Improving the National Electricity Market design in the light of recent experience

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Outline

- WMO, *Climate breaks multiple records in 2016:*
  https://public.wmo.int/en/media/press-release/climate-breaks-multiple-records-2016-global-impacts
- *We are seeing other remarkable changes across the planet that are challenging the limits of our understanding of the climate system. We are now in truly uncharted territory*
- The NEM is in trouble & won't be easy to fix:
  - Now very decentralised with a high rate of uncoordinated, near-chaotic, innovation
  - Governance failings (also in the gas industry)
  - Engineering challenges
- Background: complex socio-technical systems
- Key decentralised electricity industry issues:
  - Creating & maintaining a balanced resource mix
  - Theoretical insights, limitations & practical implications
- Recommendations

Sustainability – the underlying problem

- No universally agreed definition but equity related:
  - Human perspective: intra- vs inter-generational
  - Broader eco-system perspectives
- Much of our societal debate relates to priorities:
  - Example: Adani coal mine proposal:
    - Profits & regional jobs now vs environmental impacts now & later
- The electricity industry faces the "trilemma":
  - Reliability vs cost vs environmental impact
- Energy storage is an emerging issue:
  - Fossil fuels are stored & processed biomass being used in unsustainable ways (depletion, impacts)
  - Reversible storage such as pumped hydro or batteries:
    - Diverse characteristics & niches
    - External impacts as with all other options

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Hewson J, Markets need to work for the greater benefit of everyone, *The Age*, 16/3/17 http://www.theage.com.au/comment/im-no-socialist-but-markets-need-to-work-for-the-greater-benefit-of-everyone-20170316-guz660.html

- *In policies such as privatisation we have transferred economic power and privilege from the public to some in the private sector, in a quest for greater "economic efficiency".*
- *However, we need to first set the necessary regulations to limit the use of that power.*
- *So, in many cases, the result has been exploitation and price gouging – think of electricity and gas, airports, airlines, toll ways and hospitals*

Comment: The electricity industry including its governance regime is in danger of losing its societal licence to operate

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Robert Gottliebsen, Where did they go so wrong? *The Australian*, 21/3/17, http://www.theaustralian.com.au

- *…Our energy crisis actually started back in the first decade of this century when in both state and federal spheres we began to appoint public servants who were just "yes" men and women who would tell the politicians what they wanted to hear.*
- *And then we also surrounded ministers with advisers who all had the same view*
- *…And so if you want to go renewables in power generation to 20, 30, 40 or 50 per cent then you must find people who know what is required*

Comment: The electricity industry including its governance regime is in danger of losing its societal licence to operate

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Recent specific criticisms of the NEM: Governance
(gas governance also being criticised)

- Electricity reform has been a comprehensive failure[1]
- Policy uncertainty, lack of coordination and unreformed markets increase costs, undermine investment and worsen reliability risks[2]
- The SCO, AEMC, AER, AEMO are the prime bodies entrusted with delivering electricity and gas to the NEM and collectively they have done a very poor job[3]
- More clearly assign forward-looking risk assessment and management roles to agencies such as AEMO and NSPs with a view to identifying emerging technical issues early[4]

1. Quiggin J. 2017. *Grid Renationalisation*
2. Joint statement 2017. *No room for partisan politics in energy*
3. Leitch D. 2017. *The NEM is a mess – so who will clean it up?*
4. AEMO 2017. *Submission to Independent Review into the Future Security of the NEM*

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Recent specific criticisms of the NEM: Economic

- Generation & retail markets:
  - Excessive horizontal & vertical integration[1]
  - Competition in electricity retailing hasn't delivered what was promised: lower prices for consumers. The failure is worst in Victoria – with the most retailers & longest experience[2]
  - Greater load & embedded generation participation in real-time markets would enhance power system management[3]
- Transmission & distribution economic regulation:
  - Successive Australian governments have gifted the energy distribution & transmission industries a return on investment which Asian billionaires dream about[3]

1. Leitch D. 2017. *Too much power: The real crisis in Australia's energy markets*
2. Grattan 2017. Price shock: is the retail electricity market failing consumers?
3. AEMO 2017. *Submission to Independent Review into the Future Security of the NEM*
4. West M. 2017. *As power bills swell, so do fortunes of power companies & billionaires*

Recent specific criticisms of the NEM: Engineering

- Security management:
  - Reassess the market framework for frequency control to address loss of performance & power system control[1]
- Technical standards:
  - Millions of low-quality solar panels have been installed on Australian roofs in the past decade[2]
  - Contrary to recent speculation, Standards Australia is not developing standards that will ban the introduction of on-site lithium-ion battery storage in homes[3]
  - More than 80% of transmission line failures in Australia are attributed to extreme weather conditions[4]

1. Summers K. 2017. *Fast Frequency Service – Treating the symptom not the cause?*
2. Johnson W. 2017. *How long will your solar panels last, & how well will they perform?*
3. Standards Australia 2017. *Speculation regarding on-site battery storage in homes*
4. Kulkarni & McCormack 2014. *Forensic Engineering for a Transmission Line Failure*

Independent Review into the Future Security of the National Electricity Market: *Extracts from the Terms of Reference*

http://www.environment.gov.au/energy/national-electricity-market-review

- ✓ The Australian electricity market is undergoing a significant transition, including due to rapid technological change, the increasing penetration of renewable energy, a more decentralised generation system, withdrawal of traditional baseload generation and changing consumer demand.
- ✓ Energy security is the paramount responsibility of governments. Recent events have once again highlighted the importance of ensuring the security and reliability of the National Electricity Market (NEM).
- ✓ The purpose of the review is to develop a national reform blueprint to maintain energy security and reliability in the NEM, for consideration by the Council of Australian Governments through its Energy Council.
- ✓ The review will draw together and build on the analysis and findings of the recent and ongoing work streams, as identified above. It will also consider any other matters and processes that may be relevant to system security and reliability.
- ✓ The blueprint will outline national policy, legislative and rule changes required to maintain the security, reliability and affordability of the NEM in light of the transition taking place
- ✓ Consistent with the National Electricity Objective, the review will examine the costs and benefits, including to consumers and industry, of the options to address any current or future vulnerabilities identified in the NEM.

Comment: A good start but TOR too narrow

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Independent Review into the Future Security of the National Electricity Market: *Preliminary Report observations*

http://www.environment.gov.au/energy/national-electricity-market-review

- The security & reliability of our electricity supply is less assured than in the past
- The rate of technological change is unprecedented and consumer expectations are shifting rapidly
- Household energy bills rose on average almost 50 per cent (inflation adjusted) in the six years to 2014
- Inadequate supply and the high cost of natural gas are contributing to electricity price rises
- There is broad enthusiasm for a coordinated national approach to energy and emissions reduction policies

Comment: Useful observations but arguably already going outside the TOR

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NEM-related definitions for *Security* & *Reliability*

National Electricity Rules Chapter 10 Glossary:

- *Power system security:* The safe scheduling, operation and control of the power system on a continuous basis *(practical interpretation: technical parameters within & expected to remain within safe limits)*
- *Reliability:* The probability of a system, device, plant or equipment performing its function adequately for the period of time intended, under the operating conditions encountered

Finkel Review Preliminary Report:

- A *secure power system* is one that is able to continue operating within defined technical limits, even in the event of the disconnection of a major power system element such as an interconnector or large generator. (p 10)
- A *reliable power system* is one in which there is sufficient generation and **transmission** capacity to meet all grid demand. The National Electricity Rules include mechanisms to ensure reliable supply. These include a reliability standard that requires that no more than 0.002 per cent (11 minutes in a year) of customer demand within a region go unmet. (p 10)
- The increasingly active role of consumers will be important in supporting the future security and affordability of the power system (p 18)

Note: Both sets of definitions imply management of risks from physical devices, human decisions & the external environment but without clearly stating how. They also downplay the importance of the distribution network

