Influence of Electrical System *Resilience* on User Power Supply

From system-level resilience to user-perceived power quality

Power Quality Training

Matta, Stephanie.

Presentation – PQ UNSTPB | January 21st 2026.

DREAM European Master

POLITEHNICA UNIVERSITATEA DIN BUCUREȘTI FACULTATEA DE ENERGETICĂ 1818

Influence of Electrical System *Resilience* on User Power Supply

From system-level resilience to user-perceived power quality

Power Quality Training

Transmission lines,
generation adequacy,
contingencies,
security criteria

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Electricity is experienced at the user level:
(not a planning margin or a probabilistic index)

Did the lights flicker?
Did the voltage dip?
Did the frequency excursion trigger a disconnection?
How fast was the service restored?

How system-level resilience decisions propagate all the way down to the quality of power supply perceived by users

- Users experience resilience through **voltage, frequency, and continuity.**

Will more *redundancy* enhance reliability (and resilience)?

Why Investments Do Not Prevent Blackouts

The idea that increasing the capacity of the transmission network should improve the security of the system and reduce the probability of blackouts is intuitively appealing. However, this intuition does not withstand scrutiny.

Daniel Kirschen and Goran Strbac

(redundancy can reduce some risks, but it does not necessarily improve how the system behaves dynamically)

Moreover, increasing redundancy raises system costs, which are ultimately reflected in higher tariffs,

D. Kirschen and G. Strbac, “Why investments do not prevent blackouts”, The Electricity Journal, March 2004

Reliability, Security, and Resilience: what the system plans for

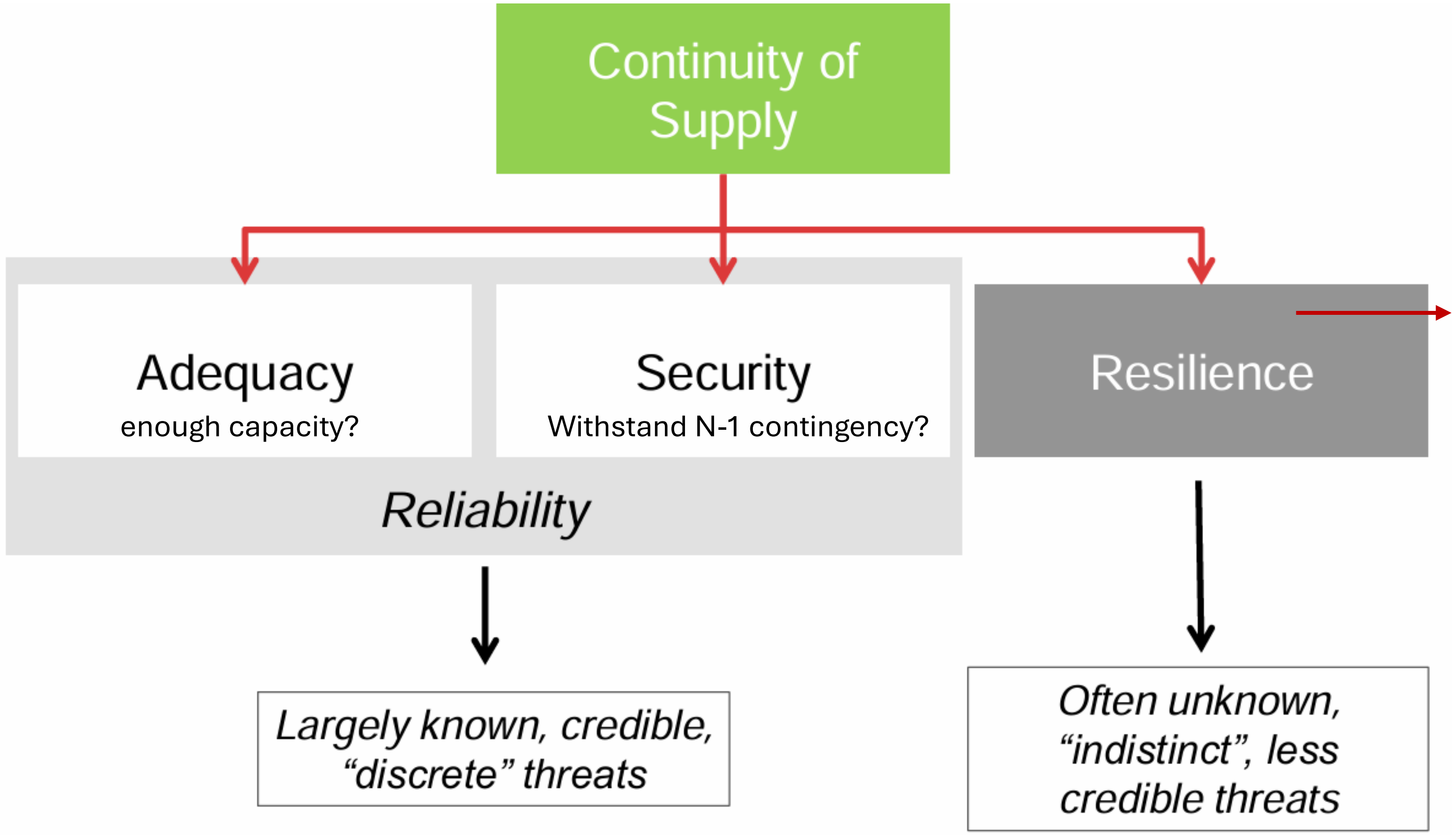
Reliability → continuity under *known* conditions
Resilience → ability to operate with **uncertain, indistinct disturbances**

PQ = main user-experience channel

Events here are:

Discrete failures, pre-defined, modelled, and protected by some rules.

