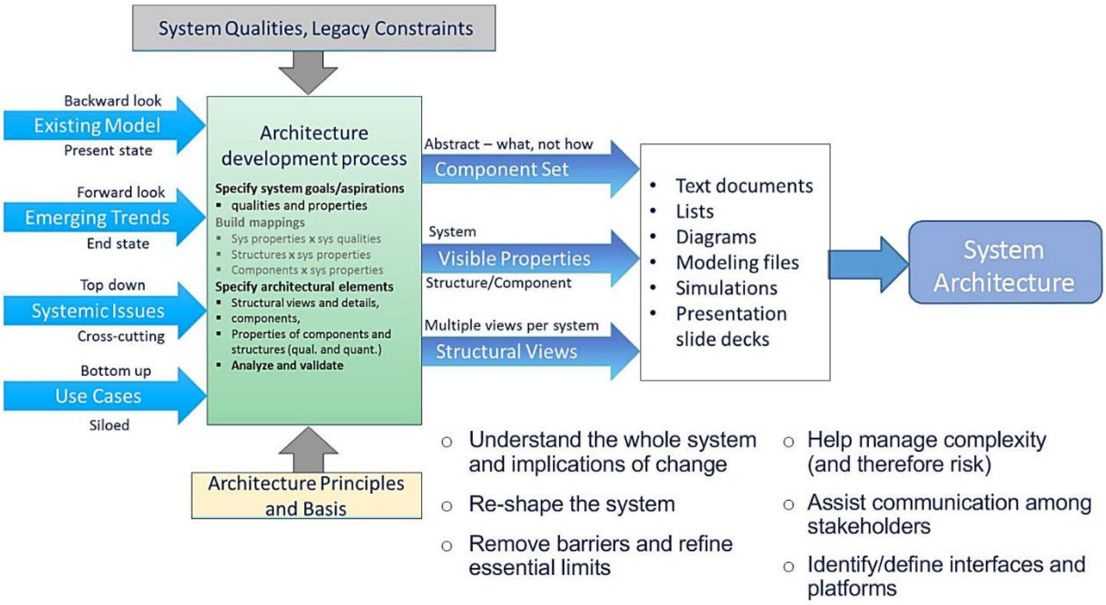


*Figure 1 An overview of the Grid Architecture Discipline and Artefacts (from the GA Guidebook 2nd Edition)*

**Key Objectives**

- Enable reasoning about a system's structure and behavior.
- Enable prediction of system characteristics.
- Manifest the earliest design decisions/constraints; shapes the system.
- Define essential limits in the form of enforceable structural constraints.
- Help stakeholders understand the whole system and the implications of change; removes existing structural barriers.
- Help manage system complexity and therefore risk.
- Facilitate communication among stakeholders (internal and external).
- Help identify gaps in theory, technology, organization, regulation, etc.
- Helps identify/define interfaces and platforms.

**Key Deliverables**

- A suite of Reference Architectures for particular system characteristics
- Numerous White Papers
- Articles and Presentations

| How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements. | |
|---|---|
| **Power System Architecture** | Grid Architecture is an integrated methodology for assessing and adapting a power system's underlying structures to be fit for purpose and future-proofed at least cost. The suite of analytical tools, mathematical models and concepts are all built on the premise that the properties of the system should map back to the desired qualities of customers. Architecture, as defined by PNNL, is not and should not include design, rather, it should specify the minimum number of constraints that simplify all the downstream decisions while defining the essential outline of shape of the system. Interface definition, and therefore interoperability, should come about as a consequence of architectural structure. An architecture should allow for multiple possible implementations. |
| **Regulatory Innovation** | Grid Architecture considers regulatory structures as one of the essential elements of the Network of Structures that make up the modern power system. |
| **Market innovation** | While the detailed design of markets is not the purview of Grid Architecture, they are considered as one of the essential elements of the Network of Structures. In particular, Grid Architecture takes a sophisticated approach to the roles of both technological controls and market functions as dual elements of the Operational Coordination structures required in a modern power system. |
| **T-D Interface** | As indicated above, coordination frameworks are a central focus of Grid Architecture focused extensively on coordination of distributed control. It provides detailed treatment of techniques for analysing and quantifying coordination, including layered decomposition, which is a form of optimization theory. This is tightly coupled with DER Control as described below. |
| **DER Control Architecture innovation** | Extensive research has been undertaken on best practice for DER control architecture – particularly on 'market-control' structures. This is essential to avoid unintentionally creating the conditions where latency cascading, structural flexibility and a wide range of other issues will arise when attempting to scale new solutions. |

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| **Roles & Responsibilities** | Grid Architecture is entirely agnostic to who does what in the power system. However, its empirical approach to analysing the Network of Structures that makes up the power system provides valuable objective insights that enable more informed, collective reasoning about the distribution of future roles and responsibilities. This can significantly reduce unnecessary stakeholder conflict on many issues and allow a more constructive and time-efficient focus on the most critical issues for debate. |
| **Key Reference Documents** | |
| 2019-09 PNNL - Selected Grid Architecture Principles & Consequences<br>2017-07 PNNL - Platforms as an Architectural Concept<br>2017-06 PNNL - Electric Grid Market-Control Structure<br>2016-06 PNNL - Architectural Basis for Highly Distributed Transactive Power Grids<br>2016-02 PNNL - Sensing and Measurement Architecture for Grid Modernization | |

| Project / Initiative Details | |
|---|---|
| **Name** | Development of a T-D Interoperability Framework (White Paper) |
| **Lead Organisation** | Independent Electricity System Operator |
| **Partner Organisations** | None |
| **Budget** | Unknown |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

This white paper aims to provide readers with a practical understanding of how interoperability between the transmission and distribution systems could evolve to support a system with growing numbers of DERs, while realising all of the benefits of these new technologies and maintaining safety and reliability. Central to this is how the roles and responsibilities of key players and functional capabilities could evolve to enable enhanced coordination between the transmission and distribution systems. The assignment of roles and responsibilities primarily concerns two players – the transmission system operator (TSO), which in Ontario is the IESO, and the distribution system operator (DSO). The role of the latter is currently performed by local distribution companies (LDCs), whose capabilities to support DSO functionalities are still evolving. This assignment may vary depending on the key players involved in the electricity system and the interfaces between them.

To guide these important decisions, this white paper provides a framework to help Ontario design a transmission distribution (T-D) interoperability model based on a set of system objectives, the System features needed to achieve these objectives, the roles and responsibilities of and interfaces between key players and the operational systems needed to enable this coordination. This paper introduces two bookend T-D interoperability models where either the TSO or DSO takes full responsibility for distribution system operations and DER optimization, and then applies the framework to two alternative hybrid models where these responsibilities are shared. A comparative analysis highlights the relative strengths and weaknesses of each, and includes changes that may be needed in order to achieve a desired system design given Ontario's emerging industry structure over the next five to 10 years.

**Key Objectives**

- Framing Questions:
    - How do we maximize the potential of distributed energy resources?
    - And how will Ontario's electricity landscape change over the next five to 10 years to accommodate that growth?

**Key Deliverables**

- White Paper: Development of a Transmission-Distribution Interoperability Framework
- The paper outlines next steps to advance the approach outlined as:

**1**

**Define Ontario's system objectives and enable regulatory changes**

A final set of objectives to guide system evolution needs to be collaboratively defined and accepted by key Ontario stakeholders, and accompanied by regulatory changes required to achieve the objectives.

**2**

**Identify and describe T-D interoperability models of interest to Ontario and apply the Ontario-specific decision framework to choose the interoperability architecture**

After fully considering a range of options, Ontario can use the decision framework that combines Ontario-specific objectives and grid architecture principles to determine the most suitable T-D interoperability model(s) for further analysis.

**3**

**Conduct a detailed grid architecture assessment of the selected model**

A detailed architectural assessment of the selected T-D interoperability model(s) applies engineering analysis and operational risk assessments to determine effective structural options, and map the functionalities to the operational system(s) that will enable them.

**4**

**Continue efforts to integrate DERs and reflect their value in market opportunities**

Examples include the York Region demonstration project, which aims to prove the value of NWAs, the IESO's efforts to identify participation models for DERs, and the IESO's plans to implement a capacity auction.

**5**

**Facilitate collaboration between the IESO, LDCs and DER providers on operational coordination requirements and systems**

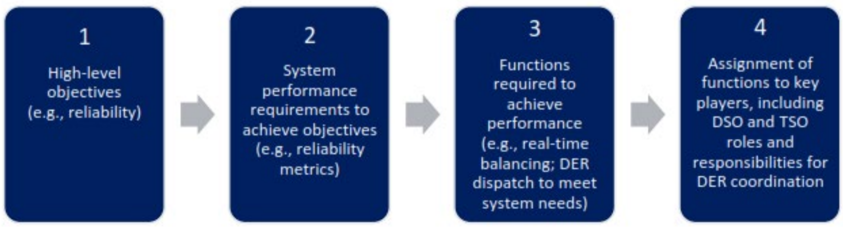
Discussions in Ontario should continue about how best to structure this coordination in the near term, considering the potential for developing a shared DER lifecycle management coordination platform.

**6**

**Design and implement pilots and demonstration projects to test key aspects of T-D interoperability**

Ontario should explore additional opportunities to test critical aspects of T-D interoperability, such as the York Region demonstration project.

<table>
<tr><th colspan="2">How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.</th></tr>
<tr><td>Power System Architecture</td><td>The white paper provides a useful example of utilizing modern architectural tools to evaluate and optimize legacy electricity system structures. The authors provide overview structure diagrams for Ontario’s current/emerging electricity system demarcated into 4 layers: the Power Flow Layer, Operational Control Layer, Market Transaction Layer, and Information/Data Exchange Layer. This enables subsequent reasoning about required new or extended interactions to support new functions – such as DER participation in the wholesale market across the T-D interface.<br><br>It also applies (and describes) seven principles of architecture:<br><br>1. Observability<br>2. Scalability<br>3. Cybersecurity vulnerability<br>4. Layered decomposition<br>5. Tier bypassing<br>6. Hidden coupling<br>7. Latency cascading</td></tr>
</table>

<table>
<tr><td>Regulatory Innovation</td><td>The white paper findings are intended to inform policy and regulatory efforts related to the evolution of the distribution system and resulting T-D interoperability needs in Ontario.</td></tr>
<tr><td>Market innovation</td><td>The wholesale market features as a consideration in the interoperability framework, but only as it relates to participation by DER at lower levels of the system.</td></tr>
<tr><td>T-D Interface</td><td>The paper interrogates three alternate options for T-D interoperability: a Total TSO, two alternate Hybrid DSO models, Total DSO. Each is assessed against a common set of structural characteristics, including coordination and allocation of roles and responsibilities.</td></tr>
<tr><td>DER Control Architecture innovation</td><td>The paper outlines what foundational systems will be needed for DER integration and some proposed conceptual architectures for LDCs (distribution operations). It also covers the operational interfaces for information and controls (dispatch).</td></tr>
<tr><td>Roles & Responsibilities</td><td>The paper provides a practical understanding of how the roles and responsibilities of key players, including transmission and distribution system operators, and functional capabilities could evolve to serve a system with a much greater number of (DERs) using the following methodology originating from the high-level objectives:<br><br>Figure 1: How grid architecture builds on system objectives<br>

