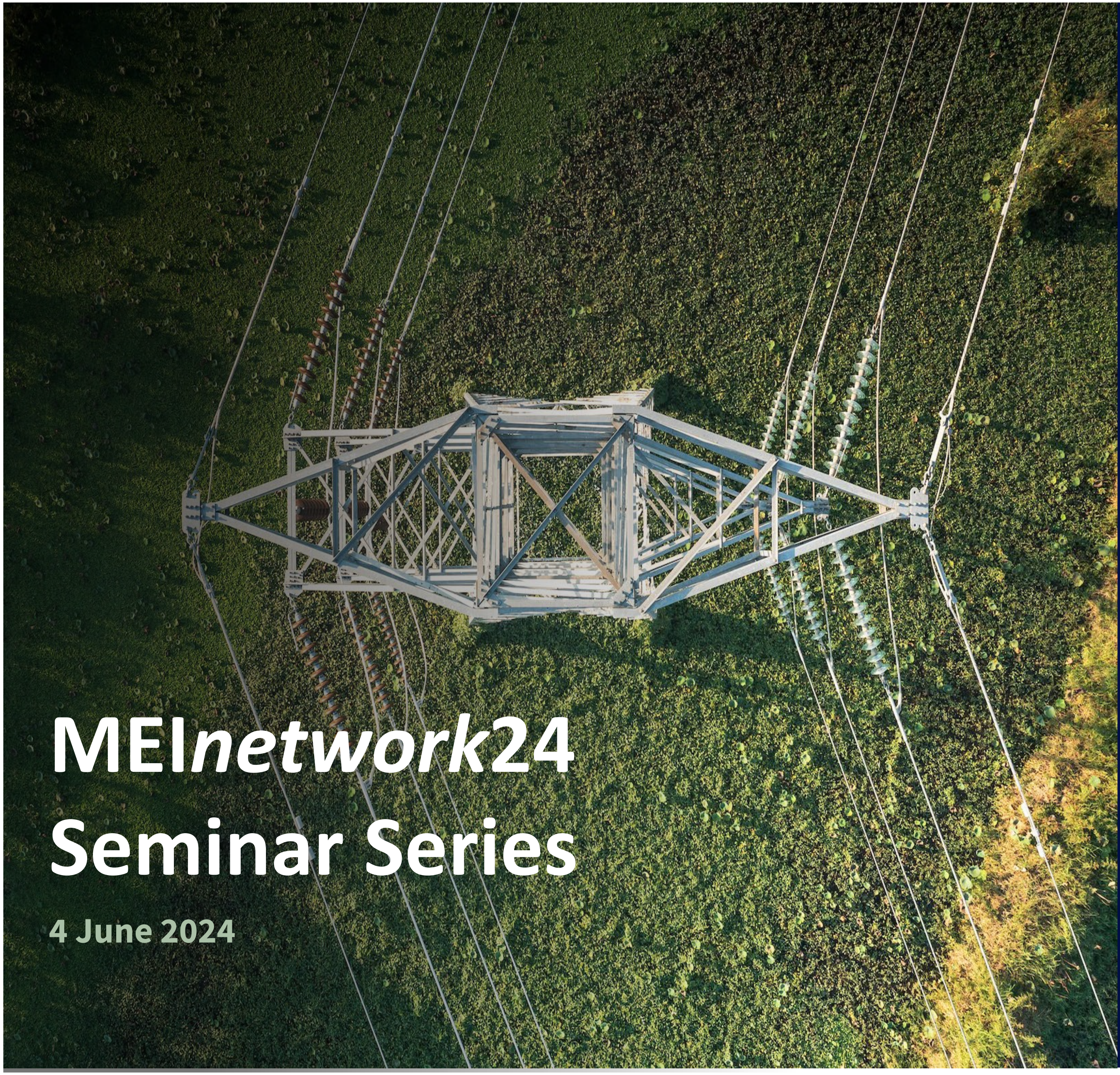

MEI*network*24 Seminar Series

4 June 2024

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THE UNIVERSITY OF MELBOURNE

Melbourne Energy Institute

Seminar #2: Transmission and distribution networks

Speaker:
John Theunissen, *Electrical engineer*

Moderator:
Arthur Goncalves Givisiez,
Research Fellow in Smart Grids,
Electrical And Electronic Engineering

MEI*network*24 Seminar Series

Seminar topic	Month
1. System overview: from generation to customer	2 May 2024
2. Transmission and distribution networks	**4 Jun 2024**
3. Wholesale markets	17 Jul 2024
4. Financial markets	7 Aug 2024
5. Retail markets	3 Sep 2024
6. Distributed energy resources	8 Oct 2024
7. Energy communities and microgrids	7 Nov 2024

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Talk Outline

- Introduction
- What's special about the Australian T&D networks?
- Impact of privatisation, disaggregation and competition
- Planning and design perspectives
- Operation – keeping the lights on
- Maintenance…..typically while "in flight"
- Asset replacement/renewal, augmentation, and future developments
- Innovation a close companion
- Key attributes for success
- Concluding remarks
- *Q&A opportunity*

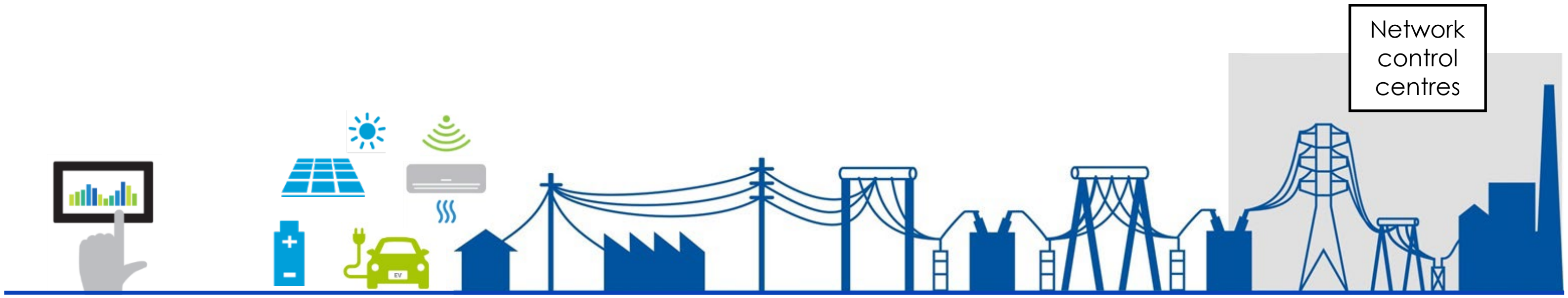
Introduction

Less about the pure theory of electricity networks, and more about practice - insights into the various activities that need to be undertaken, exploring some of the challenges to be managed, in the past and into the future, as the ecosystem evolves from a centralised to a decentralised model

.......and hopefully some story-telling along the way

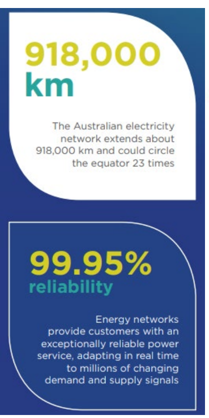
"There is a powerful agent, obedient, rapid, easy, which conforms to every use, and reigns supreme on board my vessel. Everything is done by means of it. It lights it, warms it, and is the soul of my mechanical apparatus. This agent is electricity"

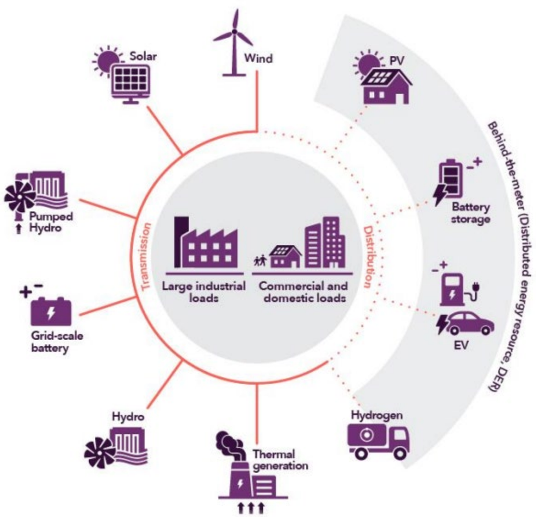
20,000 Leagues Under the Sea
Jules Verne

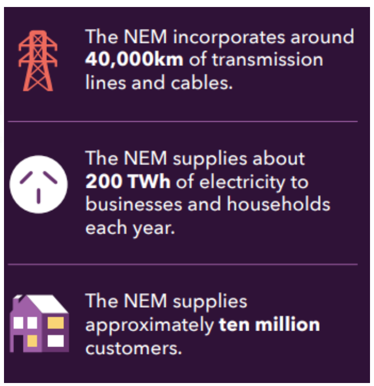


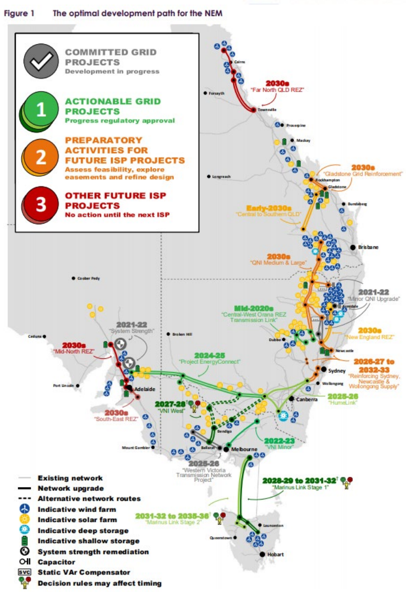
What's special about our T&D landscape?