(classic planning)



Events here are:

Non clearly defined, combined, dynamical

i.e. bad protection coordination, DER disconnected in cascade, climate events + dynamics, cyber / control interactions)

P. Mancarella et al., "Power system security assessment of the future National Electricity Market", Report in support of the "Finkel Review", June 2017

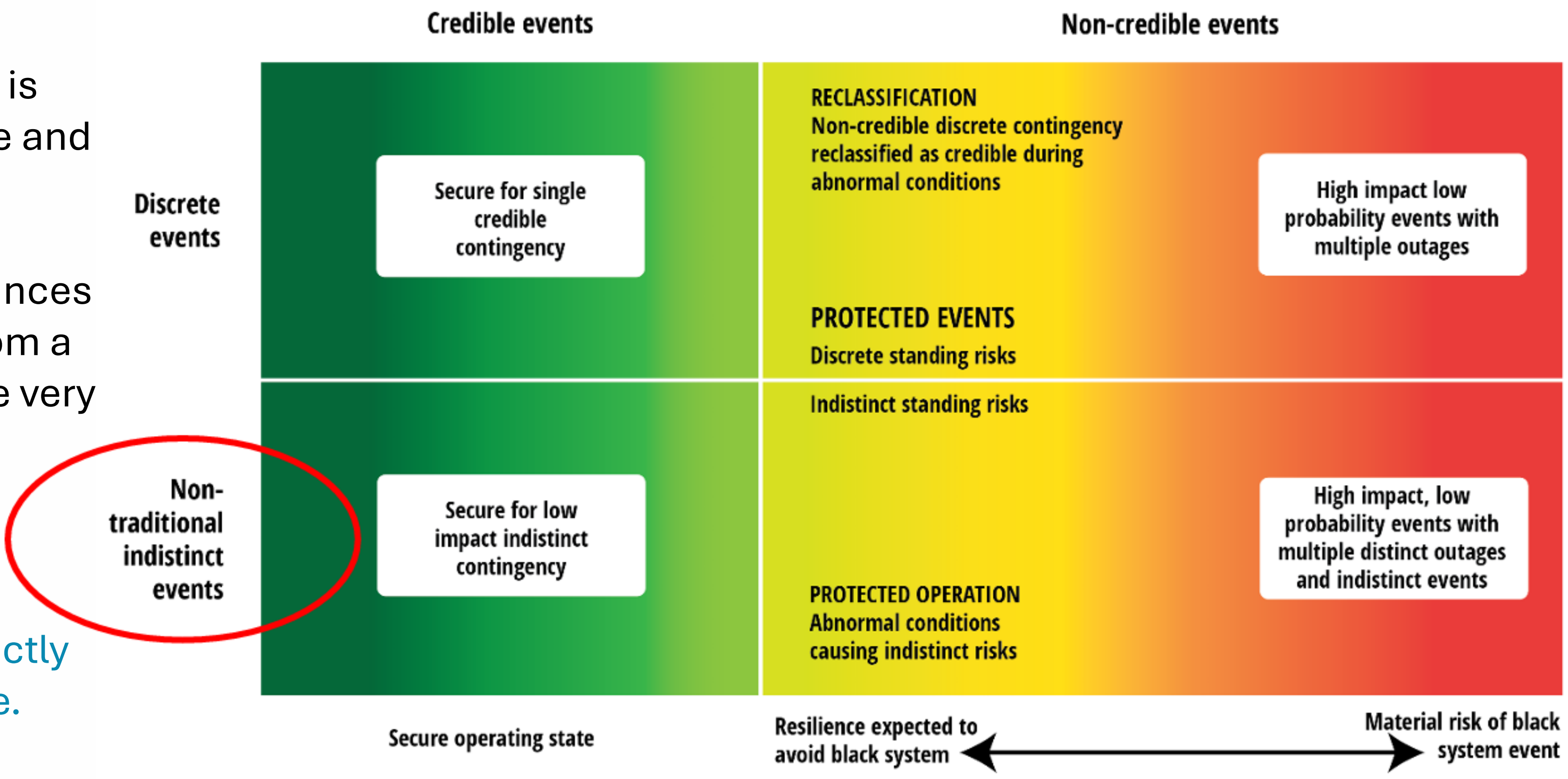
Reliability, Security, and Resilience: what the system plans for

System can be adequate, secure, N-1 compliant and still the user can suffer voltage dips, freq. deviations, tripping of sensible loads, and degradation of the PQ.

How power systems classify disturbances.
(Only a subset of events is considered fully credible and explicitly planned for)

However, many disturbances that are non-credible from a planning perspective are very real from the user perspective.

These non-traditional, indistinct events are exactly where PQ issues emerge.