<br>Additional analysis relevant to the assigning of roles includes describing the operational interfaces between entities, data exchange requirements, and information and communication technologies required to coordinate system operations</td></tr>
</table>

| Architectural Methodologies / Models applied in the design of the Project / Initiative |
| --- |
| As mentioned above, the white paper using the following architecture methodologies and principles:<br>1. Observability<br>2. Scalability<br>3. Cybersecurity vulnerability<br>4. Layered decomposition<br>5. Tier bypassing<br>6. Hidden coupling<br>7. Latency cascading<br>This discipline expertise is applied across the three hypothetical models outlined. |
| **Key Reference Documents** |
| 2020-05 IESO - Development of a T-D Coordination Framework |

| Project / Initiative Details | |
|---|---|
| **Name** | Modern Distribution Grid (DSPx) : Volumes 1 and 2 |
| **Lead Organisation** | US Department of Energy |
| **Partner Organisations** | Various state utilities, organisations and industry partners. |
| **Budget** | Unknown |

| Project / Initiative Overview, Objectives & Deliverables |
|---|
| **Project Overview**<br>The U.S. Department of Energy is working with state regulators, the utility industry, energy services companies, and technology developers to determine the functional requirements for a modern distribution grid that provides enhanced safety, reliability, resilience and operational efficiency, and integrates and utilizes distributed energy resources (DERs).<br>A multi-level taxonomy is employed to logically organize and align the identified objectives, capabilities, and functionalities of a modern grid drawn from a set of existing state principles. This taxonomy framework (DSPx taxonomy) seeks to provide a line-of-sight between what states are aiming to achieve (i.e., policy principles and key objectives of a modern grid), and how distribution system capabilities, functionalities, and related technologies can align to enable the full participation of DERs in the provision of electricity services.<br>The DSPx taxonomy framework has five layers: principles, objectives, capabilities, functionalities and technologies.<br>The report identifies 13 normalised state objectives and maps them against 28 capabilities and 42 functionalities which are categorised under Distribution Grid Operation (DGO), Distribution System Planning (DSP) or Distribution Market Operation (DMO).<br>In volume 2 the functionalities are mapped to overarching “technology categories,” and represented by means of a hierarchical taxonomy, and a maturity assessment of the technology and a summary description of tools and processes is provided.  A technology gap analysis is provided indicating areas where the framework will require further development for full functionality of DSP to be realised.<br>Volumes 1 and 2 combined enable a detailed assessment of grid modernization from state policy objectives to the related functional requirements and ultimately the technology needed. |
| **Key Objectives**<br>The objective of the DSPx is to develop a common framework for distribution grid modernization that establishes a consistent understanding of functional requirements necessary to inform investments in grid modernization and serve as a guide for the industry. These requirements include those needed to support grid planning, operations, and markets. |

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| **Key Deliverables**<br>• Volume 1 provides a taxonomy including mapping of objectives to capabilities to functions.<br>• Volume 2 identifies the enabling technologies linked to the functionalities identified in Volume 1 of the report.<br>• Volume 2 also identifies technology maturity and areas for future R&D. |

| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
|---|---|
| **Power System Architecture** | The DSPx taxonomy provides a normalised set of objectives and functions, spanning the entire gamut of distribution grid management and operation, and maps their interrelationship. It is a useful accompaniment and input to ensure consistency and standardisation of definition across GA models.<br>The DSPx taxonomy maps to parts of the Gridwise Architecture Council and EPRI Intelligrid reference models. |
| **Regulatory Innovation** | Not considered. |
| **Market innovation** | Not considered. |
| **T-D Interface** | Not considered. |
| **DER Control Architecture innovation** | Not considered. |
| **Roles & Responsibilities** | Not considered. |

| **Architectural Methodologies / Models applied in the design of the Project / Initiative** |
|---|
| None used. |

| **Key Reference Documents** |
|---|
| 2019-11 DOE - MODERN DISTRIBUTION GRID (DSPx) – Volume 1<br>2019-11 DOE - MODERN DISTRIBUTION GRID (DSPx) - Volume II |

| Project / Initiative Details | |
|---|---|
| **Name** | Future Power System Architecture |
| **Lead Organisation** | Institution of Engineering and Technology (IET) Energy Systems Catapult |
| **Partner Organisations** | UK Government, Innovate UK |
| **Budget** | Unknown |

**Project / Initiative Overview, Objectives & Deliverables**

**Project Overview**

The Future Power System Architecture program was a collaboration between the UK Energy Systems Catapult and the Institution of Engineering and Technology. Developed over 5-years to 2019, it had a key focus on enabling the UK's ambitious national decarbonisation goals.

FPSA applied a Whole System approach to considering the evolving power system and demand side together with how they interact with other energy vectors including transport and heat. The program focused on:

a) Identification of the new or significantly modified functions required by Britain's power system to support deep decarbonisation ambitions by 2030;
b) Investigating the barriers to developing and implementation of the identified functions; and,
c) Developing proposals for more innovative change and governance approaches to support more agile and holistic delivery of the required functionalities.

The critical functions and related change mechanisms were identified in the context of the four dominant time horizons, namely: investment planning, operational planning, real time operation and markets and settlement.

**Key Objectives**

a) Design a competitive framework to address the energy trilemma, of balancing the need for sustainability, cost effectiveness, and security of supply.
b) Manage the interface with connected energy systems.
c) Form and share best view of the state of the system in each time scale.
d) Use smart grid and other technologies to accommodate new demand, generation and energy resources.
e) Enable and execute necessary operator interventions.
f) Monitor trends and scan for the emerging risks/ opportunities on the power system, and implement appropriate responses.
g) Provide capabilities for use in emergencies.
h) Develop the market and the power system to support customer aspirations and new functionality.

<table>
<tr><td colspan="2">Key Deliverables<br><br>• FPSA Stage 1 – identify the thirty-five new or enhanced functions that need to be addressed with some urgency.<br>• FPSA Stage 2, build on Stage 1 to deepen the analysis of requirements, understand barriers to implementation, and to consider innovative frameworks for delivering required new functionality.<br>• FPSA Stage 3 – build further on the EFs activity completed in FPSA2 and validate this work by developing a framework (and associated tools and techniques) for one or more use cases (a possible use case could be the functions needed to enable EV deployment).<br>• FPSA Stage 4 – build and execute a portfolio of projects to address innovation requirements and opportunities identified in FPSA2 which are aligned with implementation of the thirty-five functions.</td></tr>
<tr><td colspan="2">How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.</td></tr>
<tr><td>Power System Architecture</td><td>The FPSA project has used systems engineering methods in a structured and systematic approach to explore potential requirements for new or extended functionality in the GB power sector as it might be in 2030.<br><br>The project identified technical functions that predominately challenged the current institutional arrangements for delivery in the future and then tested a number of new or extended system functions contextualised and justified through the systems engineering approaches (including requirements, functions, systems, and overall GB system concepts.<br><br>As distinct from similar projects, FPSA defines architecture as the designed and emergent structure of a system, and the manner in which the physical, informational, operational and economic components of a system are organised and integrated. FPSA undertook a holistic and whole-system approach to the evolution of its architecture – considering technical, governance, commercial and societal factors.</td></tr>
<tr><td>Regulatory Innovation</td><td rowspan="2">The work first distilled the 35 functions necessary for the future power system. The intent being that identified functions and the challenges to implement them could be used as an input to consider the technical, institutional, regulatory and market developments necessary to ensure that the power sector meets future needs securely and efficiently and enables emission goals.</td></tr>
<tr><td>Market innovation</td></tr>
<tr><td>T-D Interface</td><td>Many of the 35 future functions are related to the interactions between the bulk energy system and the distribution system. Dependency mapping and solution uncertainty assessments provide further clarity on sequencing of development and implementation activities to support efficient coordination.</td></tr>
</table>

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| **DER Control Architecture innovation** | Given the UK context of the FPSA program, it had less emphasis on the role of DER than would typically be expected in the Australian context.  Nevertheless, it identified the need for to provide capability to enable new energy resources (E3), to implement energy resources within the market environment (E6) and to monitor and control/influence energy resources (E7). As of May 2019, these functions were graded as requiring significant work to understand requirements, identify solutions and resolve challenges. |
| **Roles & Responsibilities** | The FPSA program considered the assignment of roles as an extension of existing activity. The relevant function is: implement and coordinate a framework where the roles and value propositions of all significant stakeholders across the power sector can be managed (H3). |

**Architectural Methodologies / Models applied in the design of the Project / Initiative**

FPSA adopted a systems engineering approach to discovering the true nature of the challenge and tackling complexities as early as possible in the project life-cycle. This involved looking at all possibilities and evaluating them using practical tools such as the *concept engineering*. In Concept Engineering, as far as possible, the power system is understood without investigating the internal operation of its constituent systems. These are treated as 'black boxes' for which their properties and interfaces, as seen externally, are sufficient to define the contribution they make to the power system.

Systems engineering processes often rely on two principles:

1. The 'separation of concerns' that allows functions to be de-coupled from the various system configurations that might deliver them, the basis of innovation.
2. A 'single point of truth', based on a project structure that maintains a consistent relationship between all the elements being addressed, allowing stakeholders to ask questions from their own perspective and all receive answers that are consistent with the others.

**Key Reference Documents**

2019-05 ESC - Future Power System Architecture 4 - Review of 35 Functions

2017-12 ESC – Future Power System Architecture 2.2 - Main Report

| Project / Initiative Details | |
|---|---|
| **Name** | Open Networks Project |
| **Lead Organisation** | Energy Networks Association (ENA) UK |
| **Partner Organisations** | None |
| **Budget** | Unknown |

| Project / Initiative Overview, Objectives & Deliverables |
|---|
| UK Energy Networks Association commissioned the Open Networks Project to provide an enhanced perspective on the network transformation and transition that is required to support a transition to a high-renewables energy system. The DSO Transition workstream has considered 5 possible future market frameworks that could materialize as part of a DSO transition. This initial work was considered by Open Networks between September 2017 and June 2018. Extensive consultations were undertaken to explore the processes and interactions required for each framework to operate. This foundation was used to map to the first three layers of the SGAM (Smart Grid Architecture Model) framework (Business, function and information layers) to allow comparison and assessment between future market frameworks to occur.<br><br>The five frameworks initially created include:<br><br>• DSO Coordinates – where DSO acts as a technical gatekeeper to ensure network performance is maintained. It is considered to be effective at managing local constraints with a high degree of coordination required between the DSO and ESO (Market Operator) to ensure appropriate levels of service provision through the DSO to markets.<br>• Coordinated Procurement and Dispatch – a shared framework where both the DSO and ESO (Market Operator) makes arrangements to manage their own requirements with careful coordination and management of conflicts required to eliminate hidden coupling or tiered bypass. Conflict resolution requires near real-time communication and decision making between the DSO, ESO and other actors to ensure secure and reliable system operation.<br>• Price Driven flexibility (Network access and charging model) – explores a framework where dynamic price signals provide direction to resources to address a range of system challenges. This requires (near to) real-time price signals and supporting data provision which is recognized as complex. Price signals also need to address (and balance) both longer-term constraints and shorter-term constraints. Potential conflicts between physical network constraints and requirements of the market will need to be managed.<br>• ESO (Market Operator) Coordinates – Allows for simple coordination of flexibility at scale to address broader market and system level operational needs. Requires close coordination between DSO and ESO however there is a risk that locational needs and requirements of the DSOs may be unaddressed. |

- **Flexibility Coordinators –** focuses efforts on a flexibility coordinator who is responsible for coordination of resources to meet the needs of DSO and ESO (market operator). It is likely to require a large degree of data processing in real-time to provide market and capacity limits to the Flexibility coordinator.

