# Fast Frequency Control of Low-Inertia Systems

# The Examples of the Irish and the Australian Transmission

Prof. Federico Milano

Email: federico.milano@ucd.ie

Webpage: faraday1.ucd.ie

School of Electrical & Electronic Engineering

University College Dublin

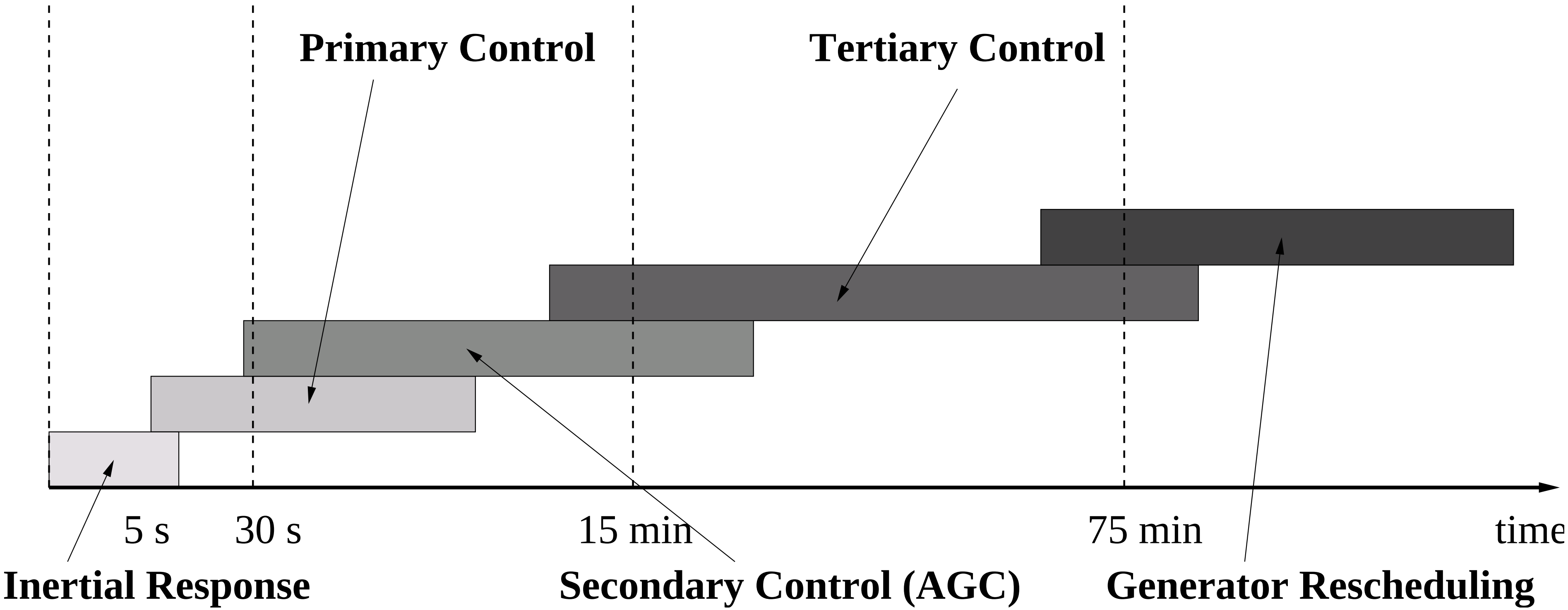
Dublin, Ireland

IEEE PES Power & Energy Society®

IEEE

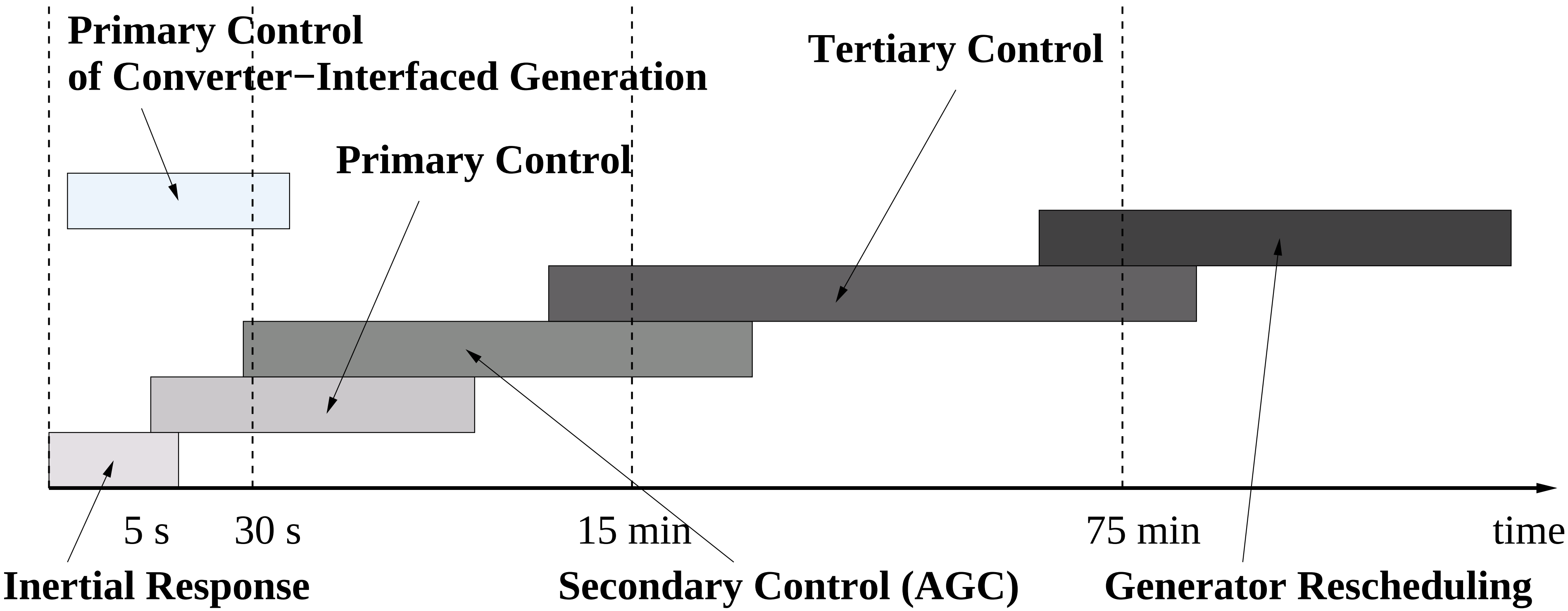
# Time scales

- Typical time scales related to inertia and frequency control



# Time Scales of a Conventional Power System & CIG

- CIG controllers can be fast (is this good?)



# Electro-mechanical Dynamics – I

- Neglecting network topology, a conventional system where generation is attained with synchronous generation can be represented as