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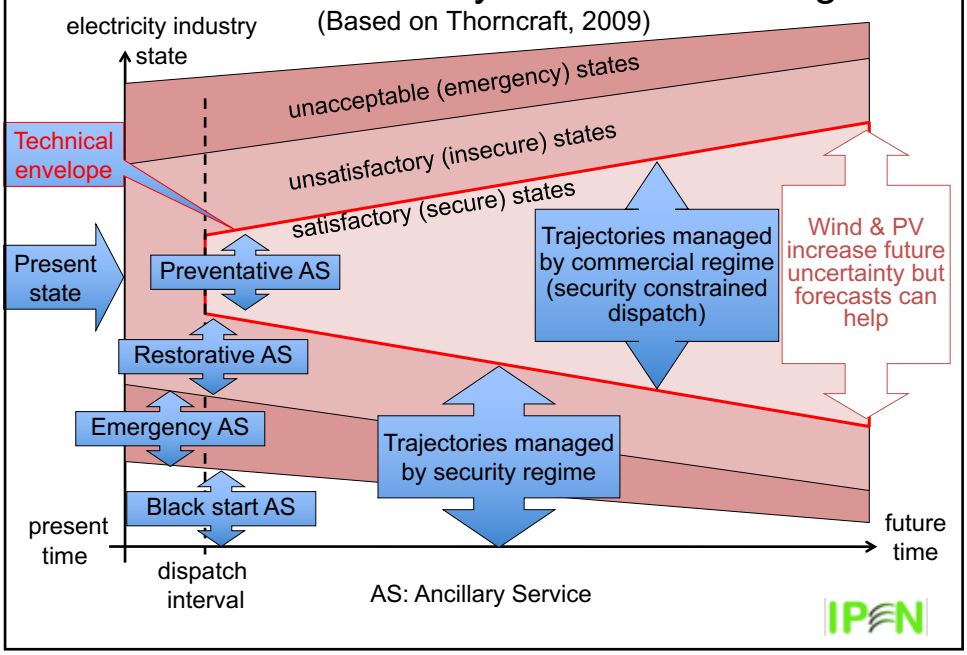
Australian NEM security & commercial regimes



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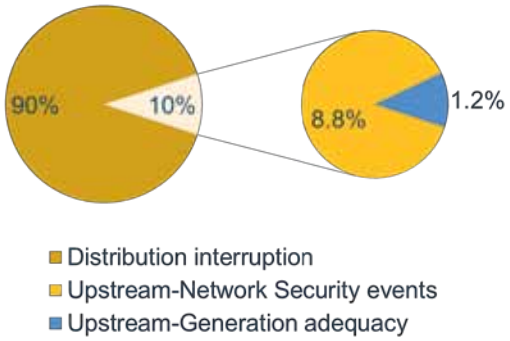
AEMO (27/2/17). Submission to the Independent Review into the Future Security of the National Electricity Market, p 25

https://www.aemo.com.au/Media-Centre/Submission-to-Independent-Review-into-the-Future-Security-of-the-National-Electricity-Market

Sources of Customer Interruption 2005-10 (AEMC)



Notes:

1. Distribution networks are more extensive than transmission networks and, if above ground, more exposed to external risks (weather, vegetation, lightning, vehicles, etc.)
2. NEM design still focused on transmission-level issues

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Critical for complex socio-technical systems

Complex socio-technical systems

(Dobrov, 1979; Carnes, 2011, Arthur, 2013)

Orgware (institutions, rules, culture):

- *Legislation etc. (federal, state & local government)*
- *Judiciary, regulatory, rule management, mores*
- *Industry structure, self-regulation, micro-economics: eg. ombudsmen, codes, culture, internal markets*

Orgware Layer

Software (know-how):

- *Knowledge & skills to design, build, connect & operate at component & system levels*
- *Systems for information gathering, decision-making & control, including commercial, technical & regulatory*

Software layer

Hardware (tools, machines, equipment):

- *Equipment for energy conversion chain – generation, transmission, distribution, end-use*
- *Equipment for monitoring, analysis & control*
- *Tools & machines for construction & maintenance*

Hardware layer

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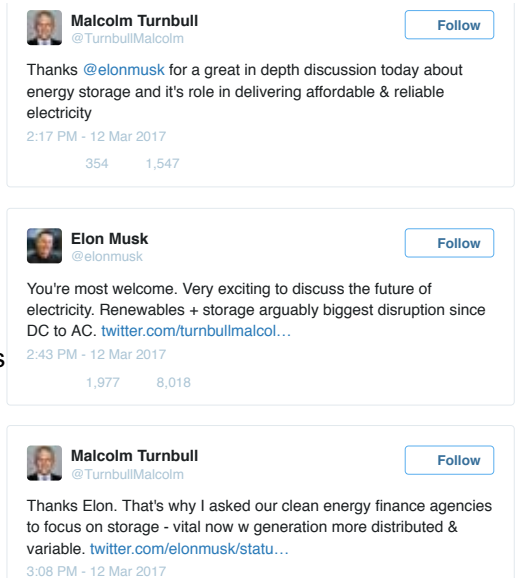
The electricity industry as an increasingly complex socio-technical system

- Capital-intense with long investment lead times:
  - Now with *a multitude of empowered decision-makers*
- Continuous, complex, shared, fast energy flow from primary energy forms to end-use energy forms via:
  - Non-storable AC electrical energy with quality attributes (voltage, frequency, waveform purity, phase balance)
- An industry infused with risk from micro-second to decades with many participants & shared risks:
  - *Never in equilibrium, inherently stochastic, emergent behaviour, significant unintended consequences*
  - *Growing problems with Observability, Predictability, Flexibility, Controllability: increasing risks of instability*
  - *Competing with other ways to provide energy services*

The role of storage in the electricity industry: *permits temporal reshaping of an energy flow*

- AC electrical energy is effectively non-storable but many other options:
  - Resource: fossil fuels, hydro, solar thermal
  - Reversible: pumped storage, inertia, batteries, flywheels
  - End-use: hot water, ice, room temperature, factory products
  - Different costs & characteristics
- Storage difficult to manage:
  - Risk/opportunity assessment
  - Needs temporally detailed CfD & option forward curves



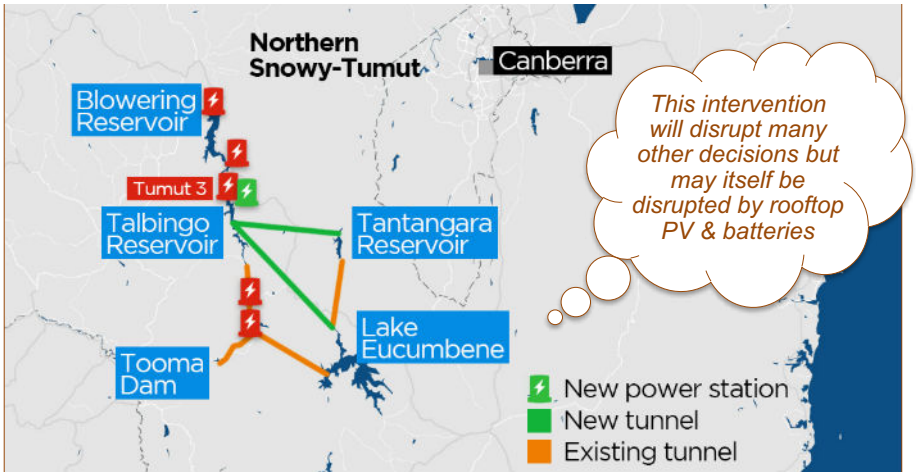
http://www.abc.net.au/news/2017-03-12/elon-musk-malcolm-turnbull-in-talks-on-renewables/8347554

Prime Ministerial intervention: Snowy scheme augmentation

www.abc.net.au/news/2017-03-16/snowy-hydro-expansion-wont-be-magical-solution-to-power-problems/8360320