Published in 2019 an independent impact assessment looked at the various options needed to make DSO a reality in Great Britain and compared the strengths and weaknesses of the different frameworks or 'Future Worlds' against over 30 criteria, including decarbonisation and cost to the consumer[23]. This detailed analysis in 2019[24] suggested that the benefits of a price-driven flexibility model were not likely to emerge in isolation but rather would create additional benefit by being embedded within the other frameworks leading to an updated set of frameworks and four transitions being:

- **Transition path 1: Continued joint procurement and co-ordination between DSOs and ESOs** – considered a 'least-change' path where coordination between ESO and DSO is proven to be effective. This is an extension of the coordinated procurement and dispatch framework.
- **Transition path 2: Move to DSO led co-ordination** – likely to be triggered by a high DER uptake scenario where coordination across ESOs and DSOs becomes difficult. Would only occur where local coordination benefits are strong in terms of local network management due to increased mix of localized DER challenges and opportunities.
- **Transition path 3: Move to ESO led co-ordination** – likely to be triggered where there is less value to be extracted from local flexibility markets due to low uptake of DER or because reformed network access and pricing arrangements are effective in eliciting coordinated customer responses at an LV/localized levels.
- **Transition path 4: Move to independent Flexibility Coordinators** – likely to be driven by concerns that conflicts between the DSO and ESO are unable to be addressed transparently or easily. An aggregator focused model, would see flexibility coordinators procuring DER services on behalf of both ESOs and DSOs.

In subsequent consultation ENA determined that the process to design and assess the four likely frameworks and transition pathways were well supported. ENA then planned to build on these four frameworks from 2019 noting that[25]: "Developing a least regrets pathway allows us to consider options in the future as more evidence becomes available. Any significant shift in future roles and responsibilities will be supported by a robust Impact Assessment on developed operating models. No future options and pathways are off the table at this stage."

[23] https://www.energynetworks.org/industry-hub/resource-library/open-networks-2021-ws3-p1-dso-roadmap-and-implementation-plan-webinar-slide-pack-(20-apr-2021).pdf

[24] https://www.energynetworks.org/industry-hub/resource-library/open-networks-2019-ws3-future-world-impact-assessment-report.pdf

[25] 2019. UK ENA. Impact Assessment consultation. https://www.energynetworks.org/industry-hub/resource-library/open-networks-2019-ws3-impact-assessment-consultation-onp-response.pdf

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| **Key Objectives**<br>The ENA Open Networks Project is laying the foundations of the smart grid in the UK and is helping to inform similar developments in Ireland. It is a key initiative to deliver Government policy set out in the Ofgem and BEIS Smart Systems and Flexibility Plan, the Government's Industrial Strategy and the Clean Growth Plan, working in collaboration with Ofgem, BEIS, 10 of UK and Ireland's electricity network operators, and other key stakeholders.<br>The Open Networks Project is organised into five workstreams:<br>Workstream 1 – T-D Processes focusing on transmission-distribution (T-D) investment and operational planning processes with a focus to put in place improved processes in the shorter term.<br>Workstream 2 – Customer Experience focusing on improving Customer experience and ensuring that processes and information meet Customer requirements.<br>Workstream 3 – DSO Transition developing and implementing Distribution System Operator (DSO) functionality to enable the development and use of Distributed Energy Resource (DER) solutions and to support whole system optimisation of investment and operation.<br>Workstream 4 – Charging assessing network access and charging arrangements and supporting Ofgem's ongoing reviews.<br>Workstream 5 – Communications leading on communications related to the Open Networks Project to ensure coordinated and effective interactions with stakeholders.<br>Design principles:<br>Open Networks and UK Energy networks Association set out key principles to underpin potential market and energy system frameworks, being:<br>• Neutral Market facilitation to enable market facilitators to enact flexibility markets and platforms that provide visibility of the opportunities for buyers and sellers of flexibility and that manage any resulting conflicts from service provision.<br>• Need for System Operators (and Flexibility coordinator role) to be neutral to ensure value is fairly apportioned to customers through neutral market facilitation.<br>• DNO/DSO as neutral facilitator of markets to apply as a principle to DSOs in all frameworks. |
| **Key Deliverables**<br>In late 2020 the Open Networks project established that[26]: We agree that action needs to be taken now, which is why we are suggesting practical development of DSO – ESO coordination now. There is no "no change" option – we need to enhance DSO – ESO coordination to start to realise DSO benefits for customers and consumers. As above, no future options/pathways are off the table at this stage. |

[26][26]2019. UK ENA. Impact Assessment consultation. https://www.energynetworks.org/industry-hub/resource-library/open-networks-2019-ws3-impact-assessment-consultation-onp-response.pdf

Subsequent work emphasizes development of the DSO-ESO coordination approach building upon existing practices while delivering flexibility commitments. This will build on the work of several DNOs to demonstrate enhanced DSO-ESO coordination to inform future learnings. Incorporating price driven flexibility will also enhance the benefits of development across all futures while recognizing the need for regional flexibility in approaches. As Distribution Networks advance towards increasing penetrations of renewables it is prudent that development towards a model more suited to the emerging environment continues. Defining the next evidence-based steps is *considered a 'least regrets' approach which can be evidenced by the most efficient and economically beneficial solutions*.[27]

The current priority of the Open Networks project is to deliver an action and implementation plan to deliver and track progress against. Assessing when networks will deliver tangible change is a high priority for Ofgem and therefore a focus of the Open Networks Project. The DSO Implementation plan will outline currently planned activities by DNOs and will map to DSO functions outlined in earlier in the Open Network Project process. This includes an emphasis on tracking network innovation in development and delivery of DSO Capability for the UK energy system.

Functions to be examined as part of ongoing implementation plan tracking and monitoring includes[28]:

- System Coordination – which considers how DSO-ESO coordination should and can occur
- Network Operation – considers the critical role of DNO in maintaining safe and secure local system operation
- Investment Planning – to develop approaches to identify capacity requirements for distribution networks and to secure the most efficient means of capacity provision.
- Connections and Connection Rights – aims to provide fair and cost-effective distribution network access through a range of connection options meeting customer requirements and system needs.
- System defence and restoration – which recognizes that DNOs and resources can play an increasing role in overall system resilience and restoration.
- Services and Market facilitation – to define distribution network service requirements and to support market arrangements put in place to provide these and other services.
- Service Optimisation – to ensure that system needs can be efficiently met across all timescales.
- Charging – recognizes a potential DSO role in setting charges for the connection and use of distribution networks. Increasingly this will require a whole of system view and close interaction between DNOs and system operators to design and efficiently manage efficient and equitable network pricing arrangements.

[27] 2019. UK ENA. Impact Assessment consultation. https://www.energynetworks.org/industry-hub/resource-library/open-networks-2019-ws3-impact-assessment-consultation-onp-response.pdf

[28] Network companies are targeting their efforts towards the DSO-ESO coordination, such as efforts related to the regional development programmes (RDPs), the co-ordinated use of Distributed Energy Resources (DER) and reactive power as well as the real-time data exchange. DSO-ESO coordination functionality is seen as a priority area and intended to be delivered early on in the process.

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| The Implementation Plan will provide insights into actions implemented to date as well as anticipated windows for future implementation. It serves as a tool to report progress and identify any barriers and gaps in delivering DSO functionality. | |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
| **Power System Architecture** | Through the SGAM assessment approach outlined above the Open Networks Project considers a range of potential transition pathways from current state to potential future state requirements. This transition will be determined by the pace of uptake of distributed energy resources and gradual development of required DSO and DSO-ESO interface requirements. Four transition pathways are mapped using the developed SGAM frameworks and will be monitored over time to determine the most appropriate pathway to progress. |
| **Regulatory Innovation** | Recognising the critical impact of pricing arrangements on network and system operation the Open Networks project highlights that understanding the effectiveness of network access arrangements and price signals at providing the flexibility which system operators require can inform the volume of flexibility services required and therefore the scale of system operation functions needed. This is particularly pertinent for consideration of a DSO led coordination framework, since effective network access arrangements and price signals can reduce complexity and, therefore, potentially the cost of the required coordination processes between the ESO and DSOs. |
| **Market innovation** | The introduction of a market-based approach to energy system transition requires the introduction of new contract requirements across a range of roles and actors. This inevitably raises the questions of how such activities are funded and where regulated entities are involved further research is required to determine how to apportion such costs fairly. |
| **T-D Interface** | Whilst the design of the energy sector is yet to be determined, it is clear that communications and IT systems will need to fundamentally change, irrespective of model selection. The DSO transition will create a large increase in the exchange of information and data.<br><br>For example, between the following actors in both directions:<br><br>– TSO – DSO<br>– DSO – Customers/Aggregators/Suppliers/DER<br>– TSO – Customer/Aggregators/Suppliers/ DER<br>– DSO – Network Assets<br>– TSO – Network Assets<br>– DSO – IDNO/IDSO. |

| | |
|---|---|
| | Open Networks recognizes that the transition to a DSO will require an integrated solution, with faster, more reliable communications. The transition to a DSO will result in a significant increase in telecommunication links between different internal stakeholders (asset management, SOs, network operators etc.) and external stakeholders (e.g. TSO, operators of distributed generation, Aggregators etc.) to provide DSOs with improved tools and information to monitor and operate the electricity network more effectively. Due to the important role telecommunications will play in future operation of the electricity network, it is essential that cyber security is fully considered and adequate controls are put into place to mitigate against the risk of future cyber-attacks.<br><br>Current work to examine DSO Functions required in "System Coordination" focuses on how network companies will operate local and regional areas and co-ordinate energy and power with other networks and systems to enable whole system planning, operation and optimisation across different timescales. The "System Coordination" Function involves considering local actions to support thermal, voltage and frequency management across networks including actions to minimise losses, manage constraints and provide capability.[29] Network companies are targeting their efforts towards DSO-ESO coordination, such as efforts related to the regional development programmes (RDPs), the co-ordinated use of Distributed Energy Resources (DER) and reactive power as well as the real-time data exchange. DSO-ESO coordination functionality is seen as a priority area and intended to be delivered early on in this process. |
| **DER Control Architecture innovation** | Not considered. |
| **Roles & Responsibilities** | The UK ENA Open Networks Project considers a range of future roles and responsibilities for DNOs transition to DSOs, expanded role for ESO (Energy System Operator) and potential for new role of Flexibility Coordinator. Different transition paths are identified and will be monitored to determine which transition will deliver the largest benefits for customers. This includes assessment of DSO capability required to support common pathways and to assess how best to manage DSO-ESO interfacing. |