$$M\dot{\omega}(t) = p_{\mathrm{s}}(t) - p_{\mathrm{l}}(t) - p_{\mathrm{j}}(t)\,,$$

where

- $M$ is the total inertia of the synchronous machines
- $\omega(t)$ is the average frequency of the system
- $\dot{\omega}(t)$ is called Rate of Change of Frequency (RoCoF)
- $p_{\mathrm{s}}$ is the power of synchronous machines
- $p_{\mathrm{l}} + p_{\mathrm{j}}$ are load demand and losses respectively.

# Electro-mechanical Dynamics – II

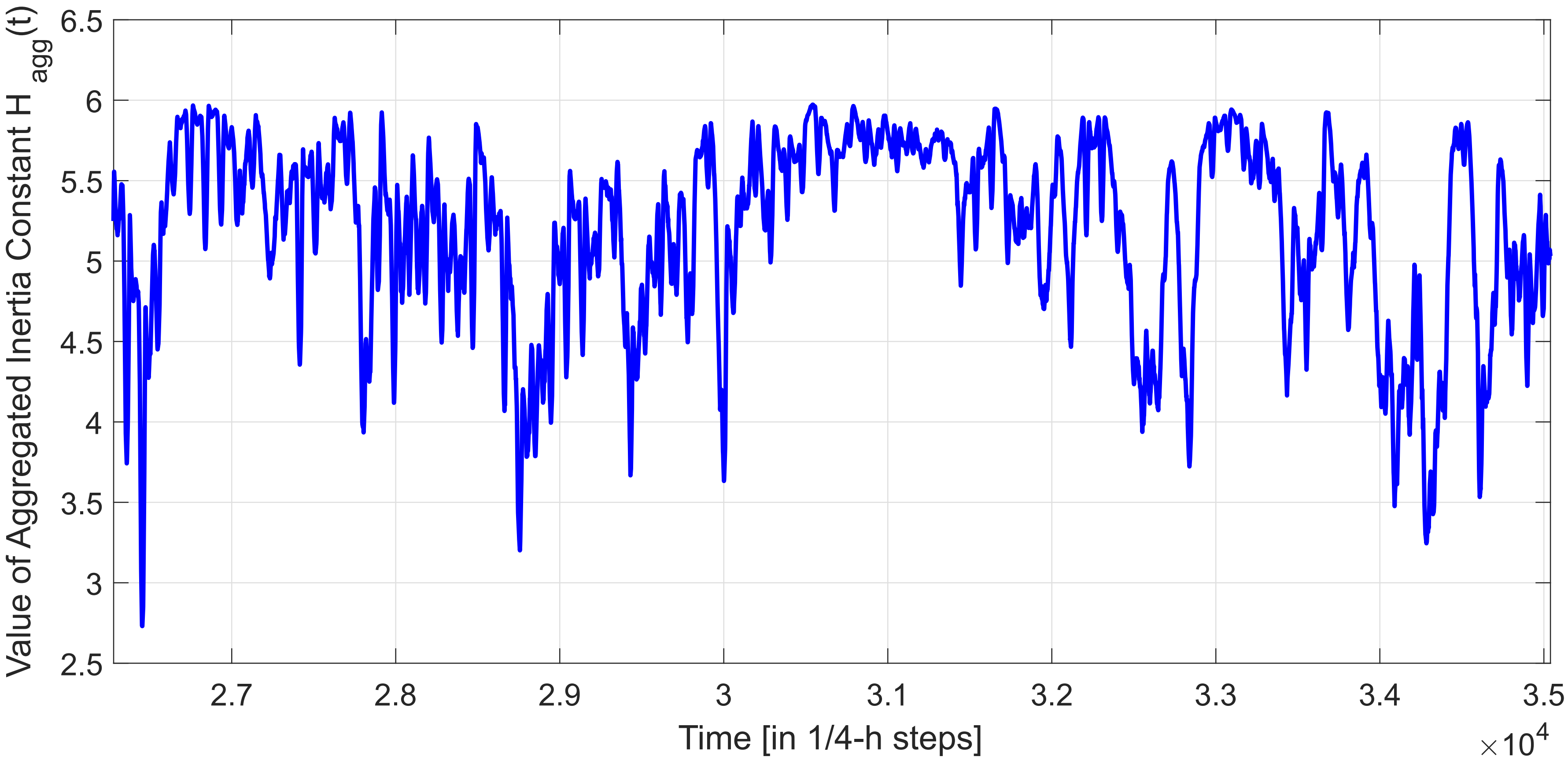
- A system where generation is attained with synchronous as well as non-synchronous generation can be represented as