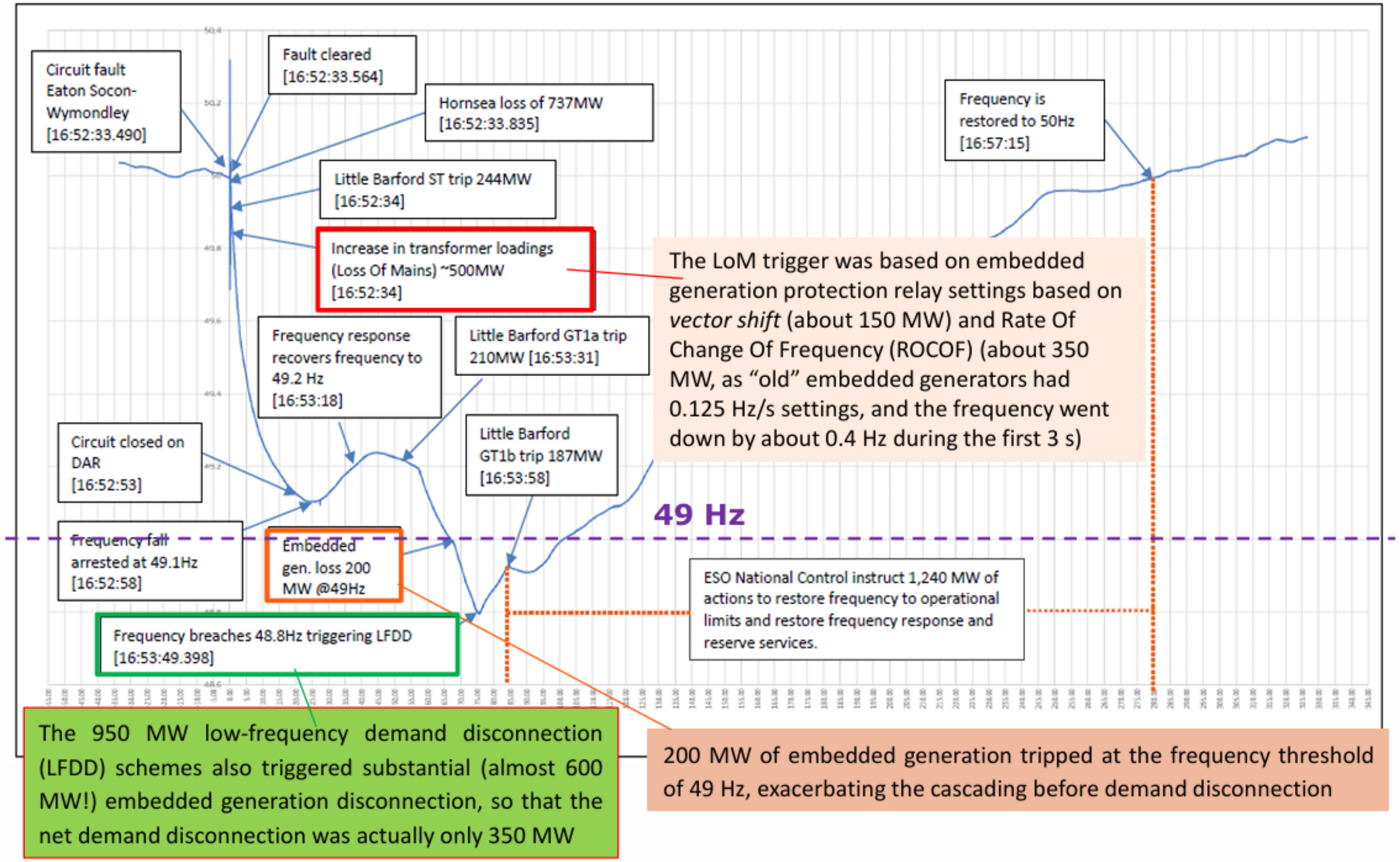


J. Eggleston, C. Zuur, P. Mancarella, "From security to resilience: technical and regulatory options to manage extreme events in low-carbon grids", IEEE Power & Energy Magazine, Sept/Oct 2021

A real example: What does a "non-credible, indistinct event" look like in reality?

Protection designed for traditional dynamics becomes a source of disconnection in converter-dominated systems.

demand disconnection event, UK, 09/08/19



What happened was a sequence of fast, interacting effects:

- Loss of generation
- High RoCoF
- Protection acting as designed
- Embedded generation disconnecting
- Load disconnection as a consequence, not as a cause

Hence,

From a system perspective, protections worked correctly.

From a user perspective, power quality deteriorated rapidly.

Source: UK National Grid ESO, "Technical report on the events of 9 August 2019", https://www.ofgem.gov.uk/system/files/docs/2019/09/eso_technical_report_-_final.pdf

Key mechanisms

Technologies that shape user power supply

At this level, power supply is shaped by a small number of fast, local mechanisms, rather than by long-term planning margins.

DER & Reactive Power

Local voltage control

As DER penetration increases, voltage quality becomes strongly location-dependent.

Two users connected to the same distribution network
can experience very different voltage profiles;
Reactive power control from DER directly affects hosting capacity,
and therefore the quality of supply perceived by users.

BESS & Fast Frequency Response

In low-inertia, IBR systems -> critical issue no longer s.s. frequency, but RoCoF and frequency nadir.

Acting before protection thresholds (not restoring to 50Hz).

Fast response in the first hundreds of milliseconds
can prevent widespread disconnections and cascading effects.