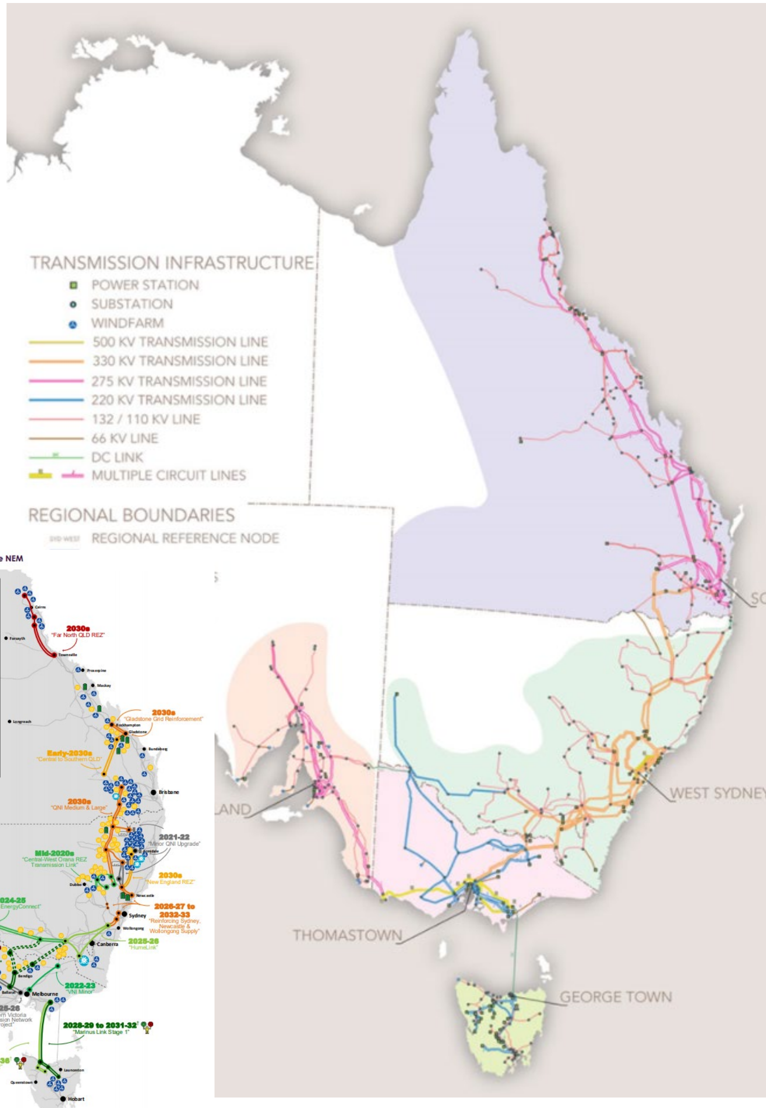
- One of the largest electricity grids in the world (geographic span)
- Ultra low customer density in parts
- Services highest number of "behind the meter" solar PV generators
- Distributed renewable generation at scale driving significant grid development









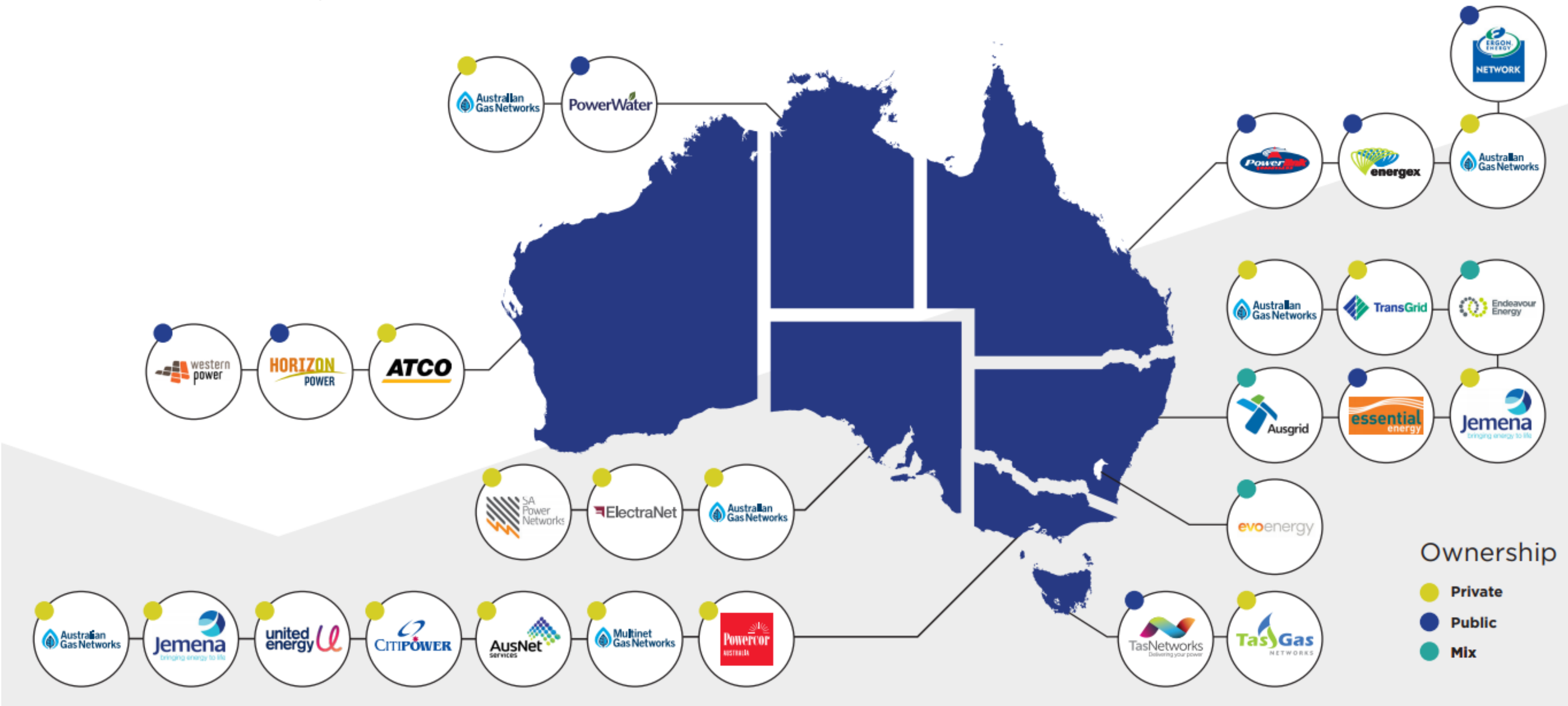


Source: ENA

Source: AEMO

What’s special about our T&D landscape?

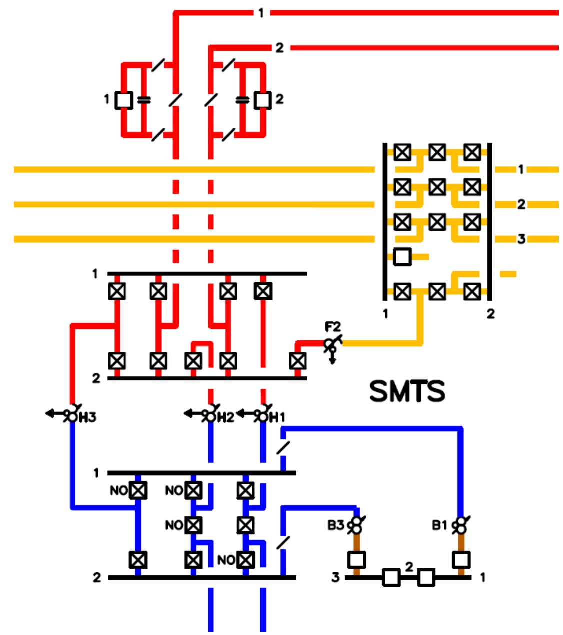
- Vertical separation of generation, transmission, distribution and retail
- Mix of private and public ownership
- Contestability in Transmission *(Victoria)*
- “Unique” regulatory framework

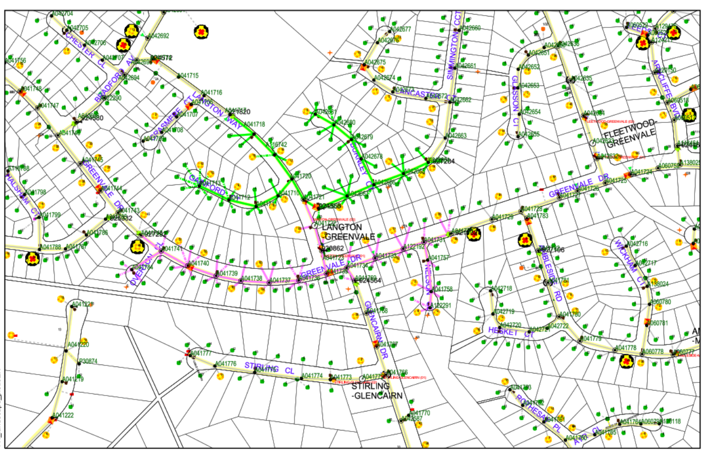


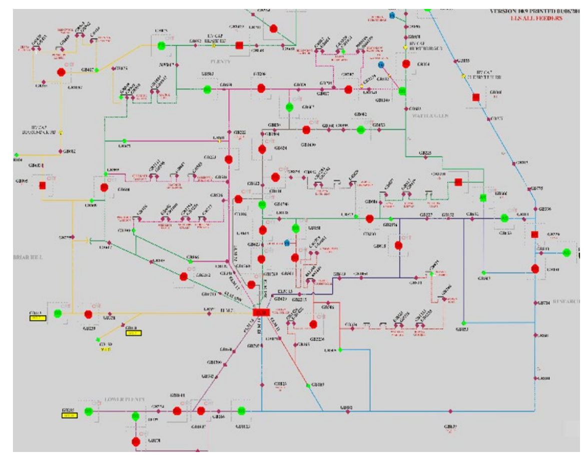
Source: ENA

What's special about our T&D landscape?