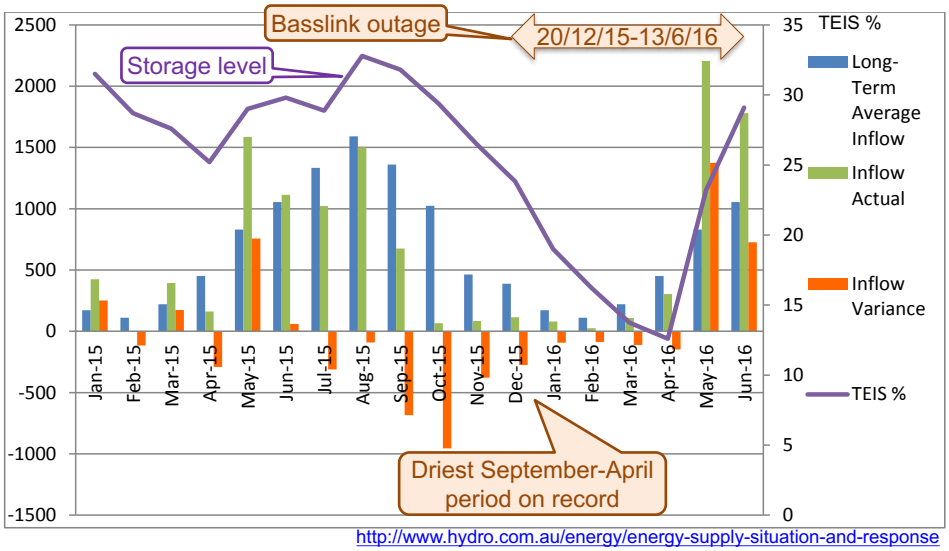
Some issues: Cost, construction time, diversion of Murrumbidgee River flow to Tumut River, environmental impacts, transmission augmentation, operating policy & constraints, water priorities during long-term droughts

One option apparently under consideration, assessed as too expensive in the 1980's



See also http://energy.unimelb.edu.au/library/opportunities-for-pumped-hydro-in-australia

Tasmania electricity supply 2015-2016
Unexpected low rainfall & Basslink failure:
Hydro storage depletion became the problem



http://www.hydro.com.au/energy/energy-supply-situation-and-response

Figure 1: Actual vs budgeted inflows January 2015 - June 2016

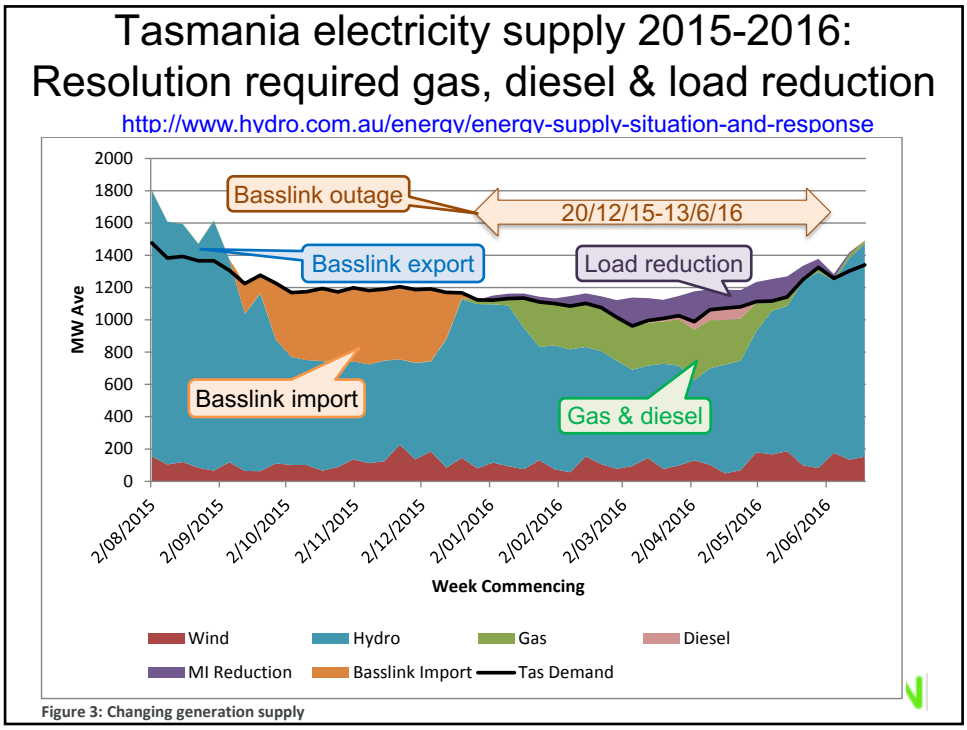
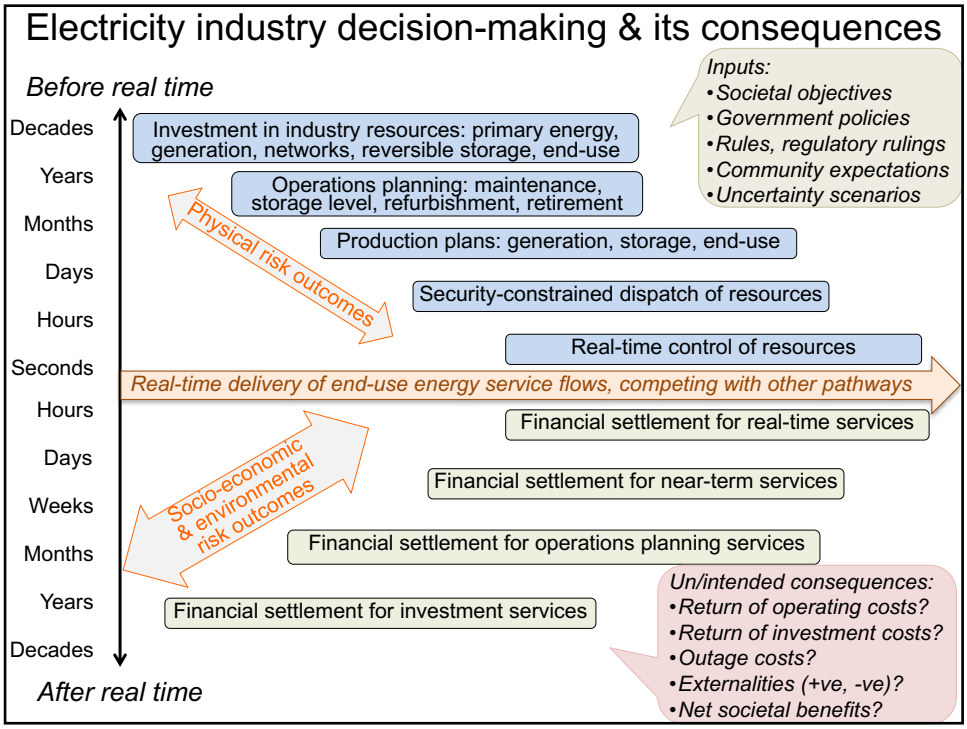
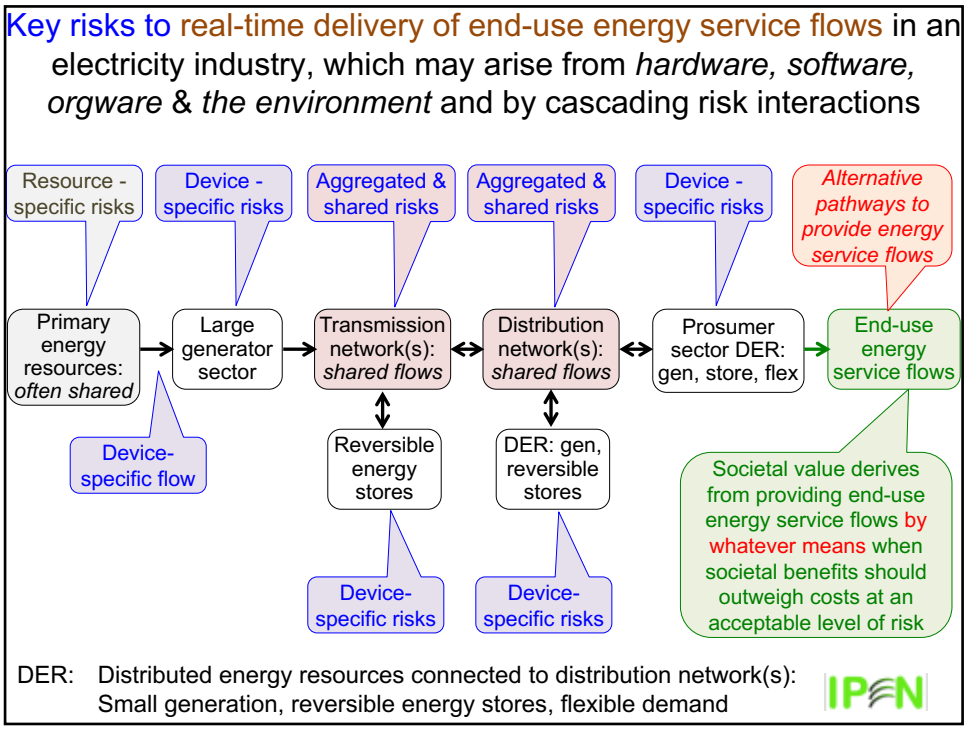