[29] 2021. UK ENA. Open Networks Project DSO Implementation Plan. https://www.energynetworks.org/industry-hub/resource-library/open-networks-2021-ws3-p1-dso-implementation-plan-report-(31-mar-2021).pdf

| Architectural Methodologies / Models applied in the design of the Project / Initiative |
| --- |
| The Smart Grid Architecture Model (SGAM)[30] was applied to explore potential future energy system frameworks as it is a powerful way to capture complex models and allows specific aspects to be considered in as much detail as appropriate. The Open Networks SGAM model has been created in Sparx Enterprise Architect software which helps maintain stringent governance around the data and makes it easier to maintain and use the model in the future.<br><br>The purpose of the SGAM modelling was twofold: firstly, to compare and contrast the five Future Worlds, and secondly to act as a base model for DNOs to build their required architectures, interfaces and business processes around for the DSO transition. To enable detailed comparison of the Future Worlds, the interactions between actors are captured and categorised as part of the SGAM work.<br><br>The Open Project recognized inherent weaknesses within the SGAM model being[31]:.<br><br>1. SGAM cannot model the details of market operation. While it can capture market operation at a high level, for example how the market can operate and who will be active within it, it cannot capture the intricacies of how this market may operate.<br><br>2. SGAM does not capture human behaviour. Actors such as Customers (both active and passive) and Local Energy Markets may not always act in a logical way to financial incentives or direct instructions to change behaviour. Although the specific behaviour of these actors, or the detailed market interaction, may not be captured, providing this is kept in mind while integrating the models, then the main purpose of the models can be carried out. However, it is important to recognise that to understand these specific aspects further social science and market modelling will be required.<br><br>Open Networks intended to use SGAM to assess future frameworks by providing a tried and tested methodology for managing the scale of the task. In addition to this modelling work, in an exercise entitled Least Regrets Analysis, this approach identified key areas of functional commonality between all five Future Worlds. These areas are subsequently identified as significant opportunities to guide aspects of DSO transition; improving network efficiency, realising the opportunities for ancillary service providers and enhancing the experience for Customers. Identifying these areas and prioritising their implementation are a current focus for the Open Networks Project as these functional areas will be required in whatever Future World is agreed upon[32].<br><br>*Refer also to the ENA / AEMO Open Energy Networks (OpEN) project summary for additional information.* |

[30] https://www.energynetworks.org/industry-hub/resource-library/open-networks-2018-ws3-14969-ena-futureworlds-aw06-int.pdf

[31] https://www.energynetworks.org/industry-hub/resource-library/open-networks-2018-ws3-14969-ena-futureworlds-aw06-int.pdf

[32] 2021. UK ENA. Open Networks Project DSO Implementation Plan. https://www.energynetworks.org/industry-hub/resource-library/open-networks-2021-ws3-p1-dso-implementation-plan-report-(31-mar-2021).pdf

| Key Reference Documents |
| --- |
| 2018. Workstream 3 Modelling the Distribution System Operators (DSO) transition using the Smart Grid Architecture Model https://www.energynetworks.org/creating-tomorrows-networks/open-networks/<br><br>2018. Workstream 3 Developing change options to facilitate energy decarbonisation, digitisation and decentralisation https://www.energynetworks.org/industry-hub/resource-library/open-networks-2018-ws3-14969-ena-futureworlds-aw06-int.pdf<br><br>2019. UK ENA. Future World Impact Assessment. https://www.energynetworks.org/industry-hub/resource-library/open-networks-2019-ws3-future-world-impact-assessment-report.pdf<br><br>2019. https://www.energynetworks.org/industry-hub/resource-library/open-networks-2019-ws3-impact-assessment-consultation-detailed-analysis.pdf<br><br>2019. UK ENA. Impact Assessment consultation. https://www.energynetworks.org/industry-hub/resource-library/open-networks-2019-ws3-impact-assessment-consultation-onp-response.pdf<br><br>2020. UK ENA. DSO Innovation: Mapping to identify Distribution System Operation Gaps Mapping to https://www.energynetworks.org/industry-hub/resource-library/open-networks-2020-ws3-innovation-trials-final-report.pdf<br><br>2020. https://www.energynetworks.org/industry-hub/resource-library/open-networks-2020-ws3-p5-introductory-slides.pdf<br><br>2021. UK ENA. Open Networks Project DSO Implementation Plan. https://www.energynetworks.org/industry-hub/resource-library/open-networks-2021-ws3-p1-dso-implementation-plan-report-(31-mar-2021).pdf<br><br>https://www.energynetworks.org/industry-hub/resource-library/open-networks-2021-ws3-p1-dso-roadmap-and-implementation-plan-webinar-slide-pack-(20-apr-2021).pdf |

| Project / Initiative Details | |
|---|---|
| **Name** | Universal Smart Energy Framework (USEF) |
| **Lead Organisation** | USEF Foundation |
| **Partner Organisations** | Alliander, Stedin, ABB, DNV GL, IBM, ICT, Essent |
| **Budget** | Unknown |

| Project / Initiative Overview, Objectives & Deliverables |
|---|
| **Project Overview**<br>USEF has been established to drive the fastest, most cost-effective route to an integrated smart energy future. It delivers one common standard on which to build all smart energy products and services. It unlocks the value of flexible energy use by making it a tradeable commodity and by delivering the market structure and associated rules and tools required to make it work effectively.<br>The scope of the USEF Framework is the integration of Distributed Flexibility on the demand-side, i.e. behind-the-meter. USEF proposes seven Aggregator Implementation Models each describing how balance responsibility, sourcing position and information exchange are organized.<br>The USEF Flexibility Value Chain (FVC) provides an overview of the flexibility services which can be offered to all markets and products through distributed flexibility. The sixteen service types for explicit distributed flexibility are defined in the FVC. The service types are categorized by their purpose, i.e. why does the *Flexibility Requesting Party* request flexibility?<br>USEF defines a traffic light system comprising four different operating regimes depicting network status as normal, capacity managed, graceful degradation and outage which becomes an input to the market coordination mechanism.<br>The framework describes information flows between different phases of market coordination.<br>The USEF foundation ceases in July 2021. |
| **Key Objectives**<br>USEF primary goal is to develop a mechanism that allows Distributed Flexibility (DF) to be deployed in all markets and products whist respecting the freedom to connect, trade and dispatch electricity. |
| **Key Deliverables**<br>A pilot using USEF was completed controlling 203 smart appliances in Netherlands. Refer "Flexibility from residential power consumption: a new market filled with opportunities".<br>A selection of reference documents are available on the website:<br>https://www.usef.energy/news-events/publications/<br>Case study: Practical deployment of electric vehicle flexibility |

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| USEF Flexibility Trading Protocol Specifications 1.01<br>XSD files USEF Flexibility Trading Protocol<br>Energy & Flexibility Services for Citizens Energy Communities<br>Flexibility Value Stacking<br>DSO Workstream - Market-based congestion management models<br>Workstream on Aggregator implementation models |
| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** |

| | |
|---|---|
| **Power System Architecture** | Not considered. |
| **Regulatory Innovation** | Not considered. |
| **Market innovation** | The USEF Flex trading protocol (UFTP) is a subset of the USEF Framework. UFTP can be used as stand-alone protocol for flexibility forecasting offering, ordering and settlement processes.<br>The UFTP provides a complete XML messaging schema for all interactions between actors within the different processes described. |
| **T-D Interface** | Not considered. |
| **DER Control Architecture innovation** | USEF is not constrained to a prescribed coordination scheme. The USEF White Paper (refer references) considers its implementation within selected countries in Europe.<br>There are seven USEF Aggregation Implementation Models proposed to cater for a variety of market design of inter-relationships which may exist or be preferred in different jurisdictions. |
| **Roles & Responsibilities** | USEF provides a comprehensive map of the roles and responsibilities of various participants in the provision of DER Flex based upon implementation of an open market model for transacting services. |

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| **Architectural Methodologies / Models applied in the design of the Project / Initiative** |
| USEF provides a complete framework for DER Flexible dispatch including descriptions of actors, roles and responsibilities, constraints, information exchange and supporting protocol. Thus it is a turn key solution for implementation within the market and data and information layers of grid architecture. |

| Key Reference Documents |
| --- |
| 2021-05 Universal Smart Energy Framework (USEF) Summary<br>2021-03 USEF White Paper: Flexibility Deployment in Europe |

| Project / Initiative Details | |
|---|---|
| **Name** | TSO-DSO Coordination for Acquiring Ancillary Services from Distribution Grids - The Smartnet Project Final Results |
| **Lead Organisation** | Ricerca sul Sistema Energetico |
| **Partner Organisations** | 22 partners from 9 European Countries, including TSOs (Energinet.dk, TERNA), DSO (ENDESA, Nyfors/SE/Evonet, Edyna), manufacturers (SELTA, SIEMENS), and telecommunication companies (VODAFONE). |
| **Budget** | Unknown |

| Project / Initiative Overview, Objectives & Deliverables |
|---|
| Project Overview<br>The main aim of the SmartNet project is to compare different TSO-DSO coordination schemes for acquiring Ancillary Services (AS) from distributed resources: five coordination schemes were analysed in depth corresponding to different typologies (centralized, decentralized) and roles of the network operators (TSO and DSO):<br>1. Centralized AS market model (CS A): TSO contracts services directly from DER. No congestion management is carried out for distribution grids;<br>2. Local AS market model (CS B): DSO manages a local congestion market. Unused resources are transferred to the AS market managed by TSO (procuring balancing and congestion management);<br>3. Shared balancing Responsibility Model (CS C): TSO transfers to DSO balancing responsibility for the distribution grid. DSO manages local congestion and balancing market using local DER;<br>4. Common TSO-DSO AS Market Model (CS D): TSO and DSO manage together a common market (balancing and congestion management) for the whole system;<br>5. Integrated flexibility Market Model (CS E): TSOs, DSOs, and commercial market parties contract DER in a common flexibility market (raising regulatory problems: not implemented in simulation).<br>Four of them were implemented in simulation and compared in their technical and economic performance on the basis of three national scenarios referred to the target year 2030 for: Italy, Denmark and Spain.<br>Main findings can be summarized in the following eleven points:<br>1. Traditional TSO-centric schemes could stay optimal if distribution networks don't show significant congestion<br>2. More advanced centralized schemes incorporating distribution constraints show higher economic performances but their performance could be undermined by big forecasting errors<br>3. Technical reasons and high ICT costs dis-advise to give balancing responsibility to DSOs. |

4. Decentralized schemes are usually less efficient than centralized ones
5. Decentralized schemes request to put in place further coordination actions between TSO and DSO
6. Local congestion markets should have a “reasonable” size and guarantee a sufficient number of actors are in competition
7. Intraday markets should bring gate closure as close as possible to real time. However, it is not feasible to overlap a real-time session of intra-day market with a services market
8. Balancing and congestion markets should have as target not to optimize system social welfare (that is, by contrast, the goal of energy markets) but just to buy the minimum amount of resources to get the needed network services while perturbing the least possible the results of the energy markets.
9. Ensuring level playing field in the participation of distributed resources (especially industrial loads) to the tertiary market means to be able to incorporate into the market products some peculiarities of such resources
10. Reaction to commands coming from TSO or DSO in real time of the control loops which were initially planned for real time services provision can be too slow
11. ICT is nearly never an issue

**Key Objectives**

To compare different TSO-DSO interaction schemes and different real-time market architectures with the goal of finding out which would deliver the best compromise between costs and benefits for the system. The objective is to develop an *ad hoc* simulation platform which models all three layers (physical network, market and bidding), analysing three national cases (Italy, Denmark, Spain).

**Key Deliverables**

A comprehensive list of project deliverables is found at the end of the report.