- An interesting blend of North American and British transmission network design concepts, with economic factors in the mix
- Unbalanced 3 Phase distribution networks
- Lots of Single-Wire-Earth-Return (SWER) for rural areas
- Multiple point earthing in LV networks
- Rapid Earth Fault Current Limiting (REFCL) in Victoria







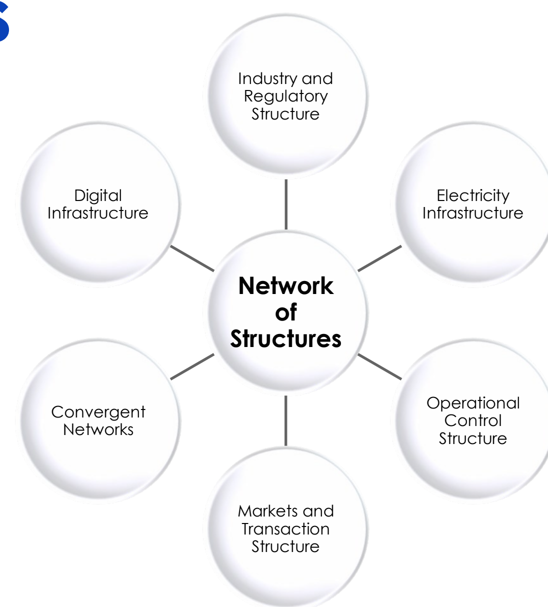
Privatisation, disaggregation and competition

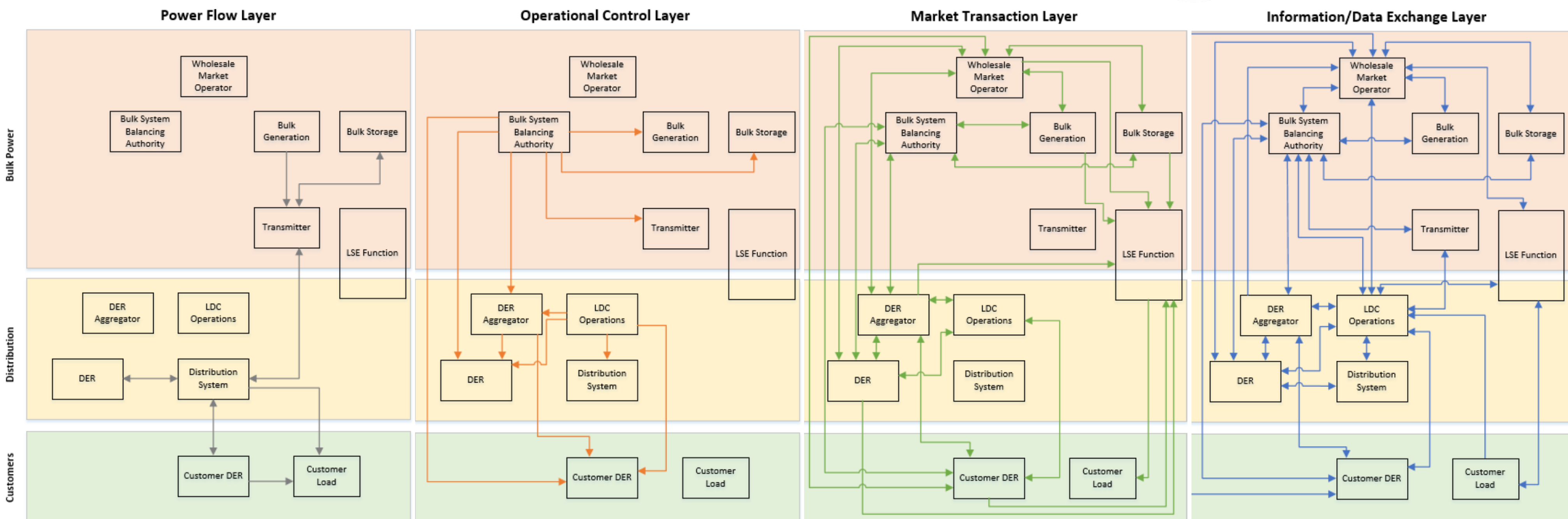
Transmission and distribution impacts and insights

- A more complex regulatory framework coupled with state-based government responsibilities and interventions/derogations
- Increased focus on commercial performance, introduction of value-based regulatory incentives and productivity benchmarking, responses geared to out-perform incentive regimes
- Requires greater coordination and industry orchestration to achieve an integrated approach to respond to current new energy transformation and industry reformation *(disaggregation has also reduced alignment with international product development and markets)*
- Driver of innovation – targeting business objectives *(e.g. asset condition monitoring, automation schemes, smart metering data based analytics)*

Planning and design perspectives
Architecture

- Electrical power systems are complex and require the interoperation of multiple layers or structures
- Architecture considerations have always been important in planning and design, however the emergence of distributed energy resources at scale and a new energy ecosystem is necessitating a reformation of how networks and their various sub-systems are configured, operated and managed





Development of a Transmission-Distribution Interoperability Framework 2020 – IESO Canada

Planning and design perspectives

Governing factors

- Primary plant layout/configuration
- Redundancy requirements
- Plant and equipment selection
- Protection systems
- Control requirements
- Communication systems
- Maintenance Practices

Engineering aspects
– easier to address

- Reliability
- Security
- Rating
- Safety
- Risk
- Economic efficiency
- Environmental
- Status quo
  ("as-is" network)
- Social licence

Ability to implement
(brownfield)

- Policy, processes and procedures
- Environmental protection requirements
- Flora and Fauna
- Site selection
- Easements
- Customer engagement

Non-Engineering aspects
– harder to address

Planning and design perspectives

Applied Reliability Standard

Planning standards set the ***balance*** between ***reliability and cost***. In general, higher reliability standards will result in additional investment in electricity supply network facilities and higher investment costs.

- Reliability criteria are somewhat subjective *(balance between the utility's costs of providing reliability and the consumers' benefits of uninterrupted service)*
- The transmission system's capability is aligned to the strength of the integrated system
- The transmission system's capability varies over time *(e.g. as switching operations occur and as demand, generation, and transmission flow patterns change).*

Deterministic

The system is modelled under a variety of expected future initial conditions, and then failures of individual (n-1) and multiple (n-2) components are evaluated.

✓

- *Easier to explain to the public*
- *Easier to reproduce*
- *More transparent, and*
- *Familiar because of past use.*

✗

- *Not easy to demonstrate that a given solution costs less than the associated reliability benefit.*
- *Difficult to incorporate the deterministic results into economic comparisons of different alternative plans.*

Probabilistic

Probabilistic analysis evaluates the system under a variety of expected future initial conditions, and then failures of individual components, but not multiple, are evaluated.

✓

- *Easier to use for economic comparisons between alternative expansion plans.*
- *Easier to present the economic justification for selecting a particular expansion plan*

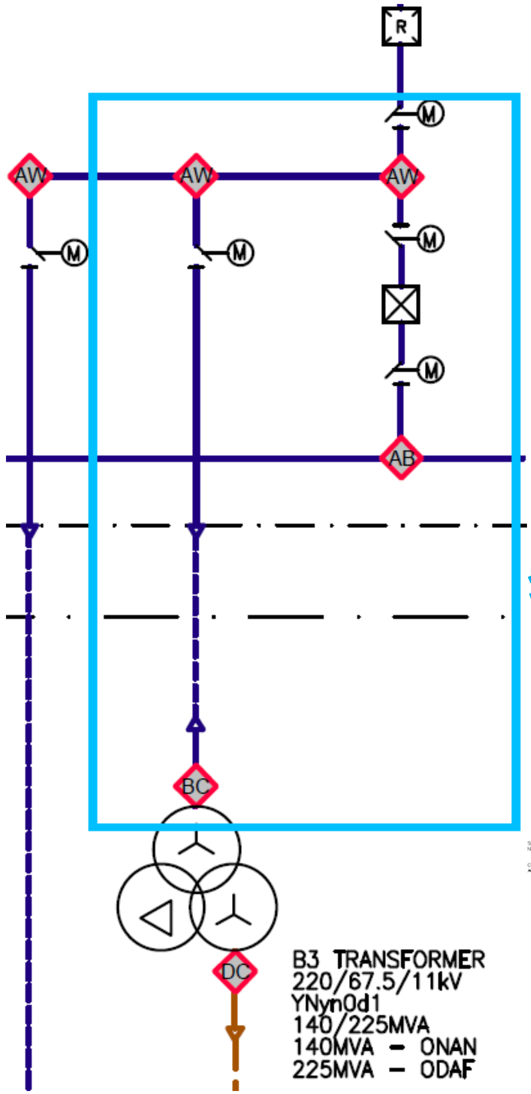
✗

- *Computationally intensive (less of an issue in digital age)*
- *Tend to be less transparent than deterministic methods*
- *Databases are challenging to develop/maintain*
- *Multiple/extreme/unusual contingencies hard to evaluate*

Planning and design perspectives

Ratings *(How much power can be transported?)*

It's complex and often not obvious!