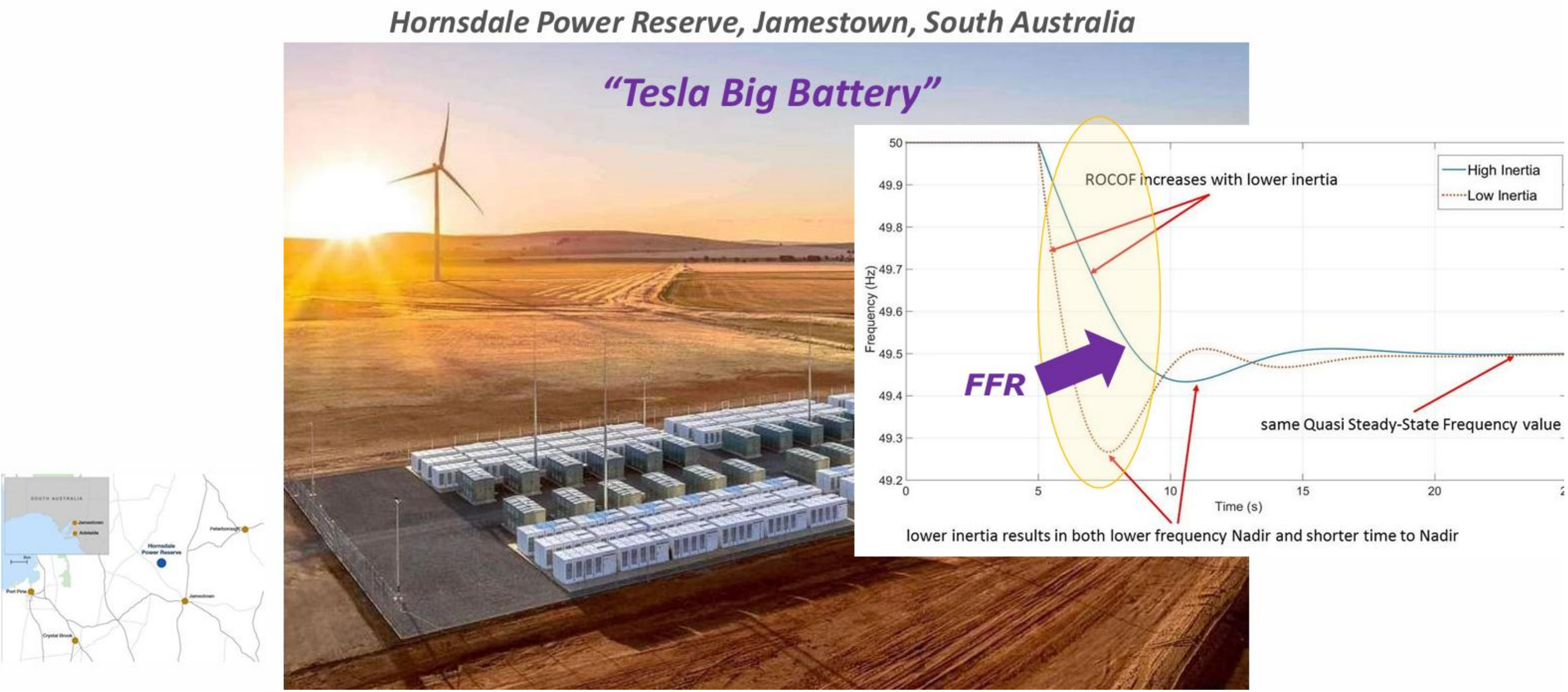
Protection systems

Need for adaptive coordination - *static protection settings can unintentionally amplify disturbances, leading to unnecessary tripping and loss of supply.*

Fast, local, and coordinated actions determine whether users stay connected.

Short example: BESS & Fast Frequency Response

Technologies that shape user power supply



Reducing RoCoF, frequency nadir, and that time margin is what keeps users connected.