$$\tilde{M}\dot{\omega}(t) = p_{\rm s}(t) + p_{\rm ns}(t) - p_{\rm l}(t) - p_{\rm j}(t)\,,$$

  where

  - $\tilde{M}$ is the total inertia of the synchronous machines, with $\tilde{M} < M$ or, in certain periods and certain systems, $\tilde{M} \ll M$
  - $p_{\rm ns}$ is the powers provided by CIG

# Volatility of the inertia




Acknowledgment: Thanks to A. Ulbig and G. Andersson for data and script to generate figure

# Extreme Case

- In a hypothetical system where there are no synchronous machines at all, $M \approx 0$ and the frequency is completely decoupled from the power balance of the system:

$$0 = p_{\mathrm{ns}}(t) - p_{\mathrm{l}}(t) - p_{\mathrm{j}}(t)$$

- This opertaing condition has never really happened in large networks (only in microgrids and small islanded systems)
- In this case, is still the frequency meaningful?

# Modelling

- Synchronous Generator
  - “Physical” interaction due to inertia
  - Control loops to replace inertial response
- Power Electronics Sources
  - Interactions dominated by controls
  - Time constants of control loops critical

# Drawbacks of CIG

- Reduce the inertia
- The local frequency must be measured (and properly defined) first!
- Often introduce volatility and uncertainty (e.g., wind and solar power plants)
- Often do not provide primary and/or secondary frequency control
- Since it is based on converter, its control can be potentially very fast

# Advantages of CIG

- Can provide primary and secondary control (if the resources are properly handled and/or storage is included)
- Quantities other than the frequency can be utilized (voltage?)
- Since it is based on converter, its control can be potentially very fast