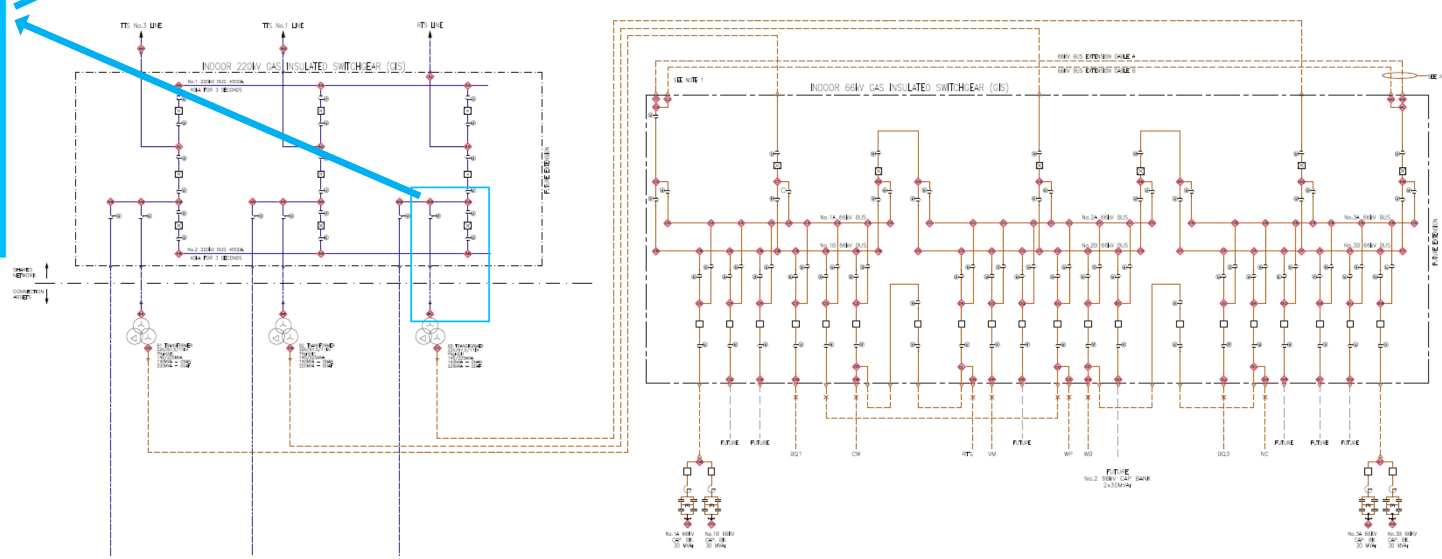


All Data items must be checked

	Sum	Win	Amb	Sort By
Ambient Column (°C): 35 CALC	35	5	Cont	
Flag Items Below (Amps) 0 CALC — Maximum:	0	0	0	Summer

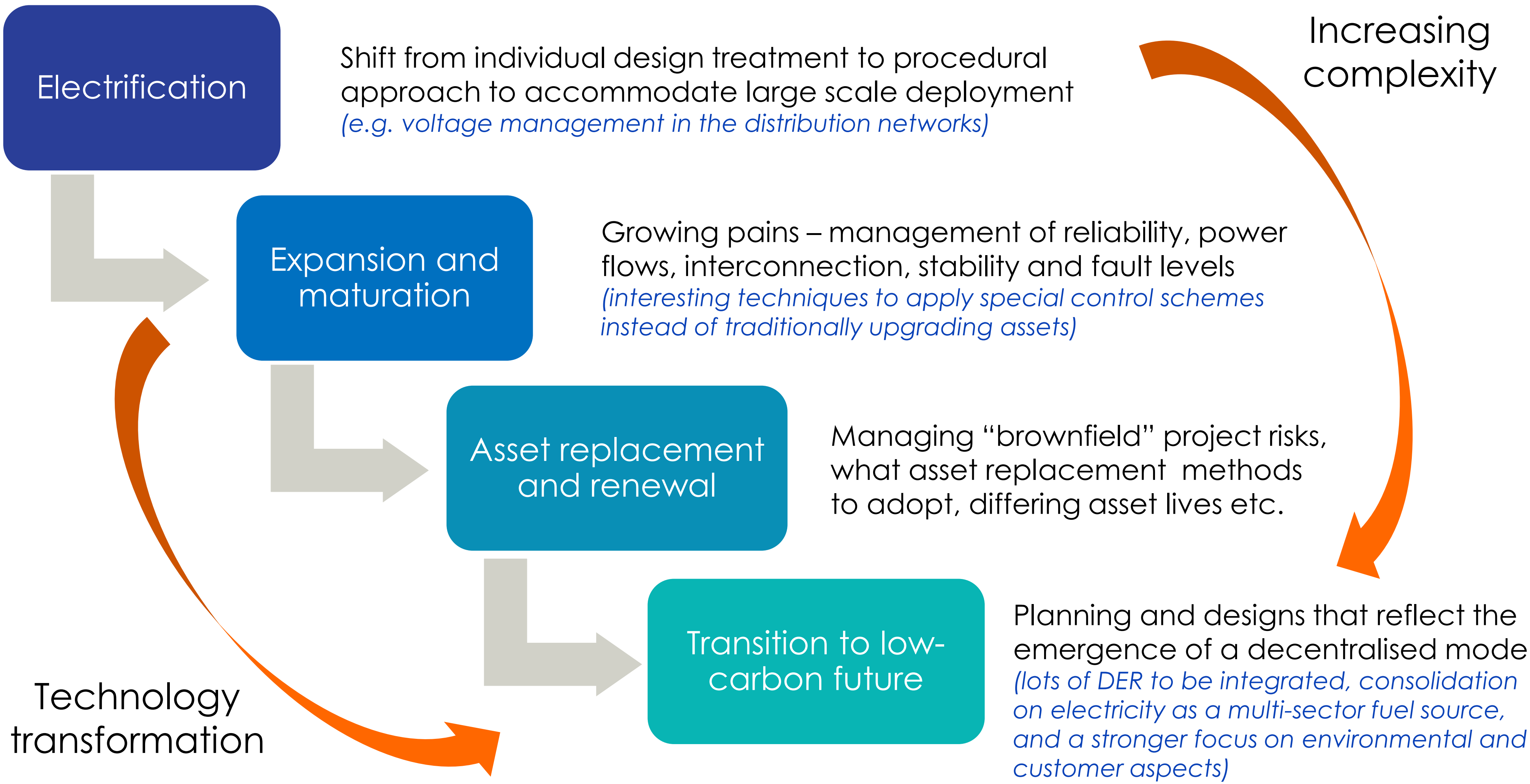
Station/Line	From	To	Equipment Type	Description	Sum	Win	Amb	Calc	Order	Information
BTS	AB	AW	BUS				0	0	4	S B E N D
BTS	AB	AW	BUS - SWITCH		3150	3150	3150	Q	5	S B N D
BTS	AB	AW	SWITCH				0	0	4	S B E N D
BTS	AB	AW	SWITCH - CB		3150	3150	3150	Q	5	S B N D
BTS	AB	AW	CB		3150	3150	3150	L	5	S B E N D
BTS	AB	AW	CB - SWITCH		3150	3150	3150	Q	5	S B N D
BTS	AB	AW	SWITCH				0	0	4	S B E N D
BTS	AB	AW	SWITCH - JUNC		3150	3150	3150	Q	5	S B N D
BTS	AW	BC	JUNC - SWITCH		3150	3150	3150	Q	5	S B N D
BTS	AW	BC	SWITCH				0	0	4	S B E N D
BTS	AW	BC	SWITCH - CABLE TERM (GIS)		3150	3150	3150	Q	5	S B N D
BTS	AW	BC	CABLE TERM (GIS) - CABLE TERM (AIS		786	786	786	Q	2	S B N D
BTS	AW	BC	CABLE TERM (AIS) - TRREG		1285	1630	1285	Q	3	S B N D
BTS	AW	BC	TRREG		0	0	0		1	S B E N D

- Network is made up of many node-to-node ratings
- These can be constrained by many factors *(primary plant, conductors, terminations, instrument transformers, protection settings, temperature etc.)*
- Network switching and configuration dictates operational power flow limits