Source: Neoen, PV Magazine Australia

Cybersecurity as a new disturbance class

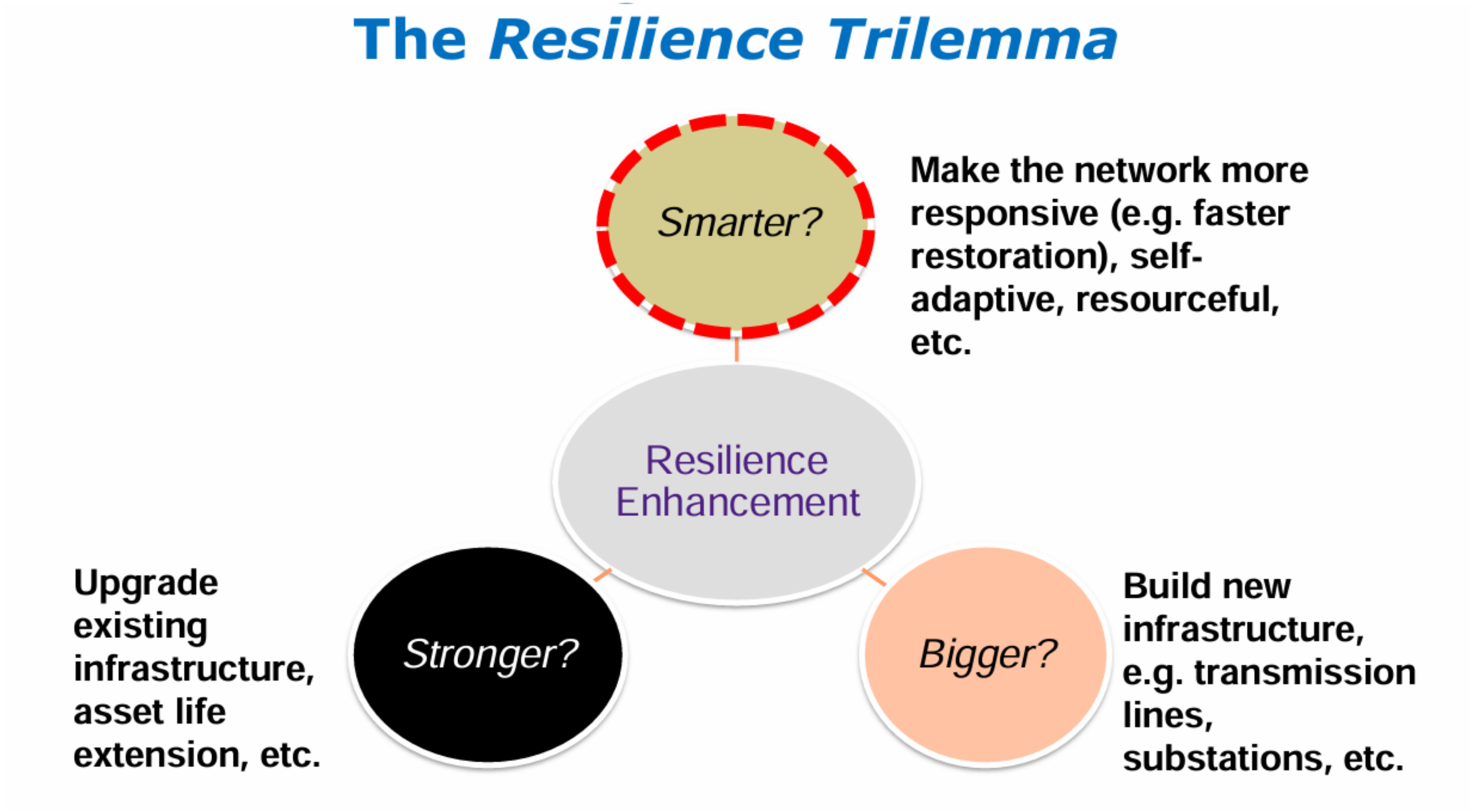
- Cyber attacks often **do not interrupt supply**
- They:
  - corrupt measurements
  - delay control actions
  - reduce observability

PQ

- Poor voltage regulation
- Flicker due to delayed control
- Longer degraded service during restoration

Cybersecurity introduces a new class of indistinct disturbances whose impact is first felt in power quality, not in continuity of supply.

What resilience really means for user power supply



- More assets ≠ better user experience
- Smarter systems preserve quality, not just continuity
- Resilience decisions silently shape **who experiences degradation**

System-level resilience decisions ultimately determine whether users experience a blackout or only a temporary degradation of power quality

M. Panteli and P. Mancarella, The Grid: Stronger, Bigger, Smarter? Presenting a conceptual framework of power system resilience, IEEE Power and Energy Magazine, May/June 2015
R. Moreno, et al., “From Reliability to Resilience: Planning the Grid Against the Extremes”, IEEE Power and Energy Magazine, July-August 2020
M. Panteli, et al., "Power Systems Resilience Assessment: Hardening and Smart Operational Enhancement Strategies," Proceedings of the IEEE, 105, 7, pp. 1202-1213, July 2017