- Final report evaluating comparison of the five Coordination Schemes (CS)
- Benchmarking of three countries as 2030 as basis for SmartNet simulation
- New SmartNet simulator to compare the CS performance across each of three countries using a cost benefit analysis
- CBA comparison of five CS
- Three technological pilots (in each of three countries) with complementary scopes

**How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.**

| | |
|---|---|
| **Power System Architecture** | Not considered. |
| **Regulatory Innovation** | Not considered. |
| **Market innovation** | The report considers an aggregator, having only a limited number of activations available in a day, may not dispatch immediately as it predicts the profit of later activation will be higher. The model proposes a Market Discomfort Cost (MDS) which represents an artificial cost, incorporated in the existing flexibility cost, that makes the aggregator indifferent between an immediate activation and the one in the future at a potentially better profit. |

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|---|---|
| **T-D Interface** | Not considered. |
| **DER Control Architecture innovation** | The project recognises latency as a risk so the aggregator in SmartNet, uses several technology specific aggregation models, aimed at separate DER categories, in order to take into account the physical constraints of the devices being aggregated, while enabling a fast, straightforward, aggregation/disaggregation procedure.<br><br>The report makes a qualitative assessment of the computational complexity of each TSO-DSO coordination scheme and finds the Centralised AS Market the simplest and the Common TSO-DSO AS and Integrated Flexibility market models the most complex.  This is consistent with the findings of the OpEN project.<br><br>The report finds that the Shared Balancing Responsibility model has lowest CBA performance under all scenarios. |
| **Roles & Responsibilities** | Not considered. |

**Architectural Methodologies / Models applied in the design of the Project / Initiative**

- The SmartNet uses CS which are similar to those proposed in the OpEN framework which were modelled using SGAM.
- SmartNet's ICT requirements capturing process is an extension to the SGAM approach. The developed analysis process enhances the SGAM approach by embedding communication and security requirements in each SGAM layer. As a result, ICT requirements are specified in business, function, information, communications, and component layers.
- SmartNet went beyond simulation and analysis to implement the structures into three pilots across three countries so they could be tested in real world scenarios.

**Key Reference Documents**

2019-05 SmartNet - TSO-DSO Interactions - Final Report

| Project / Initiative Details | |
|---|---|
| **Name** | Lessons learned from international projects on TSO- DSO interaction |
| **Lead Organisation** | ISGAN - International Energy Agency (IEA) Implementing Agreement for a Cooperative Program on Smart Grids |
| **Partner Organisations** | None |
| **Budget** | Unknown |

| Project / Initiative Overview, Objectives & Deliverables |
|---|

**Project Overview**

The project identifies EU projects which incorporate TSO-DSO interaction and relevant stakeholders (including ISGAN Annex 6 participants, project leaders, DSOs, TSOs, interested groups, etc.) to collect information pertaining to four key questions:

1. What have been the key **challenges** during the project
2. What have been the key **successes** during the project?
3. What have been the key **lessons learned** based on the outcomes of the project?
4. What are the **recommendations** based on the outcomes of the project?

The outcomes were acquired from the perspectives of four EU projects:

SmartNet

SmartNet is a European research project which aimed to compare different TSO-DSO coordination schemes and real-time market architectures for acquiring ancillary services from distributed resources. This was done by comparing each of the methods used to coordinate the action of TSOs and DSOs for acquiring ancillary services from DER connected to distribution grids.

CoordiNet

CoordiNet is a European research project which aims to demonstrate how TSOs and DSOs should act in a coordinated manner to procure and activate grid services most reliably and efficiently.

InteGrid

The InteGrid project is a European research project which aims to bridge the gap between citizens, technology providers, and other participants within the energy system. The project aims to demonstrate the role of the DSO in enabling the active participation of all stakeholders within the energy market. This is achieved through the development of smart tools which include various data management and customer participation techniques using a traffic light system at an individual bus level to ascertain whether DER is available or should be curtailed.

INTERPLAN

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| The goal of the INTERPLAN project is to provide an INTEgrated opeRation PLAnning tool towards the pan-European Network, with a focus on the TSO-DSO interfaces to support the EU in reaching the expected low-carbon targets, while maintaining the network security and reliability.<br>A study conducted in Switzerland<br>In 2019, an analysis of the current and future interaction between TSO and DSOs in Switzerland was conducted by ETH Zurich. Within the analysis two cases studies were performed (Swissgrid and EWZ), which aimed to assess the use of aggregated reserve power from the distribution grid and TSO-DSO coordination for congestion management. |
| **Key Objectives**<br>To identify and consolidate the lessons learned from international projects, use cases, and best practices on TSO-DSO interaction. Furthermore, aims to present a global view of developments of TSO-DSO interaction based on collaboration from stakeholders within the ISGAN community, as well as additional collaboration partners (TSOs, DSOs, project leaders, etc). |
| **Key Deliverables**<br>• To provide a short overview based on the key outcomes of the investigation, this will take the form of a video type deliverable.<br>• To provide a full report which forms a supplementary consolidation of the results in order to provide additional information in more detail. |

| **How does the Project / initiative engage with and/or develop the body of knowledge relevant to the following future power system requirements.** | |
|---|---|
| **Power System Architecture** | Not considered. |
| **Regulatory Innovation** | Not considered. |
| **Market innovation** | Not considered. |
| **T-D Interface** | The INTERPLAN tool provides a methodology consisting of a set of tools (grid equivalents, control functions) for the operation planning of an integrated grid from the perspective of a TSO or a DSO through the efficient and effective management of intermittent RES as well as emerging technologies such as storage, demand response and electric vehicles. The tool supports the utilisation of potential flexibility from RES, demand side management, storage and electric mobility for system services in all network control levels. |

| | |
|---|---|
| **DER Control Architecture innovation** | The InteGrid tool utilises DSO and VPP inputs to realise a Traffic Light System (TLS) on network MV nodes which were sent to VPP and DSO for scheduling of DER dispatch, refer below diagram. |

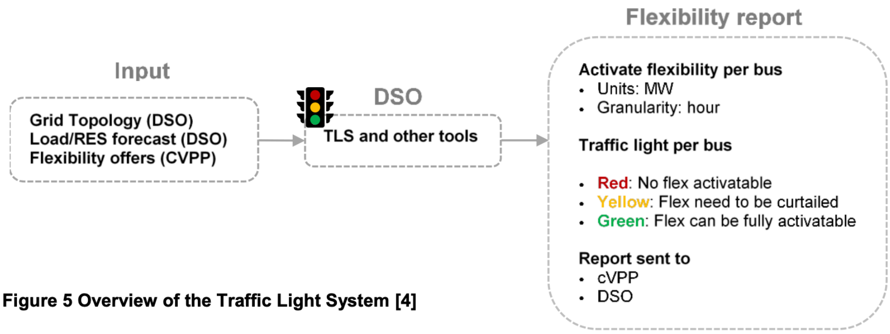


**Figure 5 Overview of the Traffic Light System [4]**

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|---|---|
| **Roles & Responsibilities** | Not considered. |

## Architectural Methodologies / Models applied in the design of the Project / Initiative

None used.

## Key Reference Documents

2020-12 ISGAN - Lessons-learned-from-international-projects-on-TSO-DSO-interaction

**Video can be found at** https://www.iea-isgan.org/lessons-learned-from-international-projects-on-tso-dso-interaction/


# Appendices

# Appendix A – References

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# Appendix B – Glossary

# Contents

# Purpose & Status

Strategen has developed this Future Power System Glossary to support more effective multi-stakeholder communication and collaboration on many complex matters that are often contested and require significant nuance to effectively navigate.

The definitions are generally informed by an expansive survey of the relevant Australian and international sources, especially although not limited to the sources nominated in Appendix A of this report.

Importantly, efforts have been made to align concepts and terminology to the Australian context for the primary use of Australia stakeholders.  To maximise universality and accuracy, several sources have been compared and contrasted for each definition wherever possible.

Finally, the topic of Future Power Systems is evolving and maturing fast.  Therefore, this is a 'living document' and the content will necessarily benefit from stakeholder comment and will require ongoing refinement.

| Power System Architecture Concepts | |
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| **Architect** | In the context of the Systems Architecture discipline, the Architect is a professional specialising in the management of systemic complexity. Cognisant of the entire System, they work closely with the full range of key stakeholders and discipline experts related to a complex System. As such, the Architect complements and does not replace the many diverse functions that require specific discipline expertise. |
| **Architecture** | Formally, Architecture is defined as the conceptual model that describes the Structure and Components together with the Qualities, Properties, Functions and essential limits of a System. This includes the way the physical, informational, operational and economic components of the System are organised and integrated.<br><br>Architecture has a primary focus on the underlying Structure of a System. This is because a System's Structure has a disproportionate influence on what it can efficiently and reliably perform. Where the Structure or Architecture is well aligned with the System's current or emerging purpose, the elements will function effectively together, and the System will be more Scalable and Extensible. Where the Structure is misaligned with current or future needs, technology integration becomes increasingly costly, investments are stranded, and full benefits realisation is placed at risk.<br><br>Architecture is not design and design is not Architecture. The disciplines for addressing Systems Architecture are more akin to strategy and planning whereas the process of design is more akin to engineering and operations. |
| **Architecture Issues** | Following are three critical structural issues that the Power System Architecture (PSA) discipline surfaces and helps navigate. Addressing such matters is key to ensuring scalable Operational Coordination mechanisms and the avoidance of computational 'time wall' constraints:<br><br>(a) **Tier Bypassing:** Creation of information flows or instruction/dispatch/control pathways that 'leapfrog' a vertical tier or layer of the Power System which opens the way to system coordination problems DER levels increase;<br><br>(b) **Hidden Coupling:** Two or more control entities with partial views of grid state operating separately according to individual goals and constraints and issuing simultaneous but conflicting signals; and,<br><br>(c) **Latency Cascading:** Creation of potentially excessive latencies in information flows due to the cascading of systems and organizations through which the data must flow serially. |
| **Centralised Legacy Architecture** | A traditional Power System Structure that is characterised by one-directional supply through 'poles and wires' infrastructure to largely passive consumers. This Architecture was traditionally almost entirely served by centralised generation. |

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| **Centralised Future Architecture** | A vision of a future Power System that aspires to whole-of-system optimisation being directly managed by the System Operator (SO), which also operates the wholesale market. In this model, the SO needs detailed data and visibility into all layers of the Power System including the distribution system. This model is a logical extension of historical wholesale market and transmission operational paradigms but with much greater diversity and volumes of energy resources. |
| **Components** | The uniquely identifiable elements, devices, organisations, individuals, building blocks, parts, or subassemblies that may be connected or related together as operating System that is capable of cooperation and the achievement of common objectives. |
| **Coordination Framework** | A formalised model for determining how a diverse range of Power System assets and customer energy resources will cooperate to solve common problems. This requires the delineation all participant roles and responsibilities together with their needs and/or capabilities regarding business objectives, market responsibilities, device or System performance constraints, and data requirements. |
| **Decentralised System** | Multiple separate Components operating independently and in a manner that is solely focused on local or 'selfish' optimisation, with either very limited or no supervision. |
| **Demand-side Flexibility** | The dynamic orchestration of large volumes of DER and Flexible Resources in a manner capable of supporting supply/demand balance over timescales from days to milliseconds.<br>Flexibility in a high-VRE / high-DER Power System is closely related to the topic of Operational Coordination. |
| **Distributed System** | An enhanced form of Decentralised System where the Components are also able to cooperate to support wider System efficiencies and/or solve common problems by means of a shared coordination model. In the case of a complex Power System, this coordination must be provided by a fit-for-purpose Operational Coordination model. |
| **Extensibility** | A design principle that takes the future growth of the System into consideration. It is a systemic measure of the ability to extend a System and the level of effort required to implement the extension. |
| **Extensible Design** | A key aspect of architectural design applied to a System that is experiencing significant transformation, with the goal of ensuring that the solutions proposed are:<br>(a) Cognisant of the plausible future developments that the solution will need to enable or migrate toward;<br>(b) Capable of accommodating future requirements without impairing core, critical functionality; and,<br>(c) Capable of enabling cost-effective migration to longer-terms solution when required. |