Planning and design perspectives

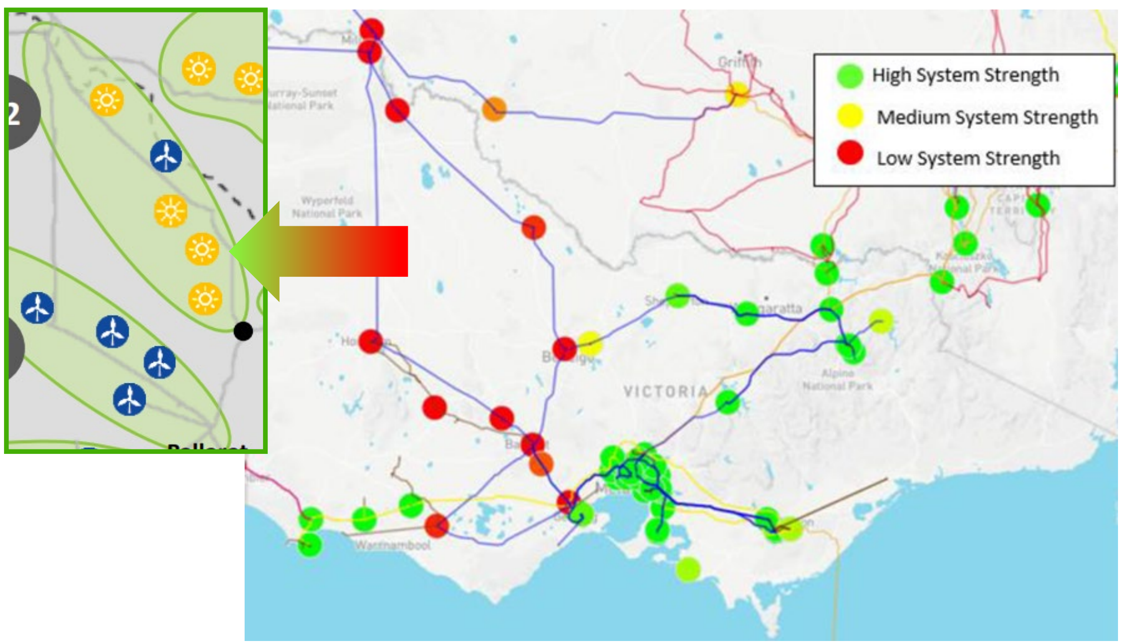
Evolution of design practices



Planning and design perspectives

Example of significant network repurposing

- Original design objective was rural electrification and load serving
- Economic factors dictated initial network build and "strength"
- Minimal reinforcement required over the years
- Recent/pending major wind and solar generation connections necessitate significant network redevelopment and increased complexity of network planning and design



Planning and design perspectives

Tools of the trade

Network modelling software

(aligned to different conditions – e.g. steady state, dynamic, transient)

Asset risk modelling

Electrical engineering theory

Historical databases and analytics

(performance, fault incidences, SCADA historian etc.)

Future Forecasting & Scenario Impact Assessment

Planning and design perspectives

Tools of the trade

Type of Modelling	Purpose	Study Types	Examples of Software Packages
Steady state power system analysis	Assessment of voltage and thermal conditions, fault levels	Load flow, voltage step, fault level contribution of DG	DIgSILENT, DINIS, ERACS, ETAP, IPSA, Power World, PSS/E, SKM Power Tools, OpenDSS
Dynamic power system analysis	Assessment of the transient and dynamic behaviour of equipment e.g. generators, DFIGs, and/or the network	Transient stability, critical clearing time, dynamic voltage step/control, fault ride through	DIgSILENT, DINIS, ERACS, ETAP, IPSA, Power World, PSS/E, SKM Power Tools
Harmonic analysis	Assessment of harmonics, distortion levels and identification of resonances	Impedance scan, harmonic load flow (including impact of VSC)	DIgSILENT, ERACS, ETAP, IPSA, PSS Sincal, SKM Power Tools
Electro-Magnetic Transient (EMT) Analysis	Assessment of eletro-magnetic transients and phenomena	Insulation coordination (lightning, switching), HVDC/ FACTS equipment design, sub-synchronous resonance (SSR)	ATP-EMTP, EMTP-RV, PSCAD/ EMTDC
Real Time Simulation (RTS)	Closed loop and scenario testing in real time	Real time simulations, protection testing, control system testing	RTDS, Opal-RT
Hybrid Simulation	Assessment of multiple models/ programs in the same dynamic simulation environment	Dynamic analysis of the interaction between two systems	ETRAN (PSS/E and PSCAD)
Multi-Domain Analysis	Assessment of multiple systems and their interactions	Study of interactions between electrical, power electronic, mechanical and fluid dynamic systems	MATLAB (including Simulink and SPS/Simulink), DYMOLA Plexos *(market related)*

Operation – keeping the lights on

Roles and actors

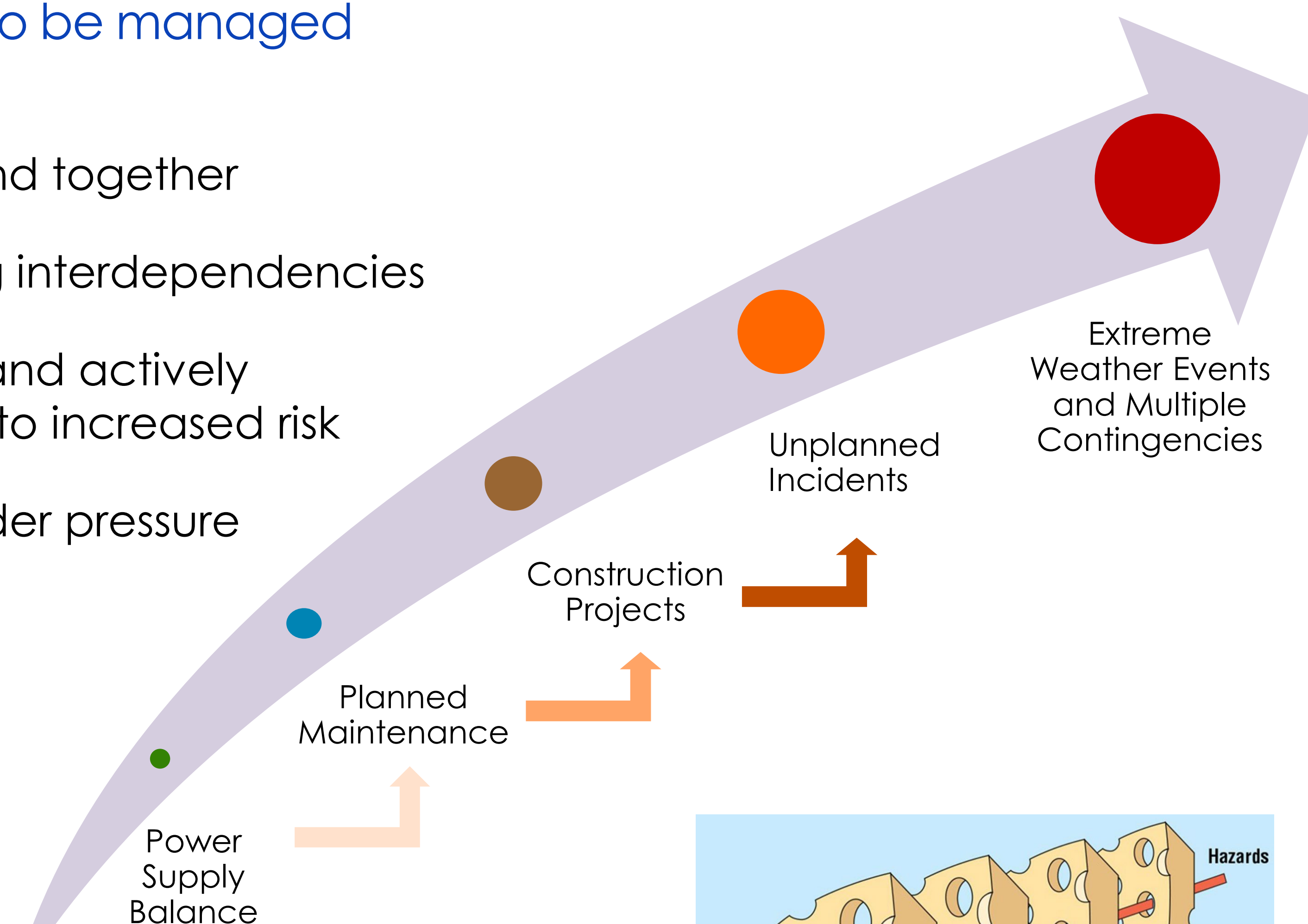
Simple interpretation *(focus on T&D network operations not on markets but of course they are interrelated, and everything is underpinned by the National Electricity Law)*

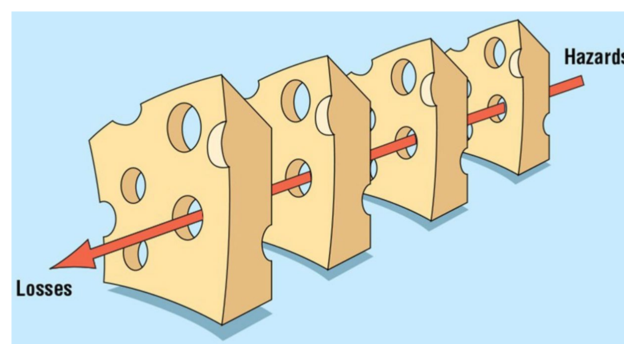
- AEMO manages the power flows across the interconnected network and looks after power system security and overall reliability
- The Transmission Network Service Providers (TNSPs) in each state look after the operational health of their networks and carry out network switching activities at AEMO's direction
- The various Distribution Network Service Providers (DNSPs) operationally manage the operation of their networks to provide Code compliant electricity services to connected customers
- In certain operational contingencies, AEMO can direct TNSPs and also DNSPs to take specific actions to safeguard system security *(e.g. load shedding)*

Operation – keeping the lights on

Challenges to be managed

- Separate and together
- Recognizing interdependencies
- Evaluating and actively responding to increased risk
- Working under pressure