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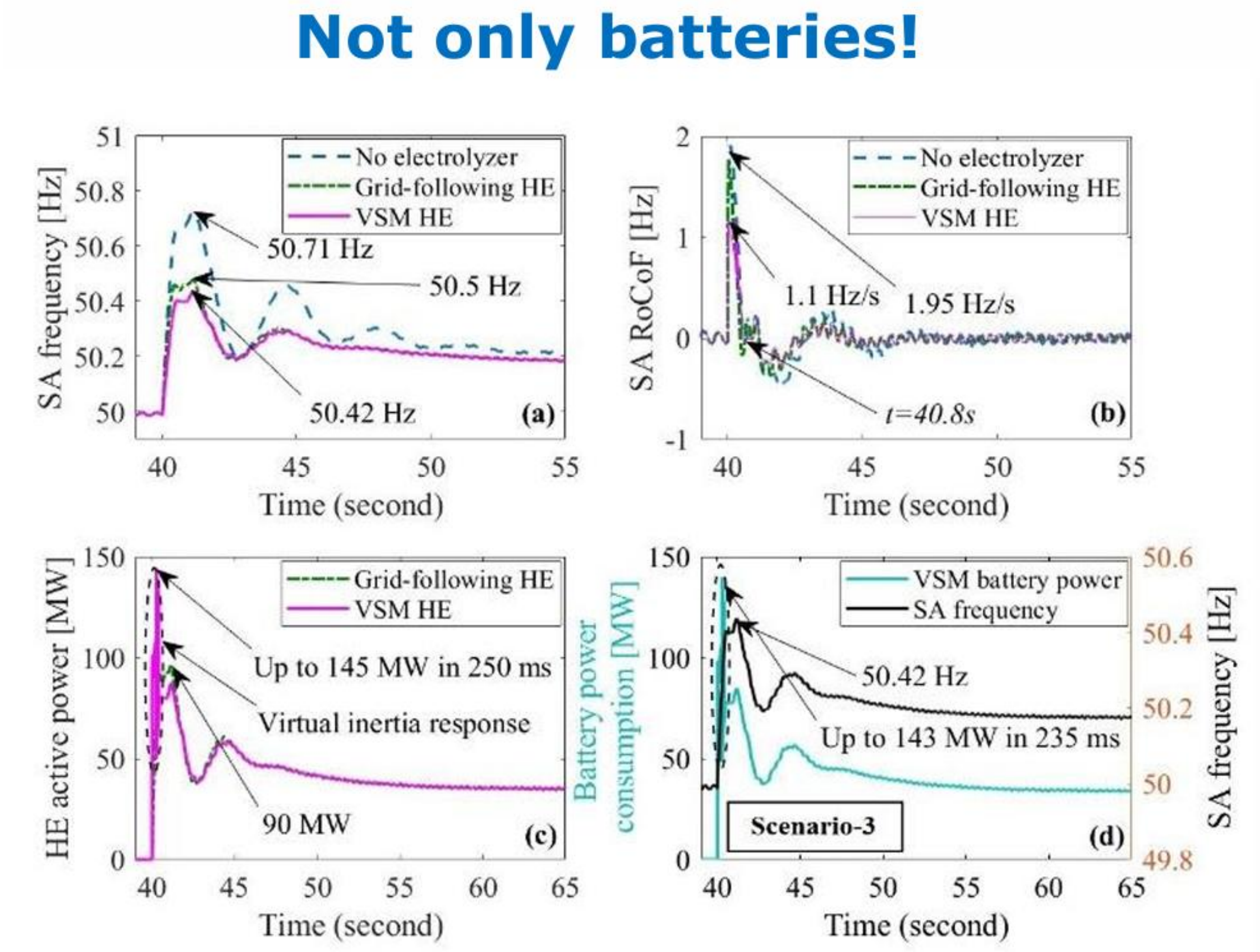
Appendix

Risk	Emerging issues	Possible Mitigations
Frequency control and inertia	- Sustained frequency excursions (regulation) - High ROCOF following contingency - Insufficient regional inertia - Insufficient PFR - Risk of low-inertia and insufficient PFR after separation	- Minimum inertia levels - Compulsory droop response - Additional amount of PFR - Co-optimization of energy, frequency response, and (regional and system-level) inertia - Regional allocation of reserves - New sources of fast frequency response (e.g., batteries, electrolysers) - Management of largest contingency and interconnector flows (system at risk of regional separation)
Variability, uncertainty and visibility	- Large variation in net demand - Insufficient short- and medium-term and ramping reserves - Visibility of Distributed Energy Resources (DER)	- Better forecasting - Artificial intelligence to assess reserves (e.g., dynamic Bayesian belief network tools) - Use of more flexible resources including energy storage (e.g., pumped hydro)
System strength and immunity	- Fault current shortage - Voltage instability - Sustained voltage oscillations after fault - Fault-ride through issues - Minimum demand issues	- Minimum level of inertia and fault current (generators constrained on) - Synchronous condensers - STATCOM and SVC to improve voltage stability - Improvements of control loops (especially in solar farms) - Grid forming inverters

P. Mancarella and F. Billimoria, ‘The Fragile Grid – The physics and economics of security services in low-carbon power systems”, IEEE Power and Energy Magazine, 2021