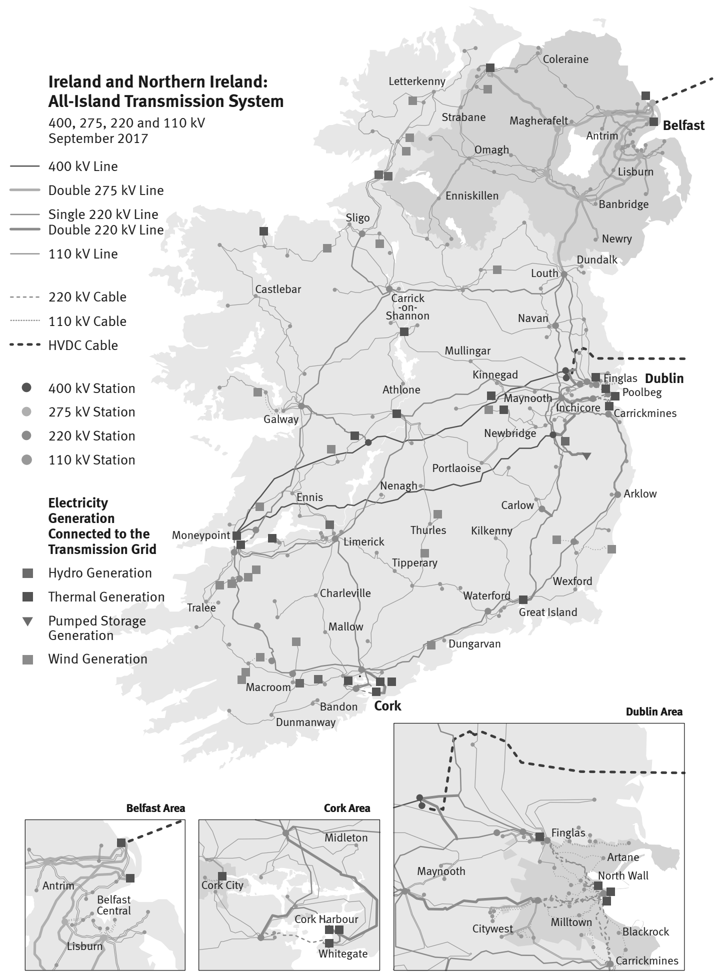
# All-Island Irish Grid

# All-Island Irish Transmission System

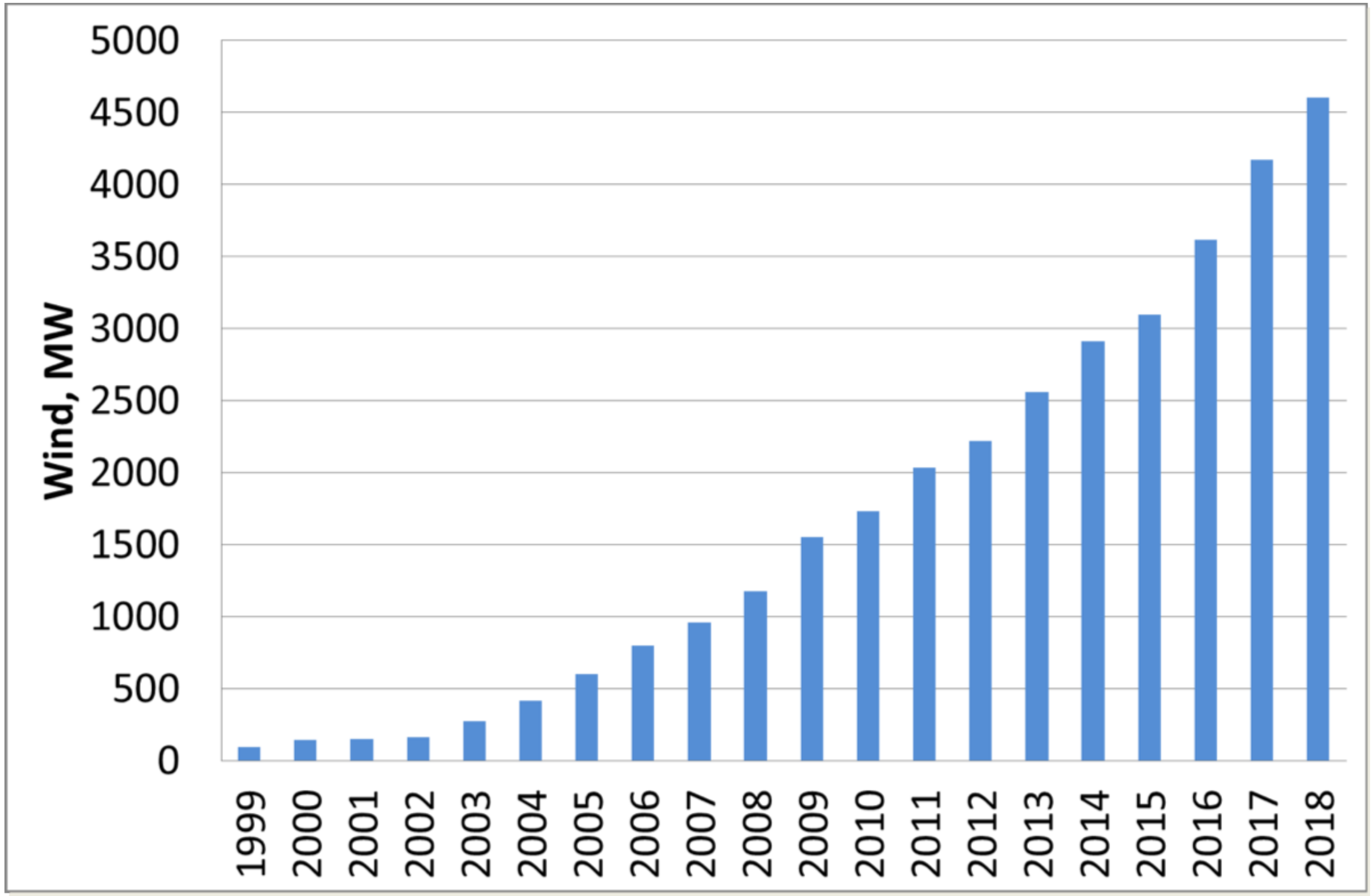
- 9500 MW of conventional plant
- 4500 MW of windfarms
- Peak 6500 MW; Valley 2500 MW
- Northern Ireland-Scotland 500 MW HVDC (LCC)
- Ireland-Wales 500 MW HVDC (VSC)
- In consideration:
  - 700 MW HVDC Ireland-France: “Celtic Interconnector”
  - 500 MW HVDC Ireland-Wales: “Greenlink Interconnector”