Level 1 at TOC due to planned outages:

- KGTS-WETS 220kv Line 0700- 1800hrs places KGTS on a single contingency
- SVTS No 2 220kv Bus, HTS-SVTS No 2 220kv Line place HTS on a single contingency
- WMTS L1 Trans places 22Kv load on a single contingency

Operation – keeping the lights on

Day-in-the-life scenario

At night

- Reporting
- Preparation for the next day's planned/forecast activities

Early morning

- Switching of plant to manage network voltages and power flows in relation to generation and load profiles in conjunction with NEM activities in the transition to day-time load/generation profile

Start of working day

- Issuing of network access permits for planned work, management of switching activities

Across the day

- Liaison with remote work teams, managing network operation in accordance with generation, load and weather conditions, responding to unplanned events – *assets not working as they should, outages because of an electrical fault on the network*

Afternoon

- Restoration of the network after completion of planned work

Late afternoon/evening

- Peak load management

Operation – keeping the lights on

Emergency and significant event management

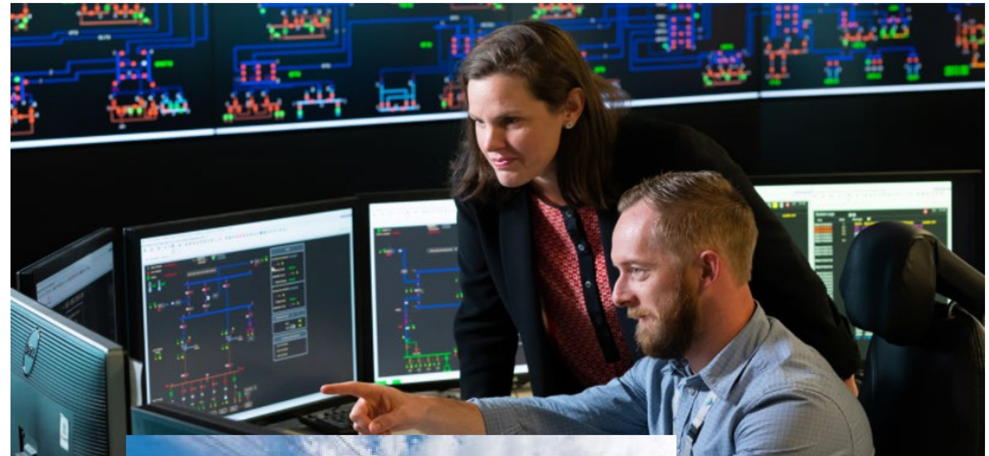
An integrated societal response management approach coupled with individual TNSP/DNSP risk management frameworks

- AEMO network control intervention in the market
- Specialised protection and control schemes
- Enactment of protocols (e.g. load shedding)
- Contingency and continuity management plans
- Special emergency powers – government led
- Black-start procedures and training

Operation – keeping the lights on

Tools of the trade

- Trained controllers and operators
- Geospatial Information System (GIS)
- Supervisory Control and Data Acquisition (SCADA)
- SCADA Historian
- Energy Management System (EMS)
- Distribution Management System (DMS)
- Outage Management System (OMS)
- Weather forecasting
- Automation
- Control room simulators
- Additional analytics and visualisation tools



Maintenance.....typically while "in flight"

What's involved?

Activities

- Periodic "servicing" of assets
- Inspection and monitoring
- Updating of network/asset data
- Vegetation management
- Network restoration, asset repair and reporting after incidents and faults
- Customer care around planned and unplanned outages
- Contingency management

Strategies

- Regulatory requirements
- Condition-based
- Predictive
- Risk-based approaches
- Maximise works during outage to minimise customer impact
- Live work

Practices

- Policies, procedures and protocols
- Standardised work instructions
- Focus on safety *(Mission Zero)*
- Current trend to have delivery partners *(outsourced services)* rather than "in-house" teams

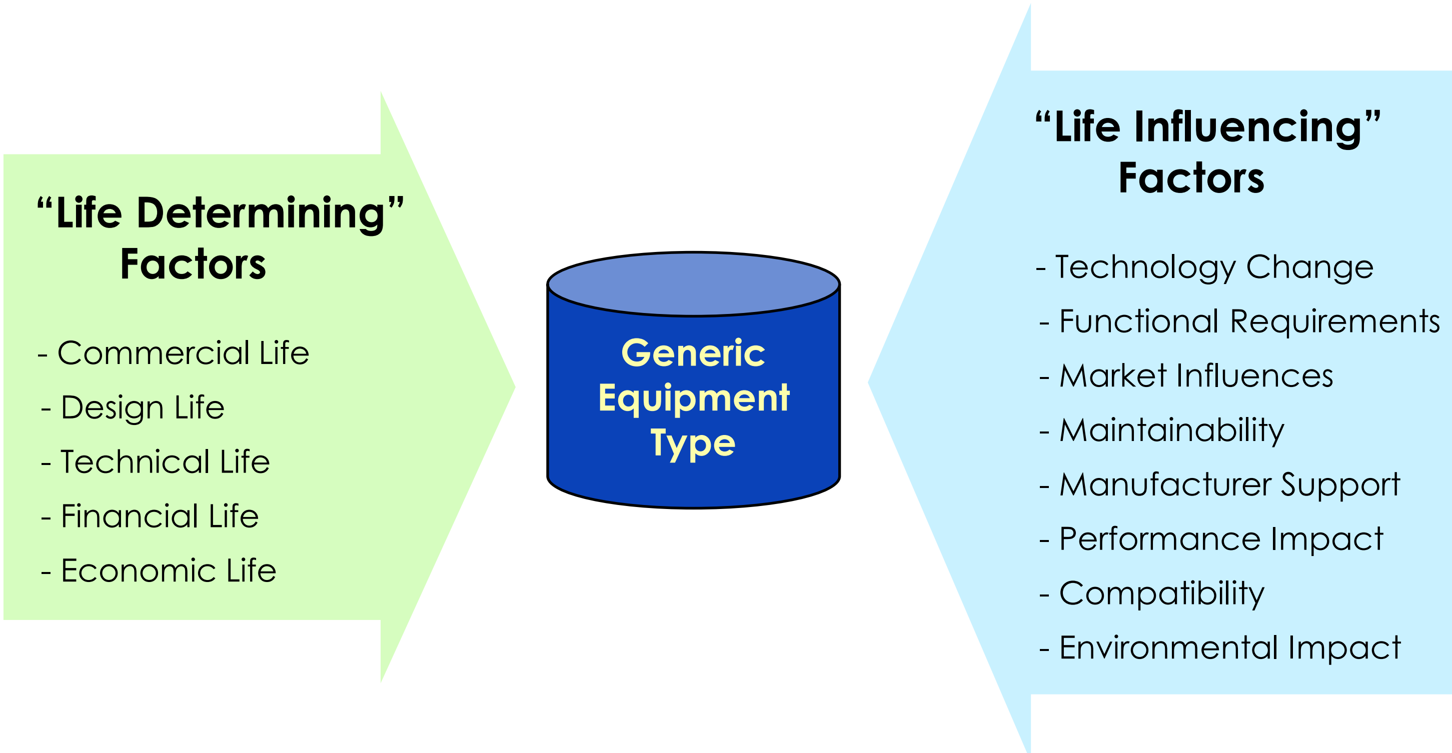
Asset replacement/renewal/augmentation

Asset lives

- Different types of assets have different lifespans and drivers for replacement, coupled with broader asset management strategies
    - *Lines, Power Transformers, Switchgear, Secondary systems etc.*
- A prevailing distinction between managing transmission and distribution assets is in the high-level approach to infrastructure management
    - *Transmission is centred on individual assets like power transformers, specific terminal stations and equipment*
    - *Distribution is more aligned to a fleet-based asset approach*

Asset replacement/renewal/augmentation

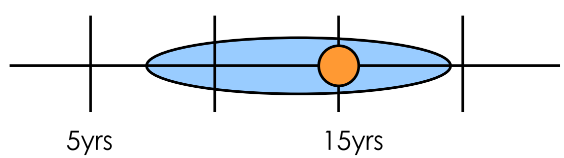
Asset lives



Cone of Uncertainty

Effective asset Life

(e.g. Communications assets)



Asset replacement/renewal/augmentation
Complexity

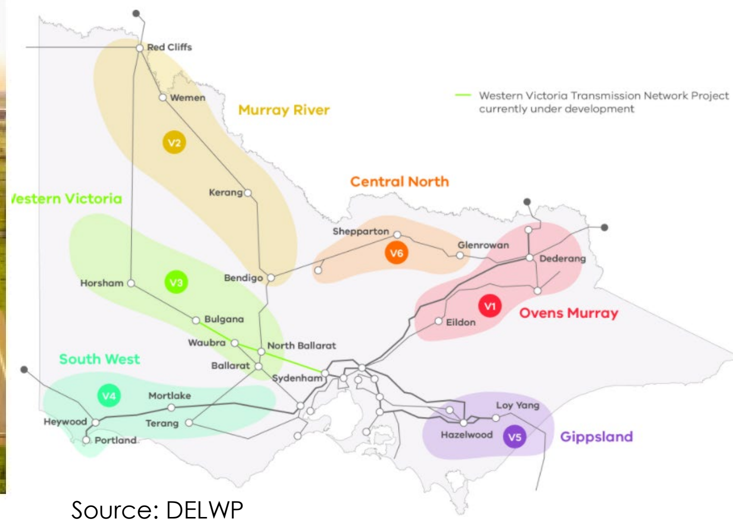
Questions to answer

- Functionality?
- Risk?
- Economics?
- Replace whole or in part?
- What technologies to adopt?
- What asset life is required?
- How to maximise the value of the asset through the replacement?
- Who should own and operate etc.?

