Panel 1:
Flexibility and Resiliency in Decarbonised Energy Systems

The Fragile Grid:
Security and Resilience Challenges in Low-carbon Power Systems

Prof Pierluigi Mancarella
Chair of Electrical Power Systems, The University of Melbourne
Professor of Smart Energy Systems, The University of Manchester
veski Innovation Fellow
pierluigi.mancarella@unimelb.edu.au

8th Annual EPRI-IEA Workshop
Challenges in Decarbonisation: Building a Resilient Net-Zero Future
October 2021
What we talk about when we talk about security and reliability

Image source: Google search
What we talk about when we talk about resilience

Image source: Google search
Example: climate change-driven windstorms


ResNet project, 2012
Example: climate change-driven windstorms


ResNet project, 2012
Example: climate change-driven windstorms

Fig. 4: The reduced 29-bus Great Britain transmission network

Example: climate change-driven windstorms

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Example: climate change-driven windstorms

Fig. 4: The reduced 29-bus Great Britain transmission network


ResNet project, 2012
Resilience thresholds and nonlinear cascading failures

- Expected Energy Not Served (EENS)
- Loss of Load Frequency (LOLF)

Planning for Resilience: The Resilience Trilemma

Resilience Enhancement

Smarter?
Make the network more responsive (e.g. faster restoration), self-adaptive, resourceful, etc.

Stronger?
Upgrade existing infrastructure, asset life extension, etc.

Bigger?
Build new infrastructure, e.g. transmission lines, substations, etc.


## The “new physics”

### Frequency control and inertia

<table>
<thead>
<tr>
<th>Risk</th>
<th>Emerging issues</th>
<th>Possible Mitigations</th>
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<tbody>
<tr>
<td>- Sustained frequency excursions (regulation)</td>
<td>- Minimum inertia levels</td>
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<tr>
<td>- High ROCOF following contingency</td>
<td>- Compulsory droop response</td>
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<td>- Insufficient regional inertia</td>
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<td>- Co-optimization of energy, frequency response, and (regional and system-level) inertia</td>
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<td>- Risk of low-inertia and insufficient PFR after separation</td>
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<td>- New sources of fast frequency response (e.g., batteries, electrolysers)</td>
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<td>- Management of largest contingency and interconnector flows (system at risk of regional separation)</td>
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### Variability and uncertainty

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<td>- Large variation in net demand</td>
<td>- Better forecasting</td>
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<td>- Insufficient short- and medium-term and ramping reserves</td>
<td>- Artificial intelligence to assess reserves (e.g., dynamic Bayesian belief network tools)</td>
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<td>- Use of more flexible resources including energy storage (e.g., pumped hydro)</td>
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### System strength

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<td>- Fault current shortage</td>
<td>- Minimum level of inertia and fault current (generators constrained on)</td>
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<td>- Voltage instability</td>
<td>- Synchronous condensers</td>
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<td>- Sustained voltage oscillations after fault</td>
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<td>- Fault-ride through issues</td>
<td>- Improvements of control loops (especially in solar farms)</td>
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<td>- Grid forming inverters</td>
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Co-optimization of energy, frequency control ancillary services, inertia and largest contingency level

Co-optimization of energy, inertia, FR and largest contingency level

Primary frequency response and Inertia requirements for secure operation

Secure Area
Low Inertia
High Inertia

System inertia after contingency

Secure Area Nadir Requirement Static Requirement RoCoF Requirement

Primary frequency response of load vs system inertia


How about new technologies?
A stronger, bigger or smarter grid? Resilience from new security technology

But there’s a catch....
Substitutability of frequency response products: “synchronous” vs “controlled” energy injections

New technologies (batteries, electrolysers) can competitively provide security services

Adapted from: S. Puschel, M. Ghazavi, S. Low, and P. Mancarella, “Separation event-constrained optimal power flow to enhance resilience in low-inertia power systems”, Electric Power System Research, 2020
Role of future technologies: Resilience from hydrogen electrolyzers in Victoria

### The “new physics”

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“Blurring” of security and resilience

Credible events

Non-credible events

Discrete events

Secure for single credible contingency

RECLASSIFICATION
Non-credible discrete contingency reclassified as credible during abnormal conditions

High impact low probability events with multiple outages

PROTECTED EVENTS
Discrete standing risks

Indistinct standing risks

Secure for low impact indistinct contingency

PROTECTED OPERATION
Abnormal conditions causing indistinct risks

High impact, low probability events with multiple distinct outages and indistinct events

Secure operating state

Resilience expected to avoid black system

Material risk of black system event

How about markets and incentives?
Running an old market with the new physics...

Directions for system strength in SA and Victoria

% of time directed

0% 10% 20% 30% 40% 50%

Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2
2016 2017 2018 2019

SA  VIC

High wind, low prices drives system strength interventions

Gas SRMC ~$1.25/MWh

As system strength approaches minimum levels, AEMO intervenes to direct some GPG to stay online

Average NEM VRE curtailed by curtailment type

Note: curtailment amount based on combination of market data and AEMO estimates™.

Source: AEMO
New markets and regulation: The ‘basket of goods’ for system security (and resilience)

Mix of:
- technology requirements
- coordinated network interventions
- new operational measures

Markets are easier to develop

Concluding remarks

- Low-carbon grids are naturally **more fragile**
- In more **fragile grids, security and resilience concepts become more intertwined**
- The “**new physics**” calls for **new security and resilience services**
- Starting from physical first principle and **bottom-up** ("from physics to economics")
- **Technical complexity** underscores **economic nuances**
  - but economic design MUST consider the physics!
- The **economic products** of system security (and resilience) comprise a ‘**basket of goods**’ with very different characteristics
- Market and regulatory design should reflect all the relevant economic nuances, but considering, most importantly:
  - **The physics!**
  - New operational solutions and technologies
  - **Risk-averse attitude** of system operator, regulator, and **consumers**
Further reading

Any question?
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