Short example: FFR

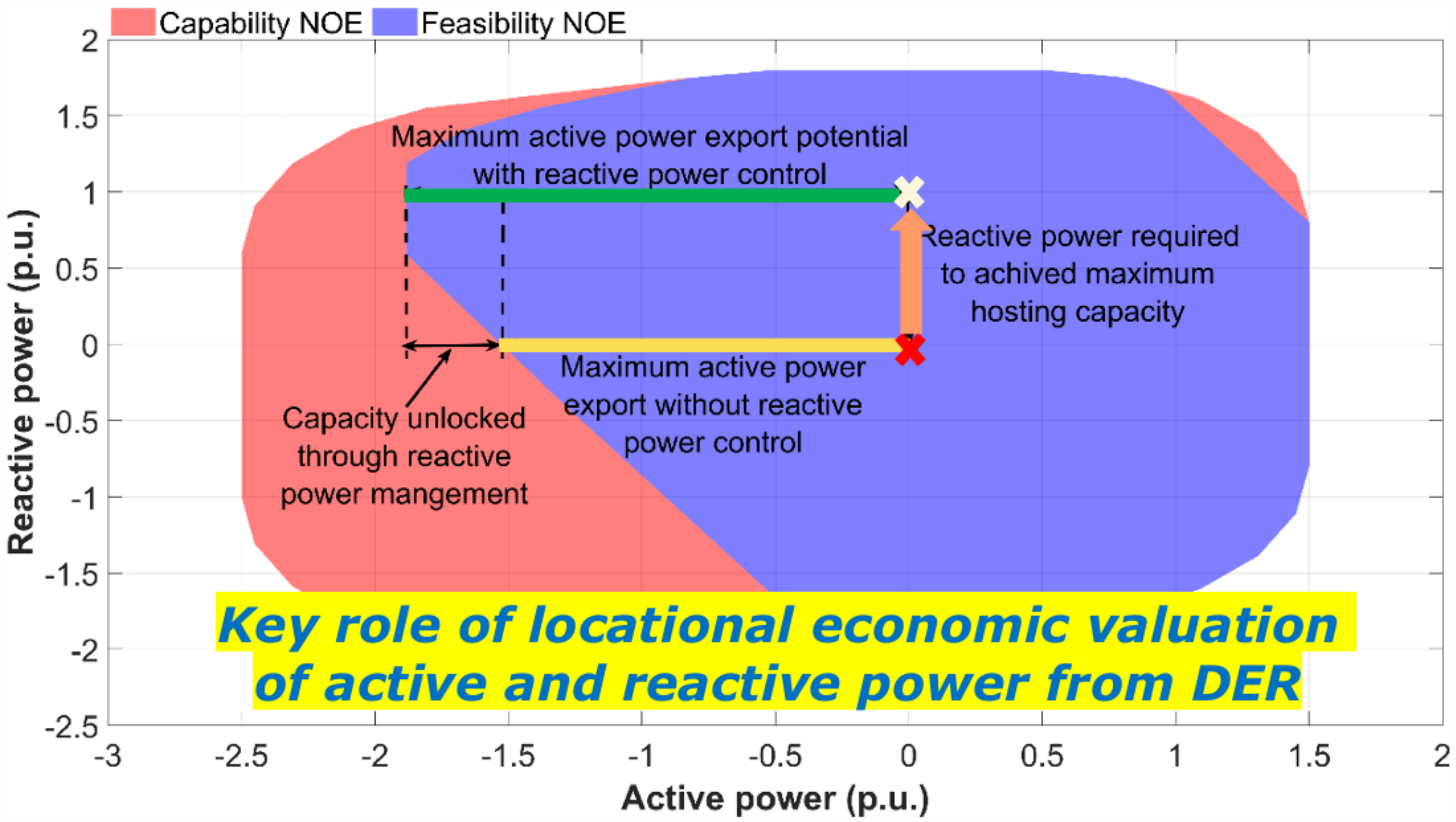
Technologies that shape user power supply



M. Ghazavi Dozein, et al., “Fast frequency response from utility scale hydrogen electrolysers”, IEEE Trans. Sustainable Energy, 2021
M. Ghazavi Dozein, et al., “Virtual Inertia Response and Frequency Control Ancillary Services from Hydrogen Electrolyzers”, IEEE Tran. on Pow. Syst, 2022
S. D. Tavakoli, et al., "Grid-Forming Services From Hydrogen Electrolyzers“, IEEE Transactions on Sustainable Energy, 2023