Asset replacement/renewal/augmentation

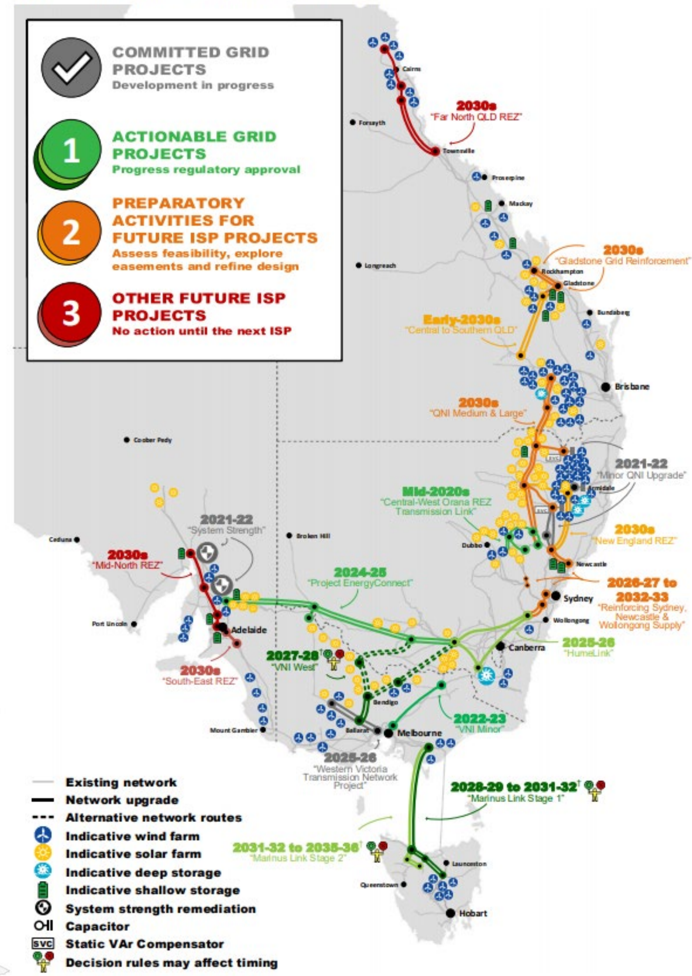
New "drivers" and required responses

- New functional requirements *(e.g. networks running backwards)*
- Increasing connection of distributed generation plants
- Energy resilience for isolated communities
- Digitalisation
- New energy technologies
- Changing requirements for operational stability *(e.g. combination of renewable generation plus firming storage)*



Source: DELWP

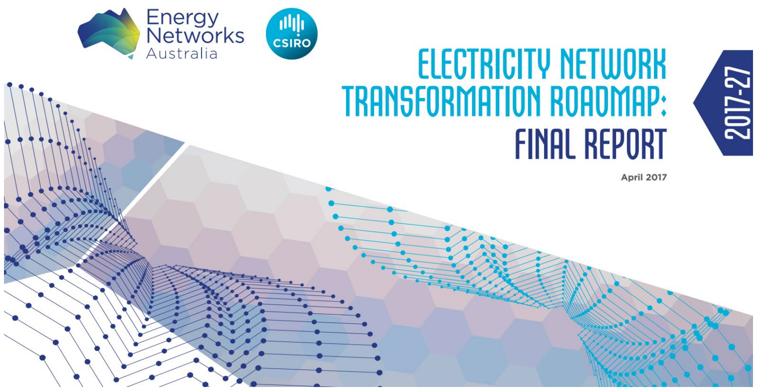
Figure 1 The optimal development path for the NEM

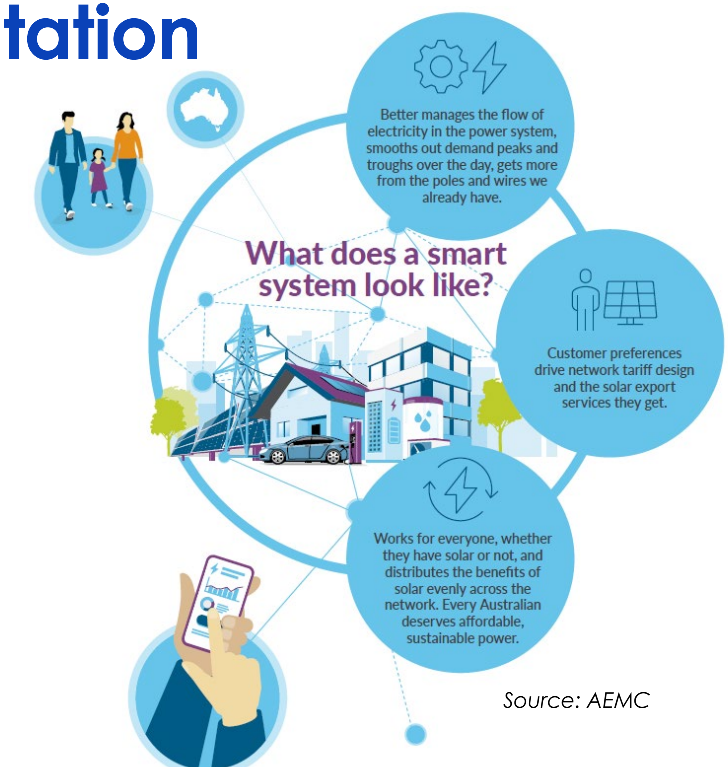


Source: AEMO

Asset replacement/renewal/augmentation

Transformation and new roles / actors

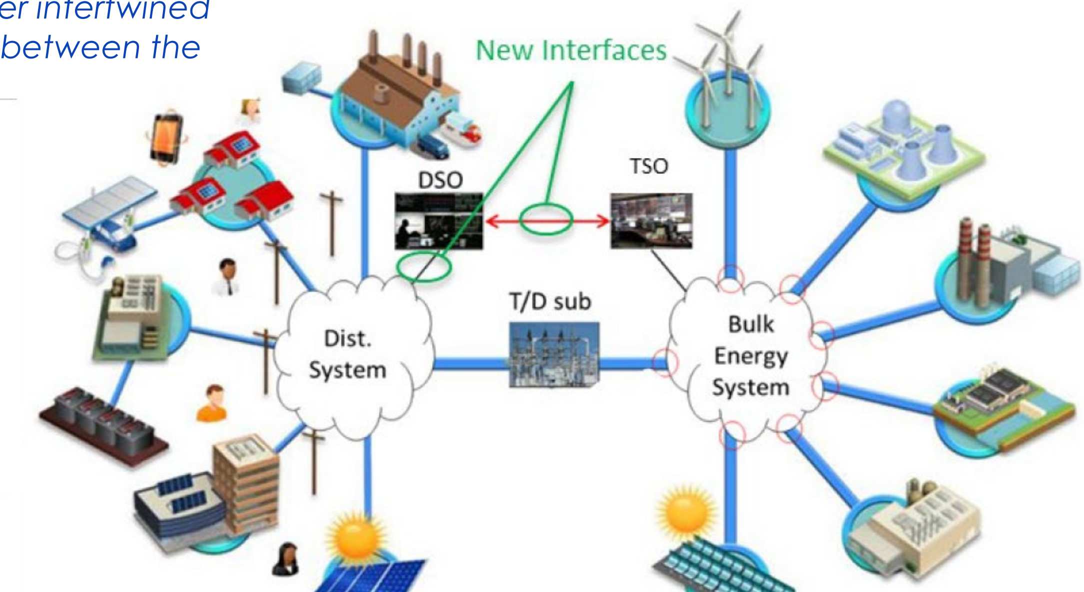




Source: AEMC

Introduction of Distribution System Operator (DSO) functions, and the increasing interplay of technical, economic and community forces at the distribution level *(network operations closer intertwined with new DER markets, and the emerging new relationship between the transmission and distribution networks)*