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| **Interoperability** | The capability of two or more devices, applications, components or networks to connect, exchange data and/or operate together without any impediment to functionality. |
| **Layered Decentralised Future Architecture** | A vision of the future Power System that requires optimisation to be managed at each layer of the System and is based on the mechanism of Layered Decomposition. Under this model, the distribution layer of the Power System would be wholly managed by the DSO which also manages its connections to the transmission system. In its most mature future state, the SO would see each Transmission-Distribution Interface as a single virtual resource. In turn, the DSO would also see a Microgrid within its distribution system as a single virtual resource. In other words, each layer of the Power System only requires data, visibility, forecasting and control at the interface points with the layers above and below. |
| **Layered Decomposition** | A widely recognised mathematical technique employed to solve large-scale optimisation problems by decomposing the problem multiple times into sub-problems that work in combination to solve the original problem. The application of Layered Decomposition to architectural design may become critical for Distribution System Operator (DSO) models and Transmission-Distribution Coordination in very high-DER environments. This is due to the impacts of market-aggregator-local control latency, computational 'time wall' and Operational Coordination constraints in the case of millions of energy resources. |
| **Layering** | Many traditional Power System functions are arranged in vertical siloes, each having their own networks, sensors and supporting systems. In a Power System undergoing significant transformation, this presents significant integration challenges and impedes Scalability.<br><br>By contrast, Layering can be used to simplify Operational Coordination challenges in very complex Systems. This is the process of identifying the core Components required in the future and configuring them as a 'horizontal' layer or platform upon which a variety of applications can be progressively added.<br><br>Key properties of such a layer or platform include:<br><br>(a) The core System Functions are relatively stable and kept separate from end-use applications via layering;<br><br>(b) The core set of services and capabilities are capable of underpinning a range of different applications that will change more frequently;<br><br>(c) Changes between applications and underlying core infrastructure are decoupled; and,<br><br>(d) May enable third parties to create applications that use the platform via open standard interfaces. |

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| **Network of Structures** | A modern Power System is an ultra-complex Network of Structures that intersect and dynamically interact with each other. When viewed from a whole-of-system perspective, it becomes clear that the Power System combines the following six distinct but interconnected structures:<br>(a) Industry & Regulatory Structure (Entity-Relationships);<br>(b) Electricity Infrastructure (Power Flows);<br>(c) Operational Control Structure;<br>(d) Market Transaction Structure;<br>(e) Digital Infrastructure (Information/Data Exchange); and,<br>(f) Convergent Networks.<br>Most of these Structures have evolved progressively over decades in the context of a highly centralised Power System. They are subject to hidden and overt interactions, cross-couplings, constraints and dependencies. While the 'system-of-systems' paradigm from software engineering is somewhat useful, being largely component-focused it does not adequately represent the complex multi-structural properties constituting a modern Power System.<br>The Network of Structures paradigm was developed by Pacific Northwest National Laboratory (PNNL) to support the detailed analysis, mapping, and optimisation of the legacy, emerging and future Architecture. This is critically important as the underlying Structure of any complex System establishes its essential capabilities and limits. Therefore, the more rigorous structural analysis that the Network of Structures paradigm enables is a key to enabling the reliable and cost-efficient transformation of the Power System. |
| **Operational Coordination** | Structured mechanisms for coordinating from hundreds to tens of millions of energy resources operating in a power system. In increasingly heterogenous and dynamic power systems, modern approaches to Operational Coordination require close 'market-control' alignment across each layer of the system. This requires both technological control and economic incentivisation elements to be tightly-coupled to function in a mutually-reinforcing manner that incentivises system stability and efficiency services across a range of time scales (days to milliseconds). |
| **Power System** | A highly complex cyber-physical-economic System that exists to provide safe, reliable, and efficient electricity services to millions of customers. The legacy Power System incorporates electricity generation, transmission, distribution, and transaction functions within structures that have evolved over decades. It is an interdependent Network of Structures that consists of electrical infrastructure, control structure, regulatory structure, industry structure, digital superstructure, convergent networks, and coordination frameworks. It is properly defined as an Ultra-Large-Scale (ULS) complex System. |

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| **Power System Architecture (PSA)** | **Power Systems Architecture**<br><br>Power Systems Architecture (PSA) is a generic term for an integrated set of disciplines that enable the strategic transformation of legacy power systems to better meet changing policy and customer expectations together with their physics-based implications.<br><br>While many traditional models of change focus on discrete parts or components, the PSA discipline enables a holistic view of the entire power system over 5, 10 and 20-year time horizons. Recognising that the legacy power system is an extremely complex 'Network of Structures', the PSA disciplines uniquely provide:<br><br>(a) **Whole-of-system insight** that enables diverse stakeholders to collaboratively interrogate and map current, emerging and future power system priorities, objectives and functions informed by a range of plausible future scenarios;<br><br>(b) **Evidence-based tools** to navigate, analyse and shortlist key transformational options through the combined application of Systems Architecture, Network Theory, Control Theory and Software Engineering complemented by Energy Economics and Strategic Foresight disciplines; and;<br><br>(c) **Future-resilient decision making** enabled by surfacing hidden structural constraints early that may otherwise drive future issues such as computational constraints, latency cascading and cyber-security vulnerabilities, which provides assurance that new investments are scalable and extensible under all plausible futures.<br><br>Most importantly, PSA expands rather than limits optionality. It enables architectural decision making based on agreed principles, objective methodologies and detailed structural analysis. It gives priority to extensive collaboration with diverse stakeholders and subject matter experts throughout to enhance trust, ensure high levels of alignment and support social license for change. |
| **Scalability** | The ability of a System to accommodate an increasing number of endpoints and Components without requiring major modifications to the System Structure. It also refers to the ability to roll out new infrastructure or investments in a proportional or incremental manner as needs may dictate. As such, the Scalability of any System has both spatial and temporal dimensions. |
| **Structure** | The formal and stable relationships between the Components of a System that enable the execution of functional interactions and the achievement of common objectives. |
| **System** | A set of Components that are formally connected together by a shared Structure in a manner that enables them to achieve a common purpose. The elements of a System are interdependent. Therefore, the operating behaviour of individual Components will dynamically influence the operation of the other Components and the System as whole. |

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| **System Functions** | The specific and detailed capabilities, processes, behaviours and operational results of a System that fulfil identified requirements. In the case of a modern Power System, the following list is a *random* set of System Functions as examples only:<br>(a) Forecast energy resources at all voltage levels;<br>(b) Provide aligned financial incentives to all actors;<br>(c) Identify constraints and plan for credible events;<br>(d) Generate and issue dynamic operating envelopes;<br>(e) Provide a spot market for inertia;<br>(f) Enable customers multiple trading relationships;<br>(g) Procure network services through a local market;<br>(h) Manage microgrid islanding and grid-synchronisation;<br>(i) Control federation and control disaggregation; and,<br>(j) Provide peer-to-peer energy trading.<br>In the application of PSA disciplines, the System Functions emerge as the product of decisions made about both Architecture and then Components. These decisions are in turn informed by those made about System Qualities and System Properties (see below). |
| **System Properties** | The high-level range of characteristics of the entire Power System from the industry 'insider' perspective of Power System architects, developers and operators, and phrased in solution-agnostic terms. Some examples may include adaptability, configurability, efficiency, extensibility, flexibility, interoperability, resiliency, scalability, stability and traceability.<br>In the application of Systems Architecture methodologies, the necessary System Properties are directly informed by the shortlist of System Qualities desired by policy makers, end-users and relevant stakeholders. The System Properties themselves then inform the Architecture and Component decisions that constitute the System and ultimately enable delivery of the required System Functions. |
| **System Qualities** | The high-level, desired characteristics of the entire Power System from the perspective of external stakeholders, such as policy makers and end-users, and phrased in solution-agnostic terms. Some examples may include affordability, autonomy, customisation, optionality, predictability, reliability, safety, simplicity and sustainability.<br>In the application of Systems Architecture methodologies, it is standard practice to distinguish the System Qualities from the System Properties. This assists with more precise cause-and-effect reasoning and enables descoping where necessary. Generally, the number of System Qualities selected for a Power System should be small, ideally weighted by priority and as a set of qualities, sufficiently comprehensive in nature. |

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| **System Structures & Components** | The way that the many and diverse Components are related together as a System in a manner that reflects the System Properties and capable of performing the System Functions. The Structure of any System is fundamental as it establishes the essential limits on what the System can and cannot reliably and efficiently do. Simplistically, if the boxes in a block diagram are the Components, then the System Structure is represented by the lines that connect the boxes. |
| **Systems Architecture** | An established engineering discipline that is applied in numerous sectors including aerospace, military, manufacturing, energy and electronics sectors. It enables objective and shared reasoning about the Structure of a complex System together with its Components, interfaces, feedback loops and collective behaviour. This equips stakeholders to make more informed design decisions about both the existing System and its plausible futures to ensure optimal performance and reliability at least cost. |
| **Transmission-Distribution Coordination** | Where significant volumes of VRE and DER generation are incorporated into transmission and distribution systems, there is a need to enhance the capability of the two systems to jointly manage issues such as:<br>(a) frequency control;<br>(b) congestion management; and,<br>(c) voltage control.<br>In this case, the SO or TSO and the relevant DSO become responsible for managing each Transmission-Distribution Interface in a high-VRE, high-DER Power System. This will involve the exchange of relevant data and the execution of formalised roles and protocols to jointly ensure network stability and economic efficiency. |
| **Ultra-Large-Scale (ULS) System** | Extremely large and complex technological Systems consisting of unprecedented volumes of hardware, software, data, participants, stakeholders and end-users. A ULS System typically exhibits the following characteristics:<br>(a) wide geographic scales;<br>(b) wide-time scales (microseconds to years);<br>(c) long-term and near-continual evolution and deployment;<br>(d) decentralised data, control, and development;<br>(e) inherently conflicting diverse requirements and trade-offs;<br>(f) heterogeneous, inconsistent, and changing elements; and,<br>(g) failures occur as a matter of normal operations.<br>The Power System is a prime example of an Ultra-Large-Scale System. |

| ‘Network of Structures’ 4 x Functional Layers | | |
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| **Structure** | **Description** | **Examples** |
| **Electricity Infrastructure (Power Flows)** | Provides for the physical movement of electric power across the end-to-end Power System, including transmission and distribution networks, microgrids, substations, grid-connected energy storage, customer sites, etc. While historically this was primarily one-directional, it now increasingly involves bi-directional flows, especially across the distribution system. | • Power flows from centralised / bulk generation to load centres through the transmission system.<br>• Power flows to and between customers through the local distribution system.<br>• Storage of excess renewable energy capacity and subsequent Power System injection during peak periods.<br>• Customer generation and storage provides power to customer loads and/or injects power into the local distribution system. |
| **Operational Control Structure** | Provides for the holistic direction, regulation, coordination and stabilisation of the operation of diverse energy resources, flexible loads and electricity system facilities (including distribution switching, grid-connected storage, etc.). | • System Operator exerts control over bulk Power System resources and reliability services by sending control signals (e.g. dispatch instructions and basepoints) to direct their operation in a way that allows them to provide the targeted service.<br>• System Operator exerts control over the transmission system in response to a constraint or contingency to preserve safety and reliability.<br>• System Operator and emerging Distribution System Operators (DSO) conjointly exert control over relevant Transmission-Distribution Interfaces.<br>• Distribution Network Service Providers (DNSP) or emerging DSO exerts control over distribution network assets, such as to reconfigure a circuit due to abnormal system conditions.<br>• Energy Retailers / DER Aggregators exert control over contracted customer DER and flexible loads in response to wholesale market and/or DSO network service market signals. |