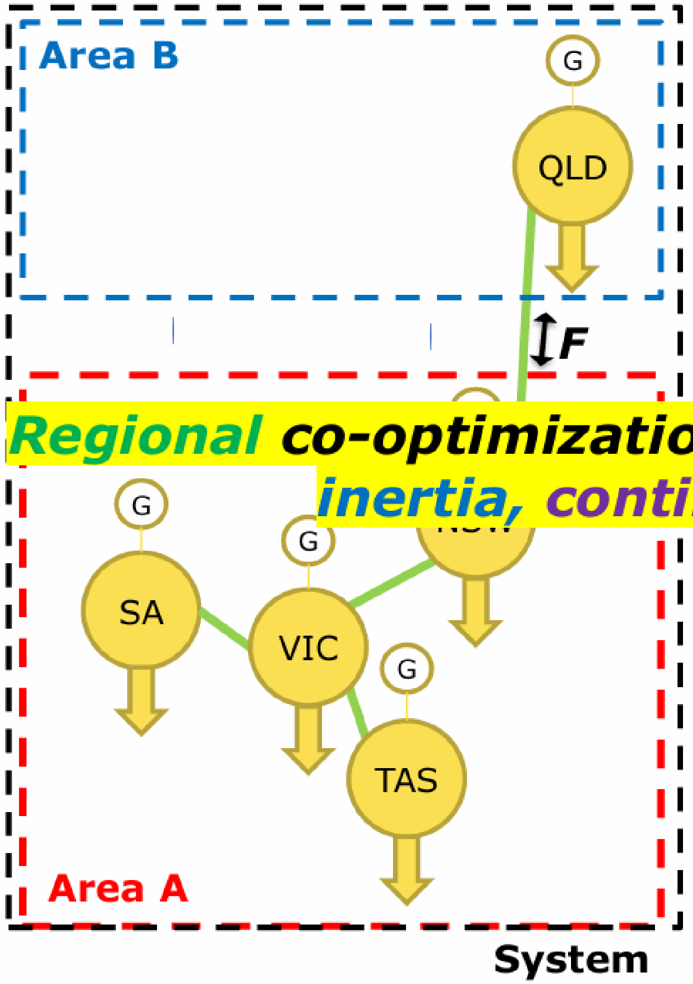
Appendix

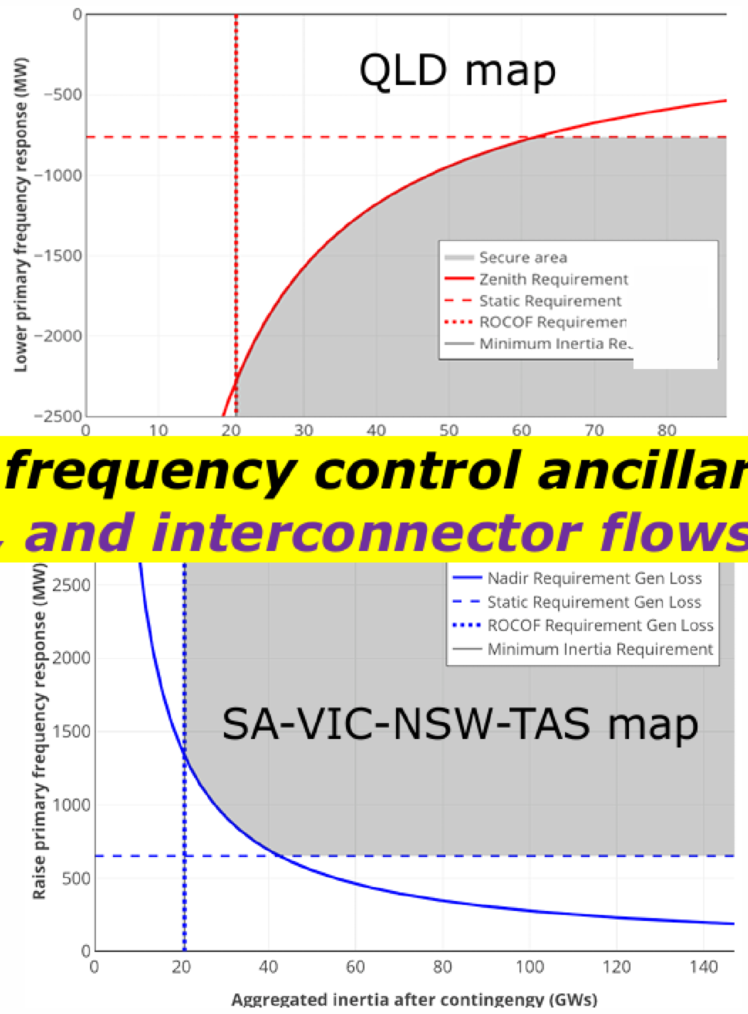
Integrated provision of system and local services from DER



Appendix

Separation-constrained UC/OPF

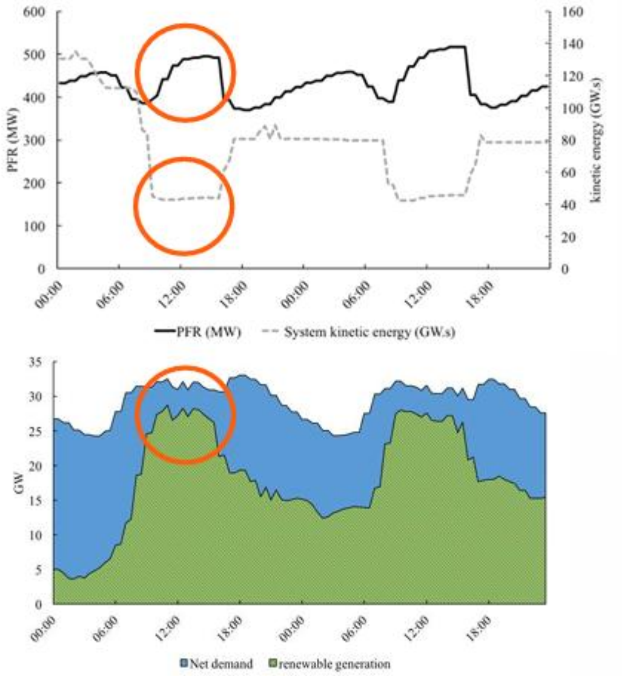


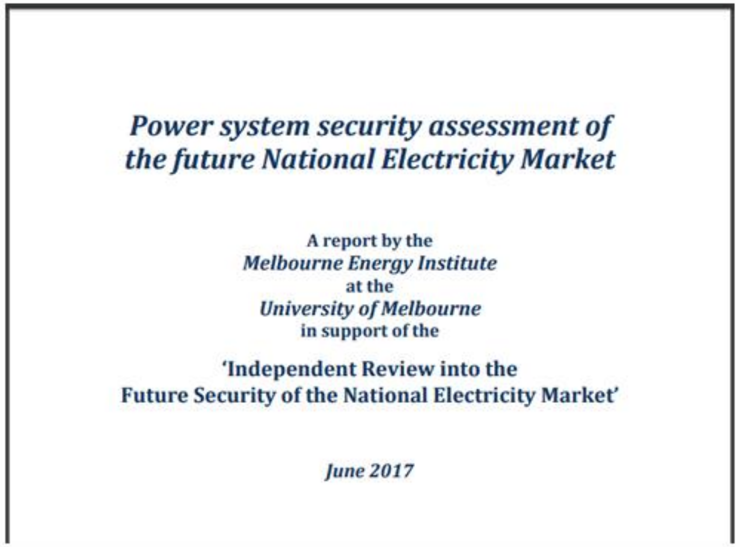


Regional co-optimization of energy, frequency control ancillary services, inertia, contingency level, and interconnector flows

Appendix

Co-optimization of energy, frequency control ancillary services, and inertia





Power system security assessment of the future National Electricity Market

A report by the
Melbourne Energy Institute
at the
University of Melbourne
in support of the
'Independent Review into the Future Security of the National Electricity Market'

June 2017

Thank you!