Figure 3: Changing generation supply




Key risks to real-time delivery of end-use energy service flows in an electricity industry, which may arise from *hardware, software, orgware* & *the environment* and by cascading risk interactions
Resource - specific risks
Device - specific risks
Aggregated & shared risks
Aggregated & shared risks
Device - specific risks
Alternative pathways to provide energy service flows
Primary energy resources: often shared
Large generator sector
Transmission network(s): shared flows
Distribution network(s): shared flows
Prosumer sector DER: gen, store, flex
End-use energy service flows
Device-specific flow
Reversible energy stores
DER: gen, reversible stores
Device-specific risks
Device-specific risks
Societal value derives from providing end-use energy service flows by whatever means when societal benefits should outweigh costs at an acceptable level of risk
DER: Distributed energy resources connected to distribution network(s): Small generation, reversible energy stores, flexible demand
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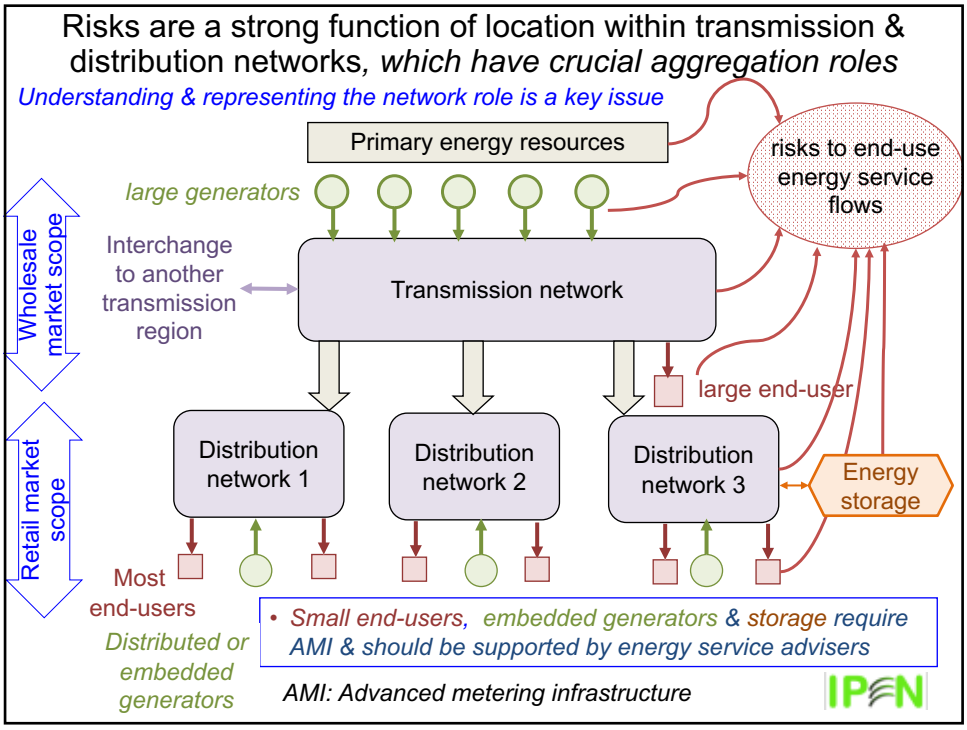
Risks are a strong function of location within transmission & distribution networks, *which have crucial aggregation roles*
Understanding & representing the network role is a key issue
Primary energy resources
risks to end-use energy service flows
large generators
Wholesale market scope
Interchange to another transmission region
Transmission network
large end-user
Distribution network 1
Distribution network 2
Distribution network 3
Energy storage
Retail market scope
Most end-users
Distributed or embedded generators
• *Small end-users, embedded generators & storage require AMI & should be supported by energy service advisers*
AMI: Advanced metering infrastructure
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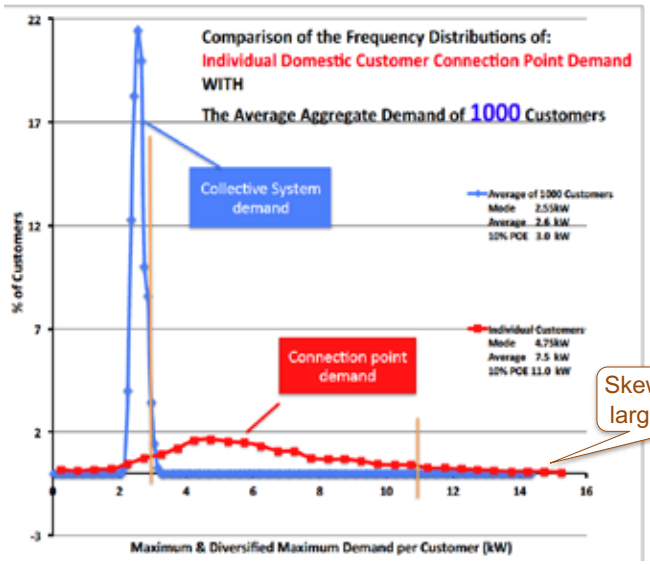
Distribution network aggregation: Individual domestic customers vs aggregated1000 domestic customers

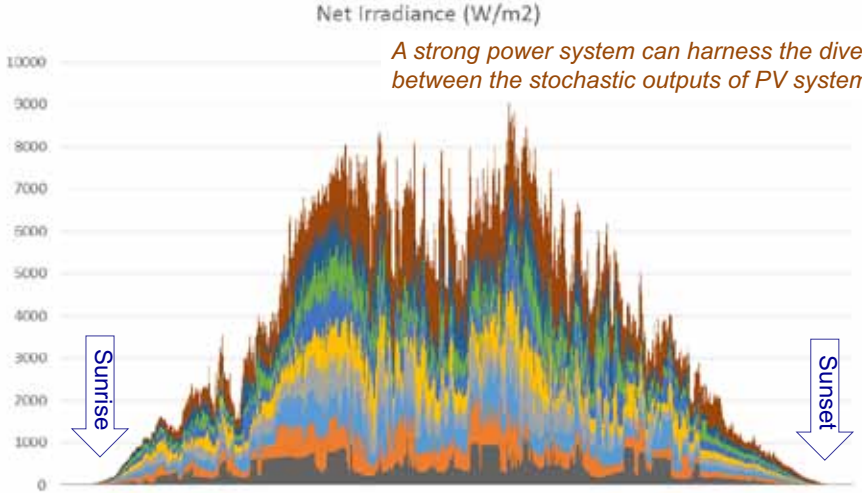
Ausgrid Finkel Review sub: http://www.environment.gov.au/submissions/nem-review/ausgrid.pdf



Note: Aggregation value falls if diversity lost, e.g. extreme temperature or rooftop PV on sunny day

Aggregation of energy from solar energy fluxes: Solar flux at 9 Alice Springs sites on 11/9/13 (cloudy & windy)

(CAT Projects, March 2015, Investigating the Impact of Solar Variability on Grid Stability)
http://arena.gov.au/files/2015/03/150302-Impact-of-Variability-Report-for-public-release.pdf



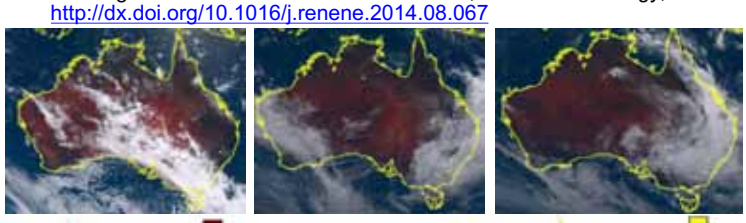
A strong power system can harness the diversity between the stochastic outputs of PV systems