# All-Island Irish Transmission System

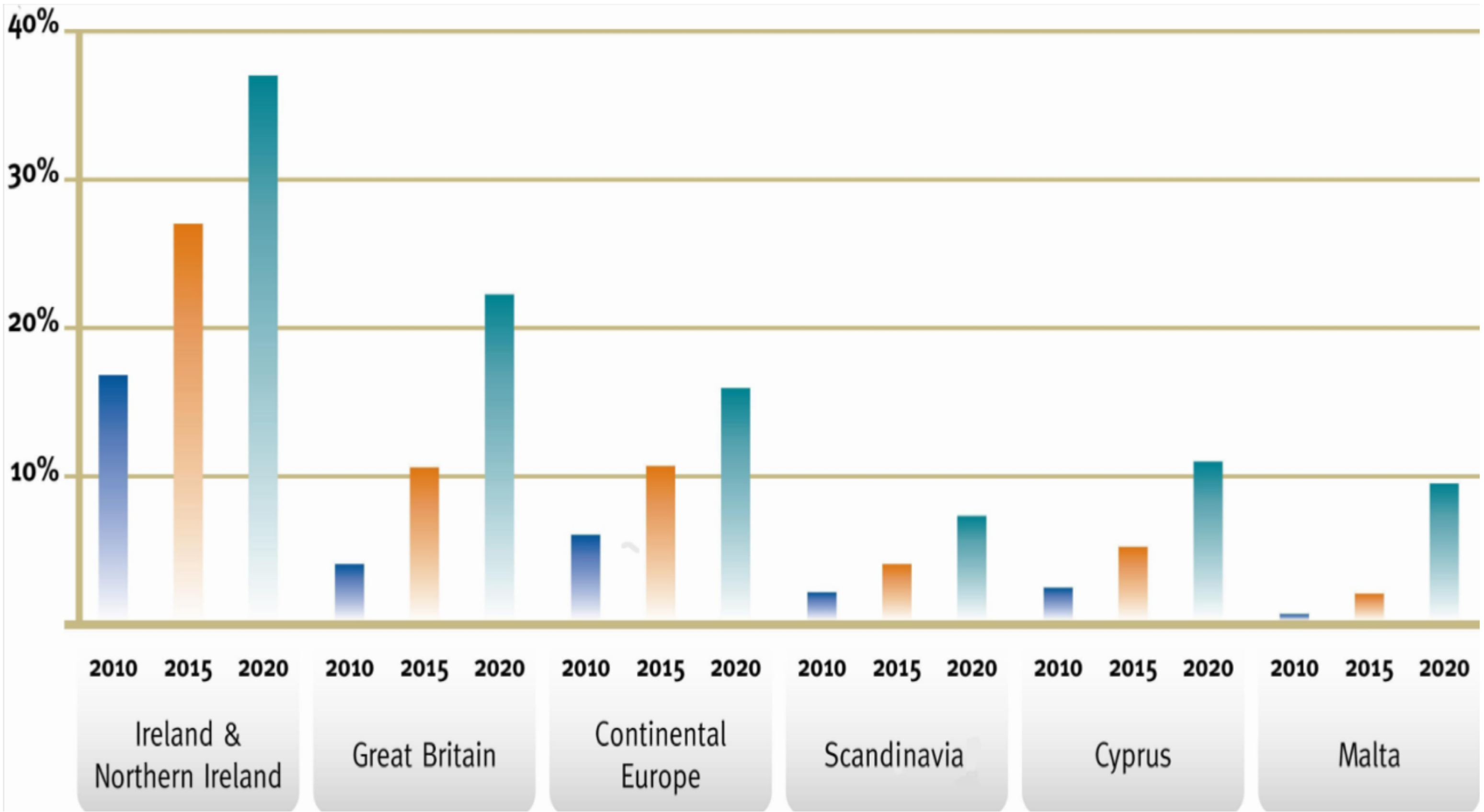
- Despite this huge potential, wind intermittency limits the capacity credit of wind.
- In 2016, 22% of the total annual energy was generated by wind.
- In 2017, 26.4% of the total annual energy was generated by wind.
- The goal for 2020 is that 37% of the total energy is generated by wind.
- The figures and information of the next slides was obtained from EriGrid Group.