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| **Market Transaction Structure** | Provides for the procurement and sale of energy, capacity, and essential system services at any layer of the Power System through market or other financial arrangements. This may include participation in wholesale markets, distribution network services markets, power purchase agreements, and capacity or service contracts. This also includes market schedules and Dispatch instructions. | • Bulk generation resources participating in the wholesale market provide bids/offers to the market operator who subsequently schedules resource Dispatch.<br>• Energy Retailers / DER Aggregators procure and contract services from customer DER and flexible loads and sell those services into the wholesale market and/or distribution network services markets.<br>• Similar to the above, Energy Retailers / DER Aggregators may procure system services from DNSP-owned energy storage assets.<br>• In some cases, DNSPs directly procure demand response services from customer. |
| **Digital Infrastructure (Information/Data Exchange)** | Provides for all information or data exchange required to maintain the safe and reliable operation of the electricity system and support coordinated operation of the above three functional layers. This includes a diverse range of elements including resource telemetry, managing system topology changes, resource interoperability, etc. | • Bulk generation and storage resources participating in the wholesale market submit telemetry to the market operator to indicate asset performance in real time.<br>• System Operator and emerging Distribution System Operators (DSO) exchange system condition information to support the conjoint management of relevant Transmission-Distribution Interfaces.<br>• Energy Retailers / DER Aggregators participating in the wholesale market and DSO network services markets submit telemetry to the relevant entities to indicate asset performance in real time. |

| Power System Architecture / Enterprise Architecture - Comparison[33] | | |
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| **Area of Comparison** | **Power System Architecture** | **Enterprise Architecture** |
| **Focus** | • Industry / Sector | • Enterprise |
| **Complexity** | • Industry Level – Ultra-Large-Scale Complexity<br>• Help manage complexity and risk within industry | • Enterprise Level - Large Scale Complexity<br>• Helps manage complexity and risk within the enterprise |
| **Stakeholders** | • Diverse stakeholders including policy makers, regulators, industry, customer groups, environmental groups, etc. | • Internal enterprise stakeholders. Generally reports to CIO and reflects interests of IT primarily |
| **Motivation** | • Power System Architecture is focused on identifying and practically addressing key industry problems, structural limits, constraints embedded in legacy structures and/or required to enable new opportunities. | • More narrowly focused on the various ongoing challenges the enterprise faces. |
| **Requirements** | • Defines qualities and properties of the future power system based on a broad range of societal and stakeholder perspectives. | • Defines business requirements primarily from the perspective of enterprise stakeholders only. |
| **Current State** | • Defines current state of essential power system structures and the relationships between these structures.<br>o Industry Structure (Entity-Relationships);<br>o Electricity Infrastructure (Power Flows);<br>o Operational Control Structure;<br>o Market Transaction Structure;<br>o Digital Infrastructure (Information/Data Exchange);<br>o Coordination Framework; and,<br>o Convergent Networks. | • Defines the current state of the enterprise.<br>o Strategic enterprise objectives mapped to capabilities<br>o Enterprise principles<br>o Business Architecture<br>o Information System Architecture<br>o Technology Architecture |

[33] Adapted from: Is Grid Architecture different from Enterprise Architecture? If so in what way? by Eamonn McCormick, David Forfia and Stuart McCafferty

| Area of comparison | Power System Architecture | Enterprise Architecture |
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| **Gap Analysis** | • Identify gaps in theory, technology, organisation, regulation | • Identify gaps in business, information systems, and technology. |
| **Target State** | • Identify and remove barriers and define essential limits<br>• Assist in developing a future vision for the power system and communicating among stakeholders around a shared vision of the future grid<br>o Industry Structure (Entity-Relationships);<br>o Electricity Infrastructure (Power Flows);<br>o Operational Control Structure;<br>o Market Transaction Structure;<br>o Digital Infrastructure (Information/Data Exchange);<br>o Coordination Framework; and,<br>o Convergent Networks. | • Defines target state of the enterprise.<br>o Strategic enterprise objectives mapped to capabilities<br>o Enterprise principles<br>o Business Architecture<br>o Information System Architecture<br>o Technology Architecture |
| **Transition Planning** | • Provide a framework for complex power system related development activities | • Develop enterprise roadmap to move from current state to target state |

| Distributed Energy Resources – Core Concepts | |
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| **Active DER** | DER that are capable of automatically altering their operating behaviour in response to the needs of the wider Power System. This may be in response to changes in the energy price, the local condition of the grid and/or upon receipt of Dispatch instructions, control inputs or data feeds from authorised external entities.<br>Active DER are significantly more valuable to the electricity system than Passive DER as they as they can provide specific physics-based services that are strongly correlated with the time and location of a wider system need. |
| **Distributed Energy Resources (DER)** | Diverse energy resources located behind the meter at residential, commercial and industrial customer premises or connected directly to the distribution network. These include:<br>(a) Small and medium scale distributed generation (such as solar PV and fossil fuel generation);<br>(b) Stationary energy storage (such as small and medium-scale batteries);<br>(c) Electric Vehicles (EVs);<br>(d) Smart inverters; and,<br>(e) Flexible Resources (such as air conditioning, electric hot water storage, water pumping, industrial loads and thermal storage).<br>DERs are typically characterised as either Active DER or Passive DER. |
| **Energy Consumption** | The volume of electric energy used by a customer over a period of time, normally monthly, quarterly or annually. Measured in kWh or MWh. |
| **Energy Storage (ES)** | A means of storing electrical energy, either directly or indirectly and either at centralised locations or widely distributed across a Power System.<br>Direct forms of Energy Storage such as chemical batteries and power capacitors are those where energy enters the storage as electrical energy and is retrieved as electrical energy.<br>Indirect forms of Energy Storage convert electric energy into thermal, rotational or potential energy and may include the pre-heating or pre-chilling of water or glycol, pumping of water to elevated storage or the pre-cooling of a building envelope. |

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| **Flexible Resources**<br><br>*(includes Demand Management, Demand Response, Controllable Load)* | Distribution-connected assets that can modify their operational behaviour in response to a need of the bulk power and/or local distribution system, without direct human involvement, and usually in exchange for a financial incentive.<br><br>Commonly (but not exclusively) owned by customers, these assets can automatically increase or decrease their electricity consumption and/or production in response to changes in the energy price, financial incentives, the local condition of the grid and/or upon receipt of a control signal from a third party. |
| **Hosting Capacity** | The amount of DER that can be accommodated within a distribution network, or a specific segment of the distribution network, without adversely affecting security, reliability and/or power quality. |
| **Inverter** | An electrical device which uses semiconductors to transfer power between a DC source and an AC source or load. In Australia, Inverters must comply with the AS4777 series of standards. |
| **Inverter-Based Resource (IBR)** | A resource connected to the network via an inverter that can operate at any frequency and does not have the same inertial properties as spinning mass. |
| **Load Shifting** | An automated 'turn-up' process that enables essential customer loads to better align their consumption with periods where there is an oversupply of renewable energy, low demand on the system or both. |
| **Passive DER** | DER that operate only under the direction of their own internal algorithms and cannot be remotely orchestrated by a third party (such as an aggregator).<br><br>Passive DER are significantly less valuable to the electricity system than Active DER due to the negligible capacity to alter their behaviour in response to changes in the condition of the Power System. This means they cannot reliably provide services that are correlated with system needs and may impose additional system inefficiencies on the system. |
| **Peak Demand** | The highest level of instantaneous electricity demand at a specific network location, customer site or appliance load. Measured in kW or MW. |
| **Reactive Power** | Reactive Power sustains the electrical field in alternating-current (AC) electricity systems while maintaining voltage within the limits specified for safe operation. Measured in kVAR. |
| **Smart Inverter** | An Inverter with a digital architecture, bidirectional communications capability and the ability to provide Reactive Power services (kVAR). |
| **Variable Renewable Energy (VRE)** | A generic term for highly intermittent forms of generation. Where installed in significant quantities, VRE can result in significant grid instability and the mismatch of electricity demand and supply. While some forms of DER (such as solar PV) are considered VRE, the term is most commonly used to describe large centralised applications of solar and wind generation. |

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| **Vehicle to Grid (V2G)** | A system that allows an Electric Vehicle to send power (i.e. discharge its battery) to the grid or to manage charging of its battery in response to changing grid conditions. |
| **Volt-Watt response** | A response mode of an Inverter that reduces its power output when needed in order to avoid exceeding the voltage limits. If this mode is not enabled the Inverter may experience frequent nuisance tripping when the network is lightly loaded. |
| **Volt-VAR response** | A response mode of an Inverter that smooths the network voltages by absorbing Reactive Power when voltage levels rise. Alternatively, when network voltages fall below 220V, the Volt-VAR mode causes the Inverter to generate Reactive Power to support the network voltage. |

| DER Orchestration & Market Concepts | |
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| **Aggregator** | An entity that Orchestrates a fleet of DER and sells the services into the NEM and/or the Network Services Market. Key functions and goals are to:<br>(a) Agree with customers the commercial terms and conditions of orchestrating their DER;<br>(b) Maximise the value of the DER Electric Products by providing them to the layer of the system with the most urgent need and/or where they attract a premium price;<br>(c) Compute optimal Dispatch configurations across their DER portfolio consistent with: a) customer contract provisions; b) DSO & SO Dispatch instructions; and, c) the DOE information pertaining to each customer;<br>(d) Mitigate or cancel out the uncertainties of non-delivery from a single customer so that the services provided to the market can be guaranteed;<br>(e) Prevent customers from being unduly exposed to the risks involved in participating in the above markets; and,<br>(f) Administer payments and invoicing associated with the delivery and receipt of DER services. |
| **Controllability** | The ability for the operation of individual DER to be remotely altered in real-time and/or near real-time by an authorised third party. This will typically be for the purpose of providing services to the bulk power and/or local distribution system and may include altering DER operation in terms of increasing or decreasing load and/or generating, storing or exporting energy. |
| **Co-optimisation** | Co-optimisation is the systematic process of ensuring that DER services being dispatched and/or financially incentivised in one layer of the Power System (e.g. wholesale market, transmission or distribution system) are not driving unintended negative consequences in other layers of the Power System.<br>Co-optimisation will become increasingly critical as the volume of grid-connected DER grows. In vertically-integrated industry structures, this may be managed by one key party whereas vertically-disaggregated structures will involve two or more. While decentralised models may be initially employed, Power Systems hosting very high levels of DER will ultimately require a comprehensive Operational Coordination model developed through the holistic application of Systems Architecture principles. |