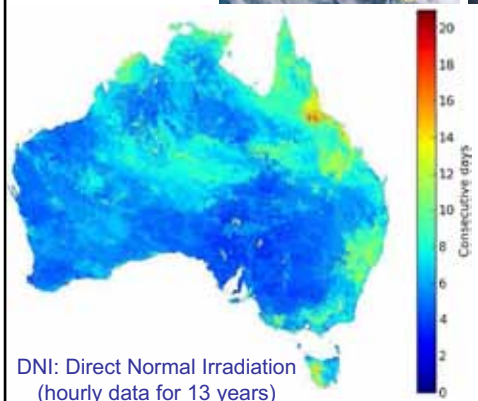
- *Diversity lost on a sunny day, at night & in a solar eclipse*
- *Second-by-second to multi-week variability due to cloud behaviour*
- *Seasonal variability depends on latitude & climate*

Consecutive days with hourly DNI always below 400 W/m^2

Elliston et al (2014) Spatio-temporal characterisation of extended low direct normal irradiance events over Australia using satellite derived solar radiation data, *Renewable Energy,* http://dx.doi.org/10.1016/j.renene.2014.08.067

12 noon cloud maps: 14/1/16, 4/6/16 & 19/6/16 http://himawari8.nict.go.jp





DNI: Direct Normal Irradiation (hourly data for 13 years)

Fig. 2. Length of longest run of DNI below 400 W/m^2

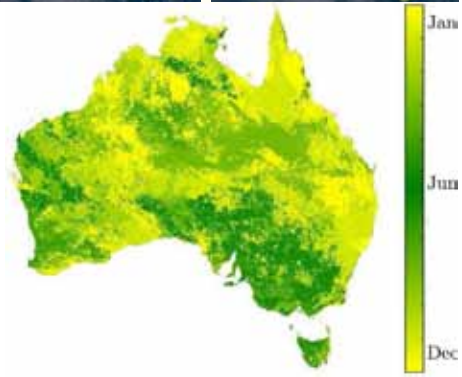
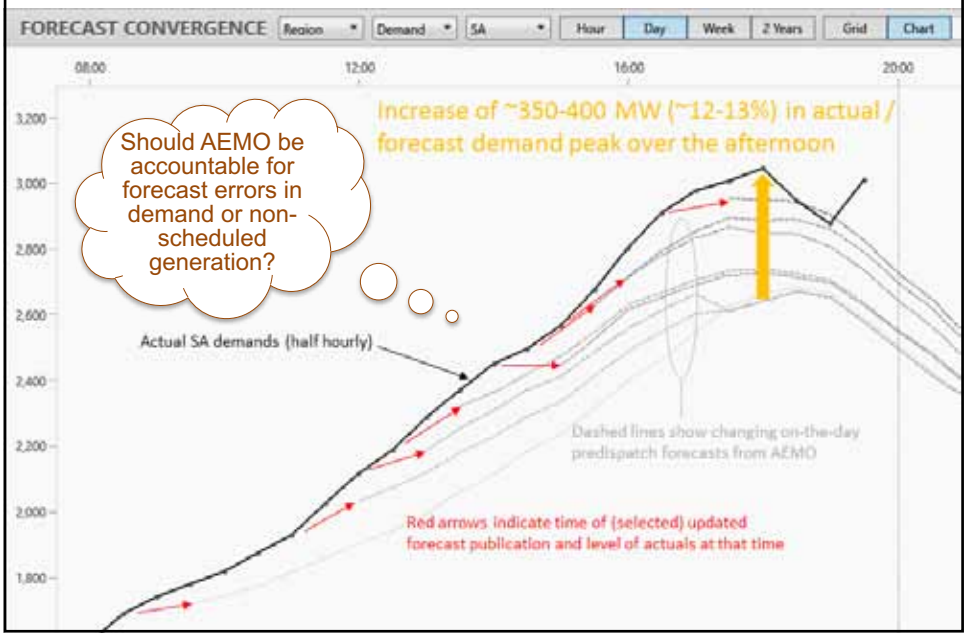


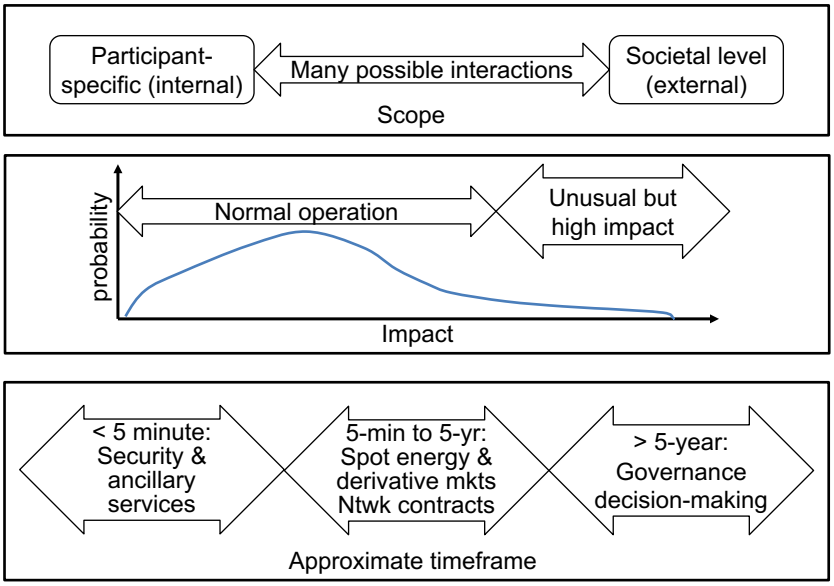
Fig. 3. Seasonal timing of longest runs of DNI below 400 W/m^2. The longest lulls occur in Winter in the Southern part of the continent and over the Northern part in Summer.

SA blackout 8/2/17: AEMO demand forecast errors

http://www.wattclarity.com.au/2017/02/initial-analysis-sa-load-shedding-wed-8-feb-2017/



Risk & decision-making impacts



Need a set of risk management strategies, avoiding overlap

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Decision-making framework (DMF) for a decentralised electricity industry (Outhred, Bull & Kelly, 2007; Outhred, 2007)

Governance & reg. regime: O *Cooperative*	▪ Formal institutions, legislation & policies ▪ Informal socio-political coordination ▪ *Long-term, societal-level risk management*
Security regime: HSO *Cooperative*	▪ Ensure core integrity on industry-wide & local basis with over-ride authority ▪ *Short-term industry-level risk management*
Technical regime: HS *Cooperative*	▪ Ensure connected components function as an effective, efficient industry-wide machine ▪ *Facilitate desirable emergent properties*
Commercial regime: SO *Competitive*	▪ Coordinate decentralised decision-making according to commercial criteria, including: ▪ *Formally designed electricity & gas markets*

Manage boundaries & minimise overlaps & gaps

Governance & reg. regime: Governance & regulation regime
Commercial regime: plays a key role in a decentralised industry
H: Hardware; S: Software; O: Orgware

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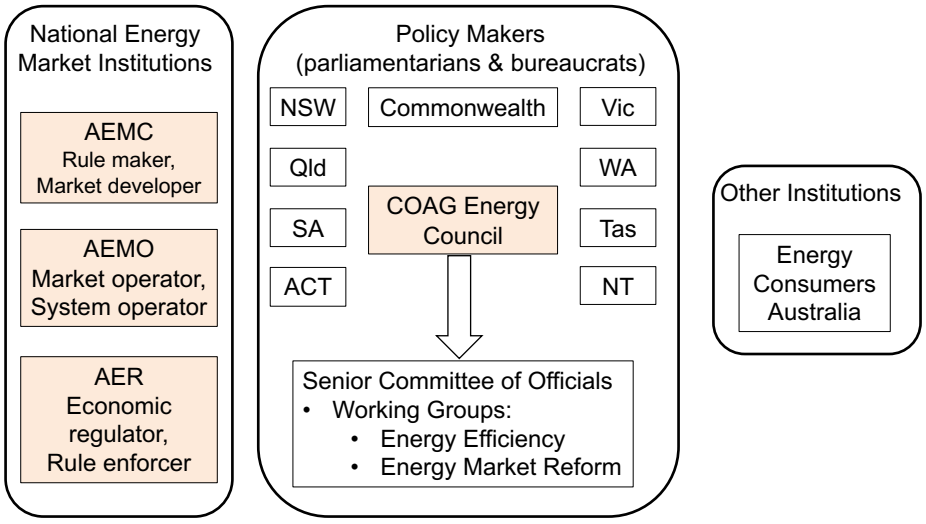
Important challenges in designing a DMF for a decentralised electricity industry