# Installed Wind in the Irish System

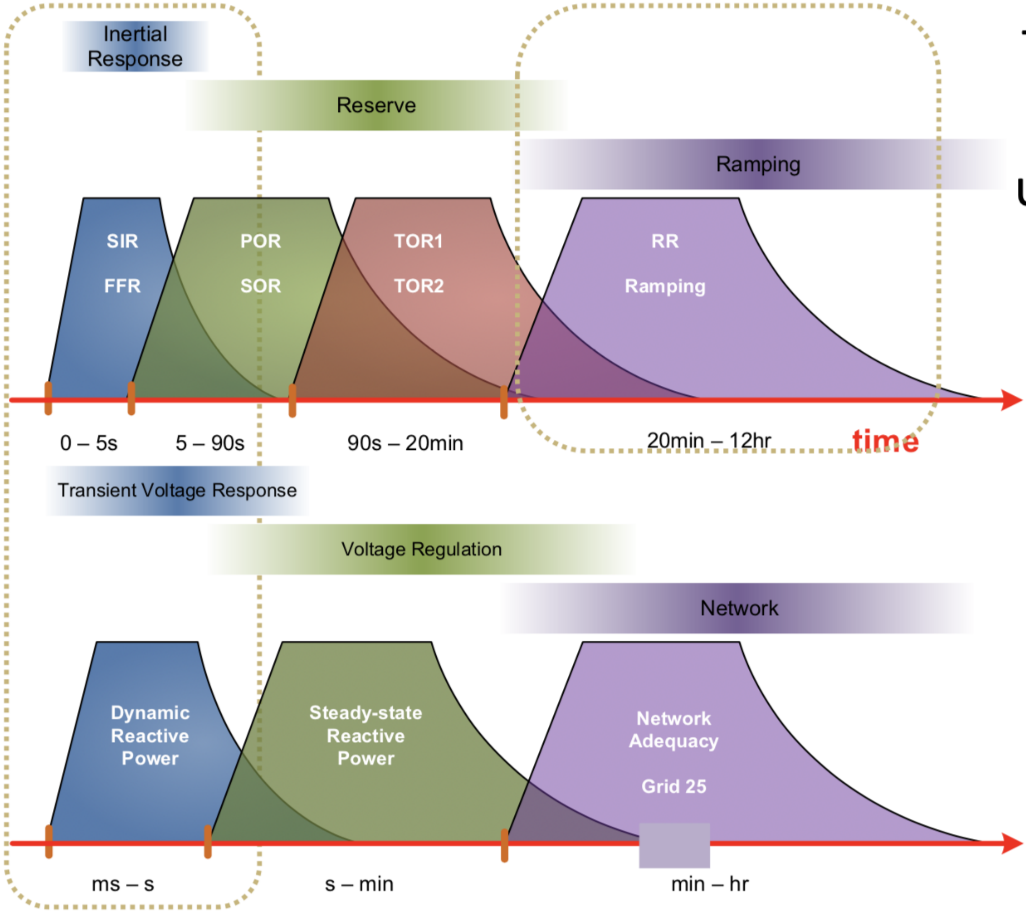


# Wind Targets



# DS3 System Services

To ensure system security



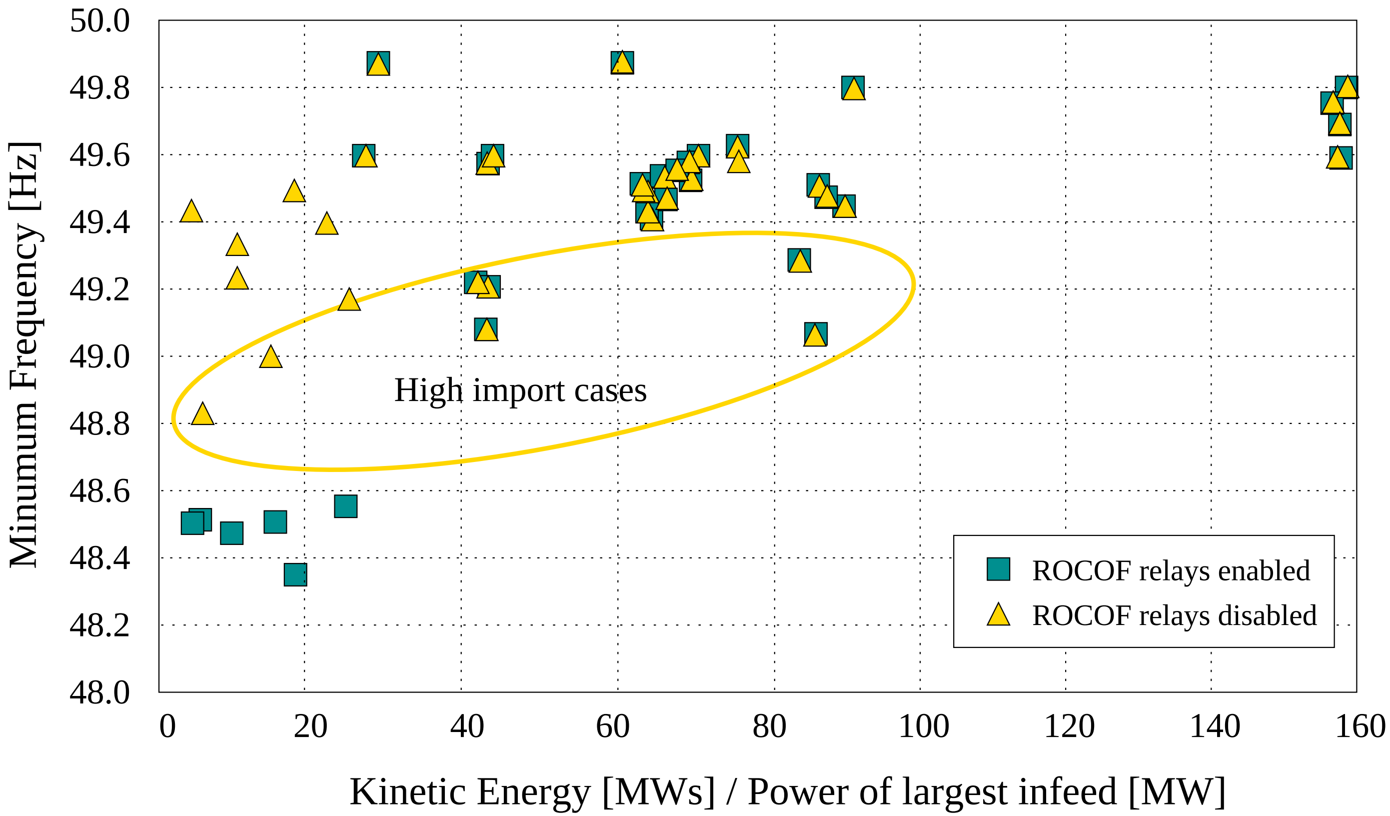

To manage forecast uncertainty

# Key Operational Milestones

| | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|
| SNSP | 60% -> 65% | 65% -> 70% | 70% -> 75% | 75% |
| RoCoF | 0.5 Hz/s | 0.5 -> 1 Hz/s | 1 Hz/s | 1 Hz/s |
| Inertia | 23,000 MW.s | 20,000 MW.s | 17,500 MW.s | 17,500 MW.s |
| Min Sets | 8 | 8 | 7 | 7 |
| Exports | 300 -> 500 MW (interim) | 500 MW (interim) | 500 MW (interim -> enduring) | 500 MW (enduring) |
| System Services | Current providers, 11 Services | | New providers, 14 Services, increased volumes to operate at high RES | |