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| **DER Electric Products** | Regardless of the control or incentive mechanism employed for DER Orchestration, the ‘3Rs’ are the core physics-based services that different DER may provide to various layers of the Power System:<br>(a) Real Energy: measured in kWh, is the fundamental electric commodity delivered to retail customers and represents the ability to increase delivery or reduce consumption of real energy in real-time;<br>(b) Reactive Power: measured in kVAR, sustains the electrical field in alternating-current systems while maintaining voltage within the limits specified for safe operation (source or sink); and,<br>(c) Reserves: measured in kW, represent contracted commitments to deliver or reduce real energy (kWh) at a point in the future (includes Flexibility services).<br>All services and energy provided by DERs to any layer of the Power System (e.g. wholesale, transmission, distribution) are derivatives of the 3Rs. |
| **DER Electric Product Value** | The financial value of a DER Electric Product will vary significantly by time, location and the extent to which simultaneous Value Stacking across several layers of the system is possible. The DER services with the highest financial value will generally be provided by Active DER. This is because the actual benefit provided to the Power System is determined by what it needs at a given time and location which will vary dynamically. In other words, providing the right physics-based service at the right time and at the right location will be key to maximising their financial value. |
| **DER Services Beneficiaries** | Beyond the direct benefits that accrue to DER owner/investors, DER may also provide services that benefit the following layers of the electricity system:<br>(a) Distribution network;<br>(b) Transmission network;<br>(c) Wholesale energy market;<br>(d) Essential System Services market; and,<br>(e) Other customers (via peer-to-peer trading).<br>All services and energy provided by DERs to any of the above layers are derivatives of the DER Electric Products summarised as the ‘3Rs’: Real Energy, Reactive Power and Reserves. |
| **Dispatch** | Instructions issued by the System Operator (SO) and/or Distribution System Operator (DSO) that either provide directives or targets for contracted Active DERs to alter their operating behaviour. Depending on the System Architecture of a given system, Dispatch instructions from the SO and DSO will often be routed via the Aggregator. |

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| **Distributed Energy Resource Management System (DERMS)** | A software-based platform for managing the technical operation of DER connected to the distribution network, primarily for the purposes of managing:<br>(a) Optimal power flows;<br>(b) Minimum and peak demand; and,<br>(c) Voltage. |
| **Distribution Market Operator (DMO)** | Distinct from the role of managing a Network Services Market (normally the role of the DSO), the DMO is the entity responsible for managing a distribution-level energy market in a system that has very high levels of DER. While this type of market may be required in Australia in the longer future, the DMO concept is perhaps most naturally aligned with vertically integrated market structures. |
| **Distribution System Operator (DSO)** | The entity responsible for the planning, operation and optimisation of a distribution system with high levels of DER. Depending on the DSO model implemented, this may include the following functions pertaining to the distribution system:<br>(a) Modelling, forecasting and real-time visibility of power flows and DER operation;<br>(b) Managing the network within the technical constraints and Hosting Capacity of the assets;<br>(c) Managing the real-time Operational Coordination of DERs at the distribution level which is foundational to system optimisation;<br>(d) Computing and issuing Dynamic Operating Envelopes to DER aggregators (and individual DER under direct management);<br>(e) Managing the distribution system connections to the transmission system;<br>(f) Identifying where longer-term network issues are likely to emerge and act to manage these issues; and,<br>(g) Establishing and operating a Network Services Market to procure DER services under regulatory oversight.<br>In the Australian context this is perhaps most likely to involve a progressive expansion of the role of DNSPs. |
| **Dynamic Operating Envelope (DOE)** | Distinct from Static Operating Envelopes, DOE's allow customer import and export limits to vary over time and location according to dynamic changes in network Hosting Capacity. Dynamic export limits could enable higher levels of energy exports from customer solar and battery systems by allowing higher levels of export when the distribution network has the capacity to accommodate it. |

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| **Integrated Resource Planning (IRP)** | A holistic approach to Power System design that recognises a growing volume of energy generation and storage capacity will be located the customer-side of the system and must be considered as an integrated part of any future system design. It actively incorporates public participation in the co-development of plans to ensure both centralised and decentralised energy assets will interoperate in a manner that optimises cost and reliability and maximises societal and environmental outcomes. |
| **Load-following Paradigm** | The traditional operating paradigm of electric systems where large-scale centralised generation is dispatched or dynamically ramped to match electrical loads as they vary across periods of time (hours, days, seasons, etc.). This paradigm was premised on a historical context where the major source of uncontrolled variability impacting an electric system was changing customer energy demand over time. |
| **Market Platform** | A digitised commercial ecosystem that enables value-creating interactions between external producers, consumers and producer-consumers. A market platform provides an open, participative and dynamic infrastructure for these interactions and sets governance conditions for them. Its key purpose is to consummate matches among users and facilitate the exchange of goods, services, or social currency, thereby enabling value creation for all participants. |
| **Microgrid** | A geographically confined collection of electrical resources that act together and with centralised generation typically playing a key role. Microgrids can be remote, embedded, or interconnected and may begin their life either detached or attached to a larger grid. |
| **Network Services Market** | A market established and operated by the entity responsible for the Operational Coordination of the distribution system for the purposes of efficiently procuring the DER Electric Products required to support network stability, power quality and economic efficiency. |
| **Orchestration** | The remote management of a fleet of dispatchable DER to provide services to the bulk power and/or local distribution system. This will typically involve a third party managing the operational performance of the entire DER fleet in a manner that functionally presents to the power system as one virtual and dispatchable resource. |
| **Supply-following Paradigm** | An emerging operating paradigm for electric systems with very high levels of VRE, in which a diverse range of customer loads are dispatched or dynamically ramped to match the output of renewable generation across periods of time (seconds, hours and days, etc.). This operating paradigm is premised on emerging contexts where the major source of uncontrolled variability impacting an electric system is generation output driven by wind and solar resource availability. |
| **Static Operating Envelope** | The technical limits that DER must operate within to maintain the security, reliability and power quality of the distribution network and broader electricity system. Static operating envelopes account for 'worst case scenario' conditions and are often fixed at conservative levels regardless of the capacity of the distribution network. |

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| **Transactive Energy (TE)** | A system of economic and control mechanisms the dynamically enable Operational Coordination by using value as a key operational parameter. It combines two-way information and localised decision-making often deployed by way of a Market Platform. |
| **Value Stacking** | The process of simultaneously providing one or more DER Electric Products to several layers of the Power System (e.g. wholesale market, transmission, distribution system) for the purpose of maximising remuneration outcomes. |
| **Virtual Power Plant (VPP)** | A software-based platform that enables the Orchestration of a fleet of DER in a manner that meets end-user needs and provides beneficial services to different layers of the electricity system. |
| **Visibility** | With reference to DER, Visibility is the ability to actively monitor the real-time and/or near real-time operation of DERs and the related network assets. This includes how many DER there are, how much electricity they can generate/store/export, their availability, current operational state and the operational state of the local network. |

| Conceptual Fallacies | |
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| **‘Centralised vs Decentralised’ Fallacy** | A position that asserts that the Systems Architecture of an electricity system that hosts high levels of DER must be either entirely centralised or entirely decentralised.<br><br>In practice, both approaches have strengths and weaknesses that must be carefully balanced in a given context. For example: wholly centralised schemes may have scalability, computational and security challenges whereas wholly decentralised schemes may have deployment, diagnostic and Co-optimisation challenges.<br><br>Where a significant transformation is underway, it is imperative to undertake a holistic examination of the most appropriate System Architecture to achieve sustained least-cost outcomes. However, rather than a ‘big bang’ architectural shift, this will always require a progressive transition in which elements of both schemes may co-exist as a legacy Architecture is progressively transitioned over time toward the required future Architecture. |
| **‘Markets vs Control’ Fallacy** | Polarised positions that assert the coordination or Orchestration of DER must be largely or entirely achieved via technological control or economic incentives. For example, a market economics view may assert that establishing the right market rules and prices will be sufficient. By contrast, a control engineering perspective may assert that establishing the right standards, protocols and optimisation equations will be sufficient.<br><br>This is a false dichotomy as elements of both markets and controls are necessary for a holistic approach to Operational Coordination where a Power System is increasingly decentralised. For example:<br><br>(a) Well-designed markets operate as excellent sensors and optimisation engines;<br><br>(b) Technical controls are required as markets alone cannot address all Power System dynamics; and,<br><br>(c) Beyond basic connection requirements compliance, economic incentives will be required to induce millions of privately-owned DERs to provide beneficial services to the Power System. |
| **‘Tariffs vs Markets’ Fallacy** | A position that asserts or implies that tariff reforms and the emergence of DER Market Platforms are in competition or even dichotomous. This is a false dichotomy as:<br><br>(a) Both tariffs and Market Platforms will co-exist for an indefinite period of time;<br><br>(b) The reform of tariffs and the emergence of new DER markets will need to be strategically aligned for maximum complementarity; and,<br><br>(c) Tariffs and tariff reform will be critical to the large number of customers who do not currently and may never own DER. |

# Appendix C – Risk Assessment

| Risk | Potential Impact | Recommended Mitigation |
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| Complexity of PSA approaches and recommendations leads to failure of industry to grasp and engage with key research content | Failure of industry to accept or engagement with key PSA content will limit the impact of research or result in realisation of capabilities gaps with significant impacts for system security and operation | Detailed engagement plan to ensure stakeholder acceptance and input sought throughout the plan to ensure alignment and evidence-based approach as PSA research progresses |
| | | Detailed customer engagement and inputs early in project to ensure that customer preferences are understood and guide detailed research activities and trend analysis |
| | | Heavy focus on early and sustained stakeholder engagement is required to ensure this research project can deliver agreed outcomes and recommendations to ensure successful impact of recommendations and to ensure agreement of early gap analysis |
| Key Industry Stakeholders Fail to acknowledge need for Future Capabilities | Failure to acknowledge scale of required future capabilities or potential constraints due to failure to consider these could result in significant future systems constraints or costs | Continue detailed stakeholder engagement as early phases of research program progress to ensure alignment and agreement with need to consider detailed future state models |
| Tendency towards incremental change means that scale of change required in future models is not acknowledged | Failure to acknowledge change required to successfully move towards required future capabilities limits industry progress | Phase 2b ensure stakeholder engagement in trend analysis and Systemic Issues Report development to ensure alignment and acceptance of findings as well as agreement with implications and findings |
| | | Inclusion of customer perspectives in trend analysis and inputs to ensure a customer perspective in gaining impetus for change |
| | | Inclusion of counterfactual in trend analysis to underpin case for change |

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| Scalability of Future Options | There is a risk that future models are not tested appropriately for scalability to ensure they are appropriately robust to potential system shocks and growing complexity | Leverage 2b modelling and trend analysis to ensure that gap analysis underpins Phase3a exploration of future system qualities, properties and functions |
| Optionality for Future Pathways | There is a risk that options explored do not allow appropriate flexibility for future system design considerations and operational possibilities | Consult broadly with stakeholders throughout the Research Plan and particularly through Phase 3 to ensure that Potential directions and functions successfully address all potential issues and directions identified Phase 3. |
| Delays to Research plan activities | Given the scale and pace of change it is important to ensure a degree of momentum in research activities to enable PSA progress to inform current industry activities and capabilities | Employ rigorous project planning and execution to ensure that project milestones progress in conjunction with stakeholder engagement and advocacy for PSA techniques |
| Acceptance of potential DSO models and Transmission / Distribution interfaces | Failure to agree on future approaches to DSO interface and critical capabilities could lead to failure to progress critical capabilities | Ensure consideration of full range of possible options and future capabilities to ensure detailed comparison of capability to deliver scalability and avoid latency cascading and tier bypassing |
| | | Test and engage on range of structural decisions and component decisions impacts on system operation and capability to address identified future system challenges and disruptions |

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