- Contrasting styles of decision-making:
  - Cooperative decision-making requires establishing & maintaining societal consensus: *difficult to achieve cooperation except within a competitive context*
  - Competitive decision-making requires effective governance oversight: *difficult to achieve*
- Limitations of decision-making:
  - Governance decisions often short-term & politicised
  - Decisions by corporations are narrowly profit-focused
  - Small participant decision-makers need support:
    - "there is abundant empirical and theoretical research to show that consumers do not always act in their own best interest"[1]
- *Wise governance essential but may not be possible*

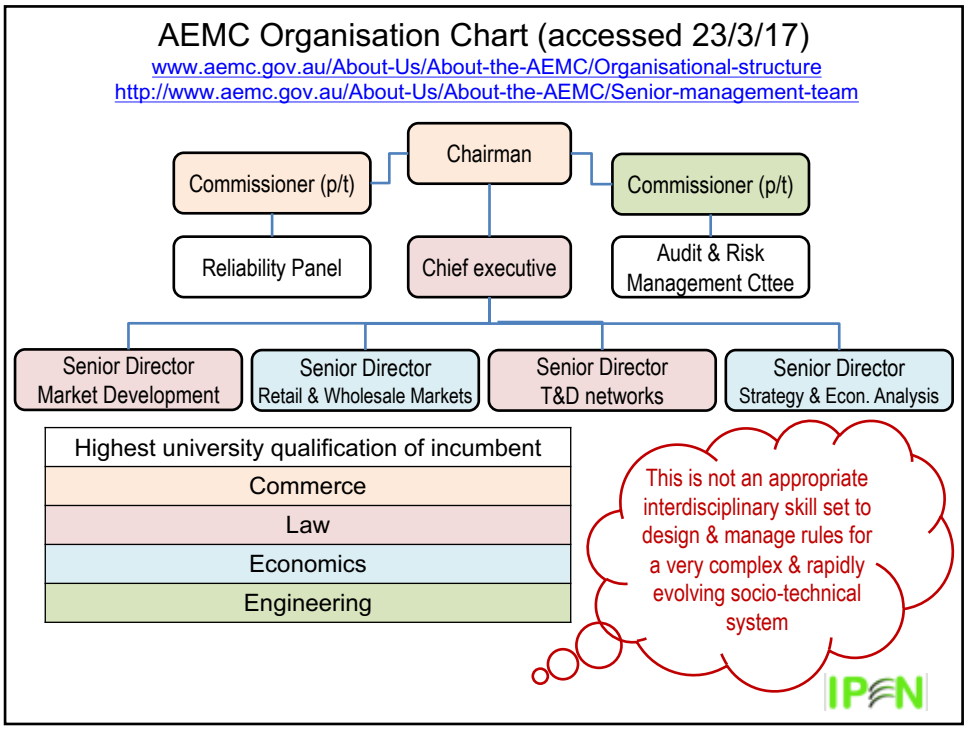
1. Philip R Lane, Governor of the Central Bank of Ireland, 23/2/17 http://www.bis.org/review/r170310b.pdf

National Energy Governance Structure

https://scer.govspace.gov.au/workstreams/energy-market-reform/review-of-governance-arrangements/
http://www.aemc.gov.au/Australias-Energy-Market/Markets-Overview/Market-Governance
http://www.environment.gov.au/energy/national-electricity-market-review



Key governance regime entities: *failing in important ways*


AEMC Organisation Chart (accessed 23/3/17)
www.aemc.gov.au/About-Us/About-the-AEMC/Organisational-structure
http://www.aemc.gov.au/About-Us/About-the-AEMC/Senior-management-team
Chairman
Commissioner (p/t)
Commissioner (p/t)
Reliability Panel
Chief executive
Audit & Risk Management Cttee
Senior Director Market Development
Senior Director Retail & Wholesale Markets
Senior Director T&D networks
Senior Director Strategy & Econ. Analysis
Highest university qualification of incumbent
Commerce
Law
Economics
Engineering
This is not an appropriate interdisciplinary skill set to design & manage rules for a very complex & rapidly evolving socio-technical system
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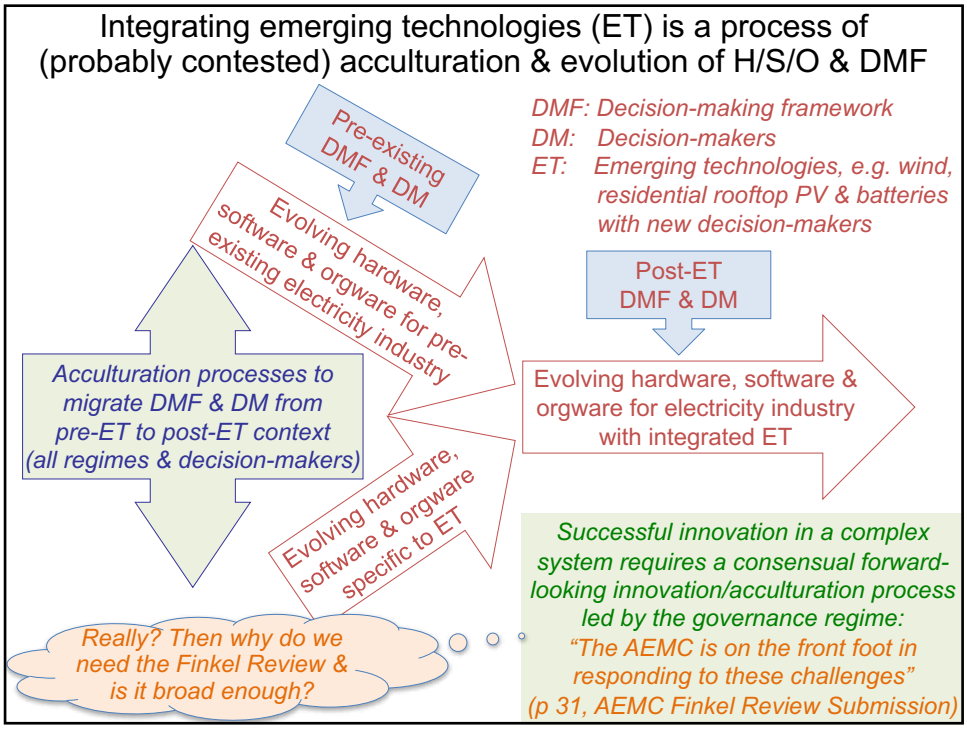
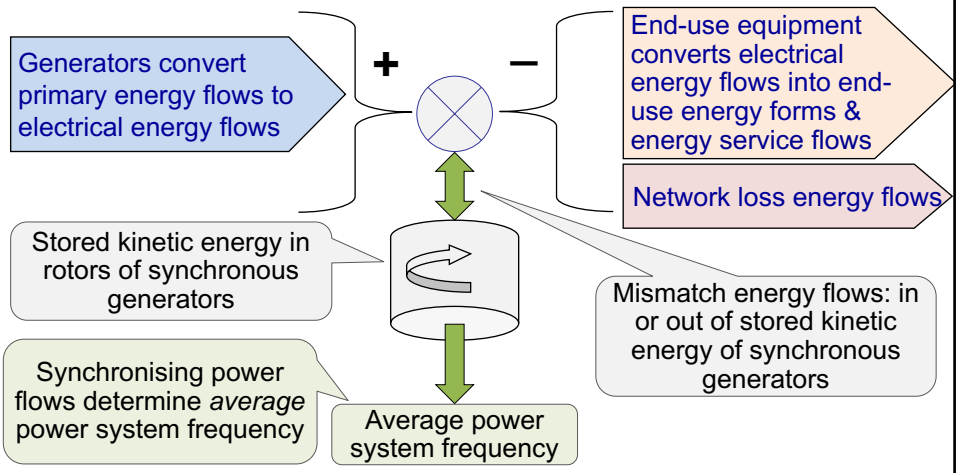