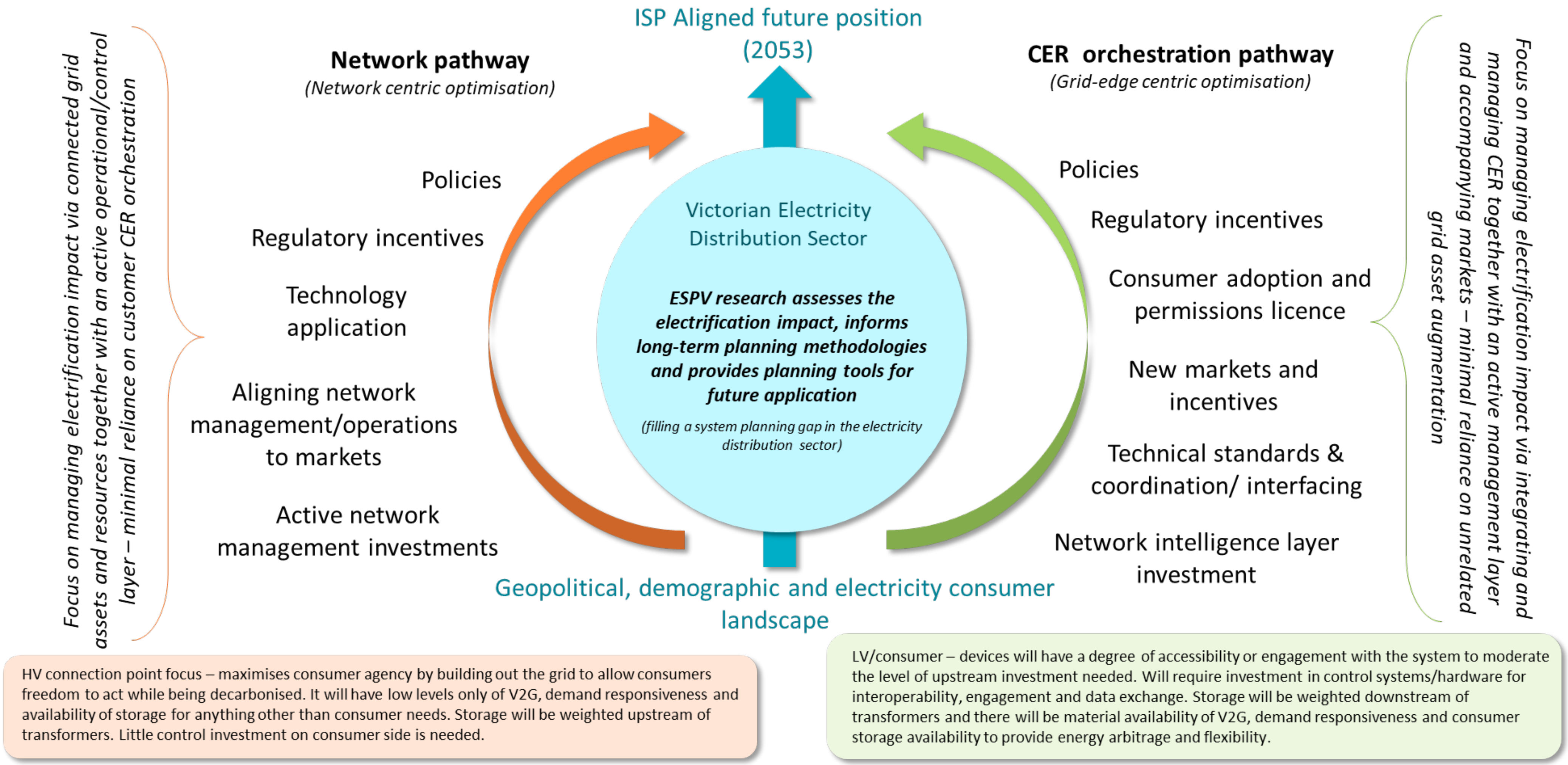
Opportunities for electricity networks to become energy integration platforms as well as enhanced essential services delivery vehicles



Underlying diagram source: EPRI

Asset replacement/renewal/augmentation

Example pathway scenarios for the evolution of distribution networks

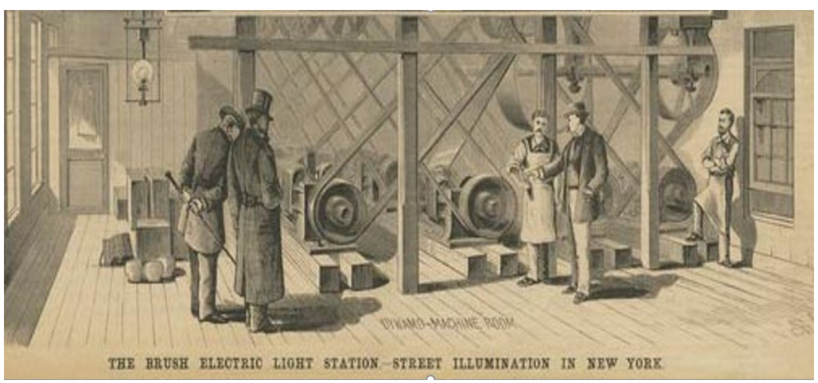


Source: C4NET Enhanced System Planning research project

Innovation always a close companion

Illustration using a maritime navigation analogy

What were the significant advances along the way and what were their implications?



Innovation always a close companion
Illustration using a maritime navigation analogy

Maritime Navigation	*Attributes*	*Our electricity network world parallel*

Dead Reckoning

- *Compass (direction)*
- *Log/Knotted Rope (speed)*
- *Primitive Maps (reference)*

✓ **Dedicated resources** *(functional)*
✓ Manual processes
✓ Minimal integration

Local instruments at Substations
Network diagrams

Celestial

- *Sextant (latitude)*
- *Chronograph (longitude)*
- *Reliable Maps & Charts*

✓ Dedicated resources
✓ **Coordinated operation**
✓ Manual processes
✓ Some interdependencies
✓ Increased complexity *(calculations)*

Land-line telecommunication from control centres to manned power stations and substations?

Celestial +Radio

- *Marine Radios*
- *Speedometer*

✓ Mix of dedicated & networked resources
✓ **Parallel technologies**
✓ Reduced manual processes
✓ "External" assistance

SCADA systems installed and telecommunications to remote sites

Satellite

- *GPS*

✓ **Network oriented**
✓ Auto processes
✓ **Integrated solution**
✓ User/service bias

Distribution Network Management
Distributed sensors and intelligence

Cloud-based Intelligence

- *Multiple data sources (weather, radar etc.)*
- *Integrated digital technology platforms*

✓ **Platform oriented**
✓ Advanced analytic processes
✓ **Ecosystem centric solution**
✓ Market bias

Ecosystem data *(internal & external)*
Big Data compute environments,
Intelligent DER
Orchestration of energy portfolios

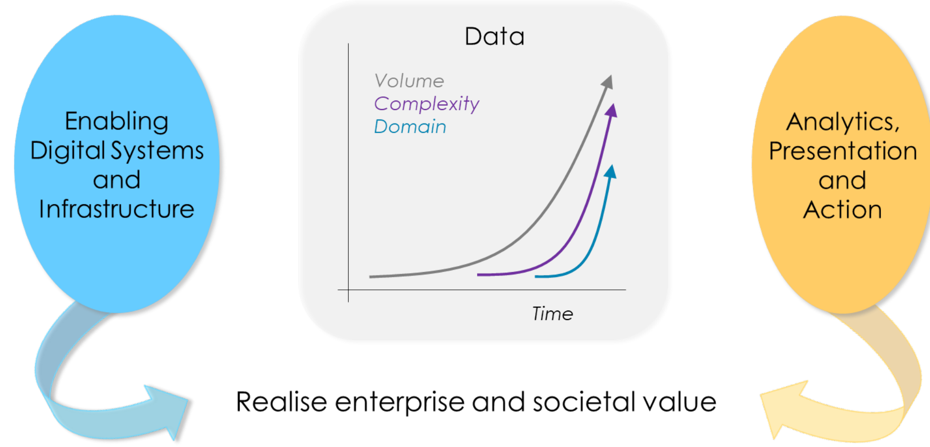
Key attributes for future success

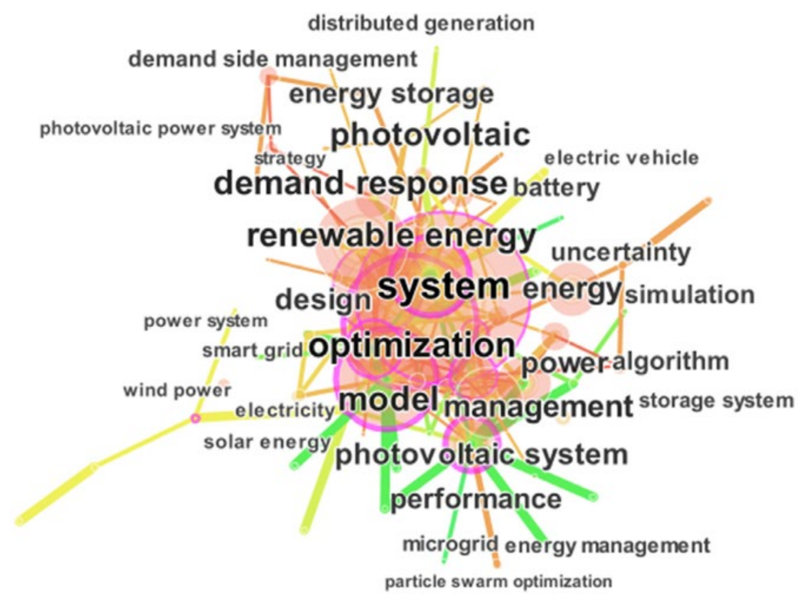
- Effective and efficient data, information and configuration management *(network, asset and customer data)*

- Flexibility and responsiveness *(regarding customer connections, network operation and access to network capacity etc.)*

- A holistic approach to providing electricity network services *(incl. non-network solutions, alternative solutions for electricity supply – microgrids, SAPS etc.)* that consider "whole of ecosystem" benefits, not limited to regulatory investment tests

- The ability to manage increasing uncertainty and volatility within the power system





Source: Balancing of supply and demand of renewable energy power system: A review and bibliometric analysis (Lu Gan, Pengyan Jiang, Benjamin Lev, Xiaoyang Zhou)

Concluding remarks

The golden age of electricity networks – then or now?

“Customers” and “communities” are more important now than ever for networks, and need to be central to their activities

Electricity networks have the potential to grow into the energy integration platform of the future

Q & A

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