Integrating emerging technologies (ET) is a process of (probably contested) acculturation & evolution of H/S/O & DMF
DMF: Decision-making framework
DM: Decision-makers
ET: Emerging technologies, e.g. wind, residential rooftop PV & batteries with new decision-makers
Pre-existing DMF & DM
Evolving hardware, software & orgware for pre-existing electricity industry
Acculturation processes to migrate DMF & DM from pre-ET to post-ET context (all regimes & decision-makers)
Post-ET DMF & DM
Evolving hardware, software & orgware for electricity industry with integrated ET
Evolving hardware, software & orgware specific to ET
Really? Then why do we need the Finkel Review & is it broad enough?
Successful innovation in a complex system requires a consensual forward-looking innovation/acculturation process led by the governance regime:
"The AEMC is on the front foot in responding to these challenges"
(p 31, AEMC Finkel Review Submission)

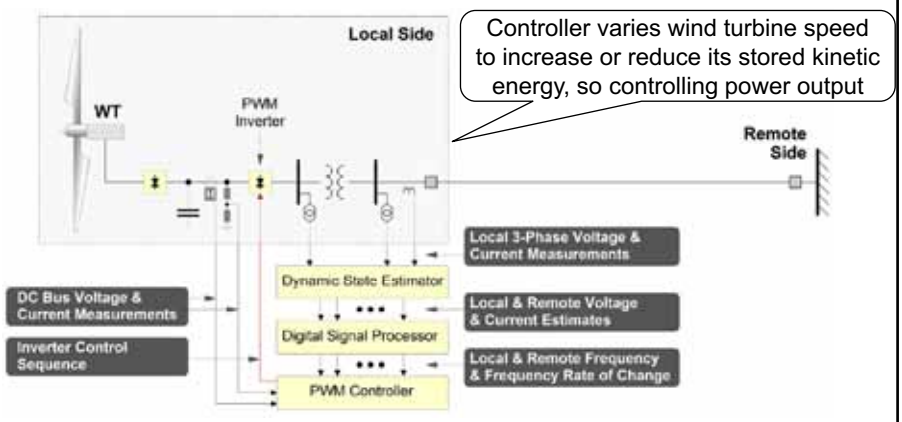
Short-term stochastic energy flow balance in an electricity industry with synchronous generators (alternators)



- *Frequency never fully uniform across a power system*
- *Average frequency responds to industry-wide supply-demand balance*
- *Converter-interfaced-devices (e.g. PV, wind, battery) need active control*

Example: dynamic control of a wind turbine

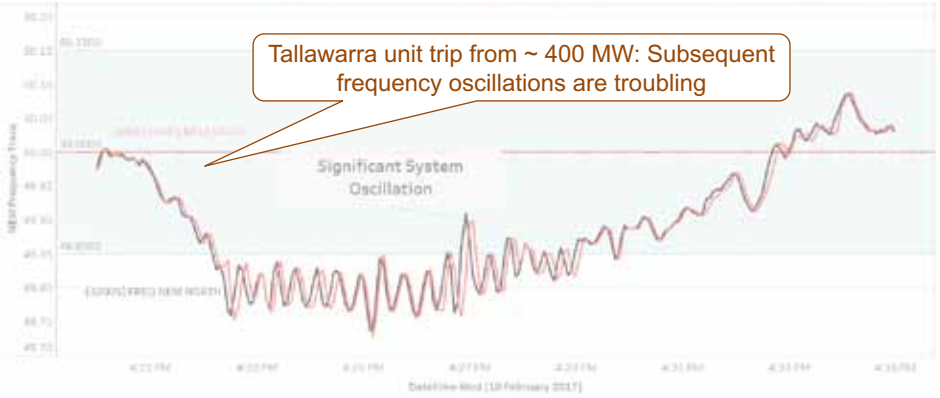
(Diagram: Meliopoulos, PSERC webinar 16/2/16)



- *Controller relies on system identification for estimates of voltage, power & frequency*
- *Not reliable for ≤ ~5 second timeframe due to noise & fast dynamic behaviour*
- *Cannot fully replicate synchronous generator behaviour in ≤ ~5 second timeframe*

NEM frequency oscillations, 10/2/17

Mackenzie H & Dyson J, Feb 2017, *NEM FCAS causer pays procedure*,
http://www.aemo.com.au/-/media/Files/Stakeholder_Consultation/Consultations/Electricity_Consultations/2017/CPPC/Wind-Coalition-consultant-submission.pdf



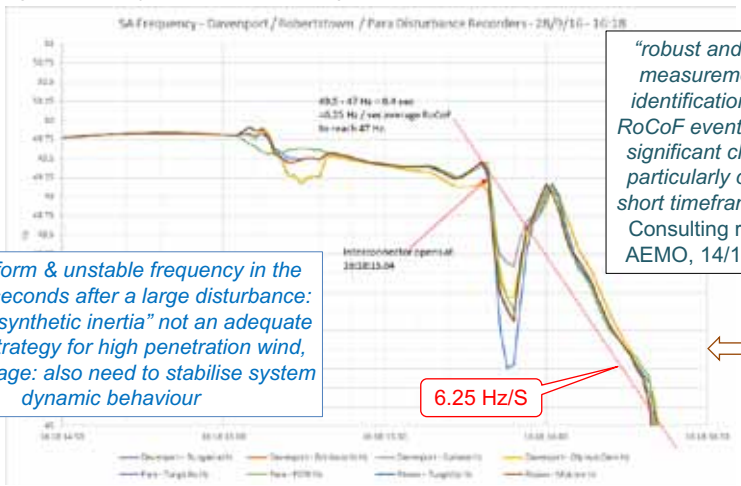
Note: The authors state that wind farms … are being charged a disproportionate allocation of the FCAS regulation costs & suggest that changes be made to the causer pays procedure

SA blackout 28/9/16 AEMO preliminary report, 5/10/16

http://www.aemo.com.au/Media-Centre/Media-Statement-South-Australia-Interim-Report

Note: conditions evolved very rapidly

Figure 5 Frequency response and RoCoF during pre-event and event



"robust and reliable measurement and identification of high RoCoF events poses a significant challenge, particularly over very short timeframes" DGA Consulting report for AEMO, 14/10/16, p 8

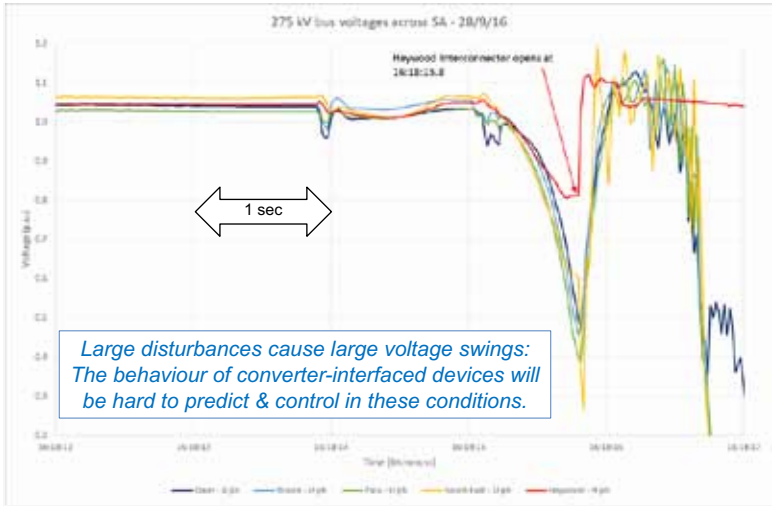
Non-uniform & unstable frequency in the first few seconds after a large disturbance: UFLS & "synthetic inertia" not an adequate control strategy for high penetration wind, PV & storage: also need to stabilise system dynamic behaviour

Virtual oscillator control (VOC) for converter interfaced devices may help but hard to see how VOC can respond sufficiently rapidly & stably. See http://www.nrel.gov/grid/news/2016/40042 & http://spectrum.ieee.org/energy/renewables/can-smarter-solar-inverters-save-the-grid

SA blackout 28/9/16: AEMO update report, 19/10/16

http://www.aemo.com.au/Media-Centre/Update-to-report-into-SA-state-wide-power-outage

Figure 1 275 kV voltage decline across South Australia prior to separation



Virtual oscillator control (VOC) for converter interfaced devices may help but hard to see how VOC can respond sufficiently rapidly & stably. See http://www.nrel.gov/grid/news/2016/40042 & http://spectrum.ieee.org/energy/renewables/can-smarter-solar-inverters-save-the-grid

Power system dynamic behaviour & its treatment in the National Electricity Rules (NER)

- Power system dynamic stability:
  - An emergent behaviour of traditional power systems that rely on synchronous generators
  - Cannot assume uniform power system frequency at timescale of ≤ ~5 seconds
  - NER V89, S5.1.8, p 554: “halving time of the least damped electromechanical mode of oscillation is not [to be] more than five seconds”
- The fast response ancillary services problem should be addressed under TOSAS (transient and oscillatory stability ancillary service)
  https://www.aemo.com.au/-/media/Files/PDF/Guide-to-Ancillary-Services-in-the-National-Electricity-Market.pdf

MIGRATE: Massive InteGRATion of power Electronic devices

https://www.h2020-migrate.eu (European Union project)

- In the short to medium term, incremental technology-based solutions are needed to operate the existing electric HVAC system configuration with a growing penetration of PE-connected generation and consumption, based on novel methods and tools.
- In the long term, breakthrough technology-based solutions are needed to manage a transition towards an HVAC electric system where all generation and consumption is connected via 100% PE, based on innovative control algorithms together with new grid connection standards.

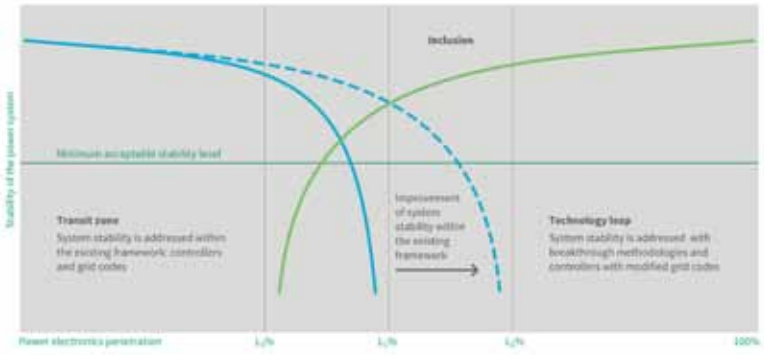


Illustration of the main concept of the MIGRATE project. The abscissa represents the PE penetration where L1 and L2 are asymptotes where severe stability problems could be met within the existing framework. The ordinate axis represents a general stability index.

Decentralised electricity industry DMF: Theoretical foundation for the commercial regime

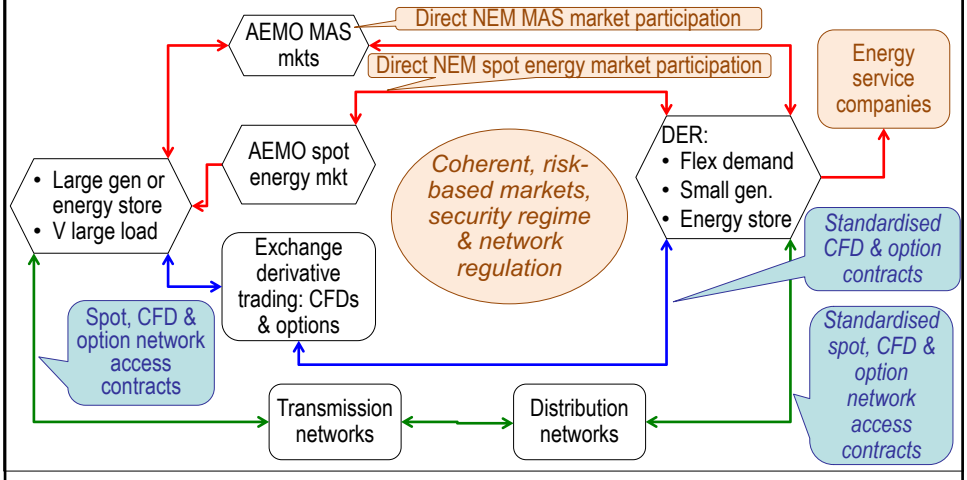
- Schweppe, Tabors, Kirtley, Outhred, Pickel, Cox, *Homeostatic utility control,* IEEE, 1980: Proposed a two-sided, five-minute, electricity spot market
- Outhred & Schweppe, *Quality of supply pricing,* IEEE, 1980: Explored two-sided spot markets for ancillary services
- Kaye & Outhred, *Theory of electricity tariff design,* IEEE, 1989: Theory of electricity pricing/contracting with uncertainty & inter-temporal links
- Kaye, Outhred & Bannister, *Forward contracts for operation of an electricity industry under spot pricing,* IEEE, 1990:
  - Showed how forward contracts could help manage spot price uncertainty
- Outhred, *Principles of a market-based electricity industry,* IEE, 1993:
  - Recommended multi-region spot & derivate markets, not nodal pricing
- Outhred & Kaye, Incorporating network effects in a competitive electricity industry, in Einhorn & Siddiqui (eds), *Issues in Transmission Pricing & Technology*, Kluwer, 1996:
  - Multi-region spot market with short-term technical forward market
- Outhred, Bull & Kelly, *Meeting the Challenges of Integrating Renewable Energy into Competitive Electricity Industries*

Decentralised electricity industry DMF: Practical implementation of the commercial regime

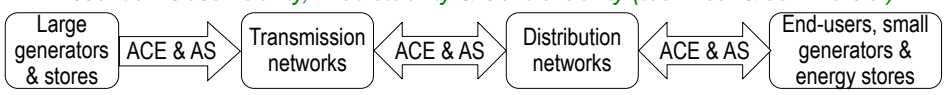
- Electricity market design - *not yet adequate in NEM:*
  - Double-sided spot & derivative markets with direct end-user participation (for efficient risk valuation & management)
  - Regional reference node pricing with network loss factors (not nodal pricing) to preserve derivative market liquidity
  - Market-based inter-regional network services represented as arbitrage between regional reference nodes
- Network service specification, pricing & regulation - *not yet adequate in NEM*:
  - Intra-regional transmission & distribution services:
    - Market-compatible spot & derivative network market access contracts (spot pricing, CfDs & options plus technical requirements)
      - *Should not be based on LRMC nor on demand charges*
    - Regulated because of large-participant characteristics

Australian NEM: a possible future implementation:

Commercial model of the electricity industry showing cash flows & desirable new features



Physical electricity industry model showing AC energy ACE & ancillary service AS flows:
Essential: Observability, Predictability & Controllability (technical & commercial)



Recommendations

1. Redesign AEMC to be fit for purpose
2. Correctly implement NEM spot & derivative markets:
   - 5-minute spot market, short-term technical forward market with call (& possibly put) options & direct end-user participation
3. Correctly implement network service contracts:
   - Market compatible access contract structure & pricing
4. Review ancillary services, particularly MAS, TOSAS, extend to distribution networks & connection requirements
5. Implement 5-minute metering & data management in a staged manner including cyber-security measures
6. Upgrade inter-regional transmission using VSC DC links where possible
7. Facilitate & regulate Energy Service Companies with brief to promote prudent, efficient & flexible energy services

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Hugh Outhred is Managing Director of Ipen Pty Ltd, which provides advisory and educational services on energy, society and the environment.

Hugh retired in 2007 after a 35-year career at the University of New South Wales (UNSW) with research contributions in power system dynamics, electricity industry design & renewable energy integration, most recently as Presiding Director, Centre for Energy and Environmental Markets and Head, Electrical Energy Research Group, School of Electrical Engineering and Telecommunications.

During his career, Hugh has been a Fulbright Senior Fellow at the University of California Berkeley, a Member of the National Electricity Tribunal, a Member of the New South Wales Licence Compliance Advisory Board, a Board Member of the Australian Cooperative Research Centre for Renewable Energy, an Associate Director of UNSW's Centre for Photovoltaic Devices and Systems, a Member of CSIRO's Energy Flagship Advisory Committee and a Lead Author for the IPCC Special Report on Renewable Energy Sources & Climate Change Mitigation, 2011.

Since 1989, Hugh has taught 125 short courses in 14 countries on electricity design issues including renewable energy integration.

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