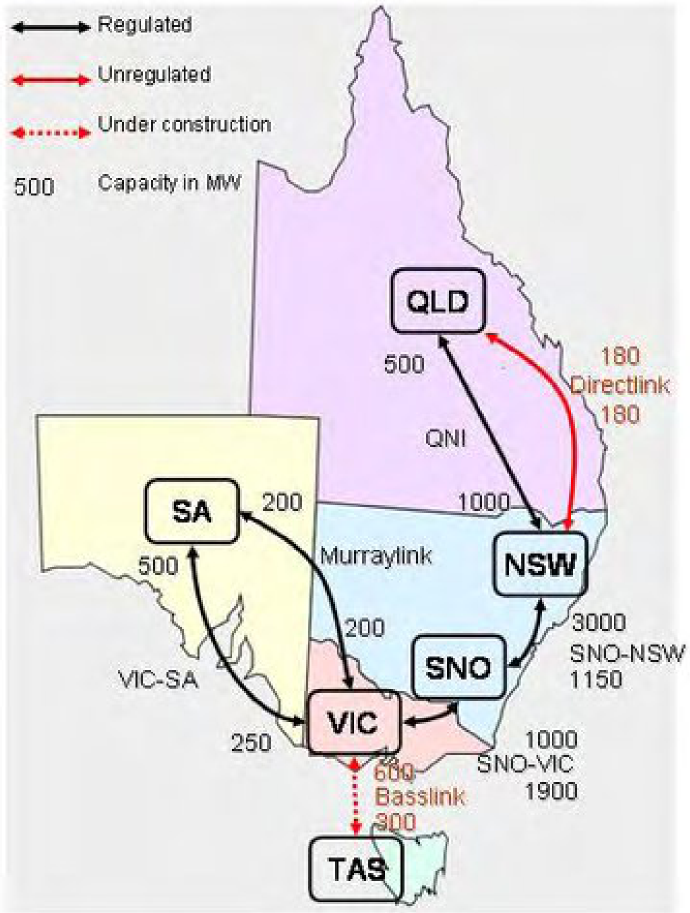
# Impact of RoCoF Protections

- EirGrid has fixed that 65% of CIG is the stability limit

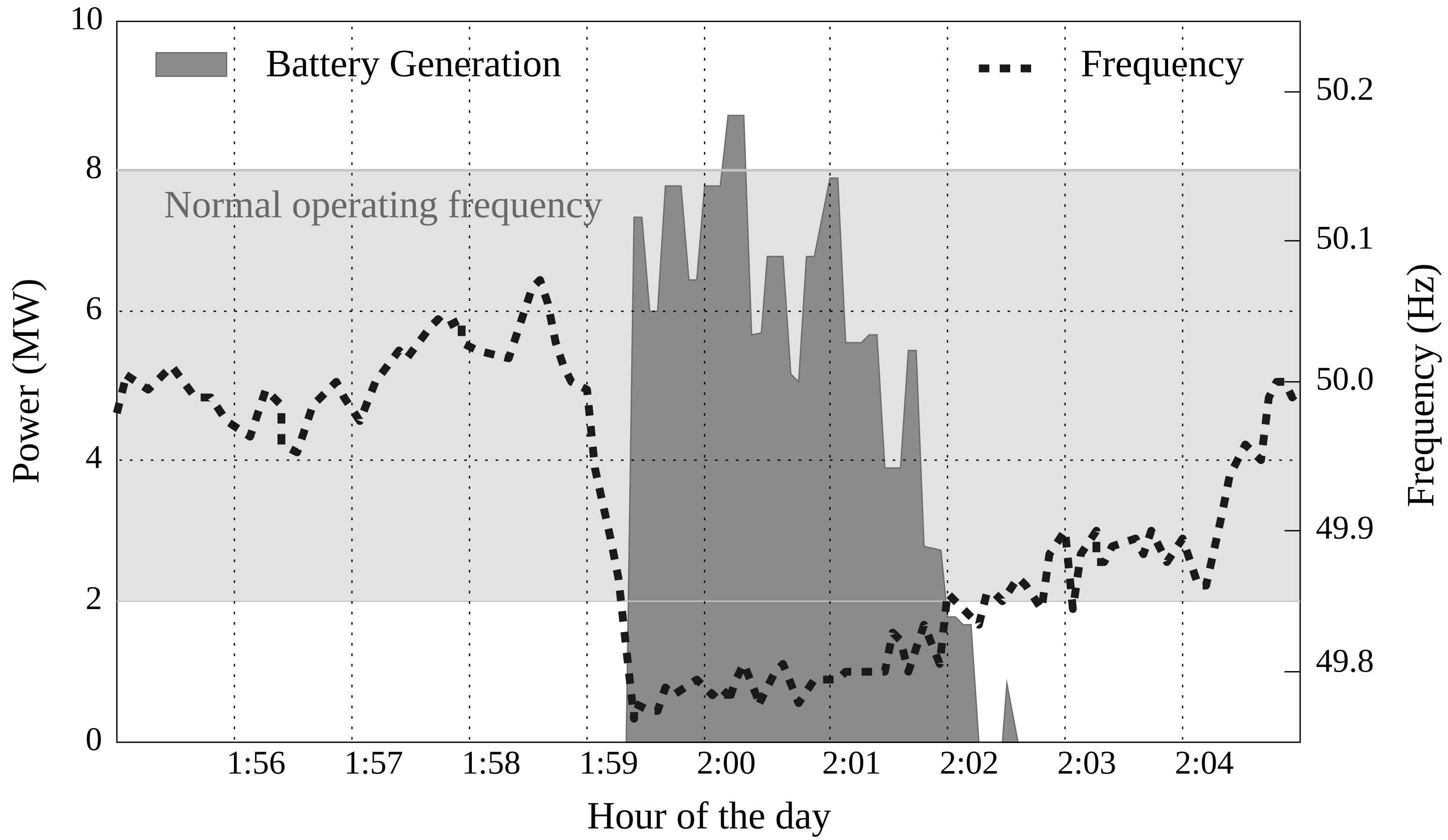


# Australian Grid

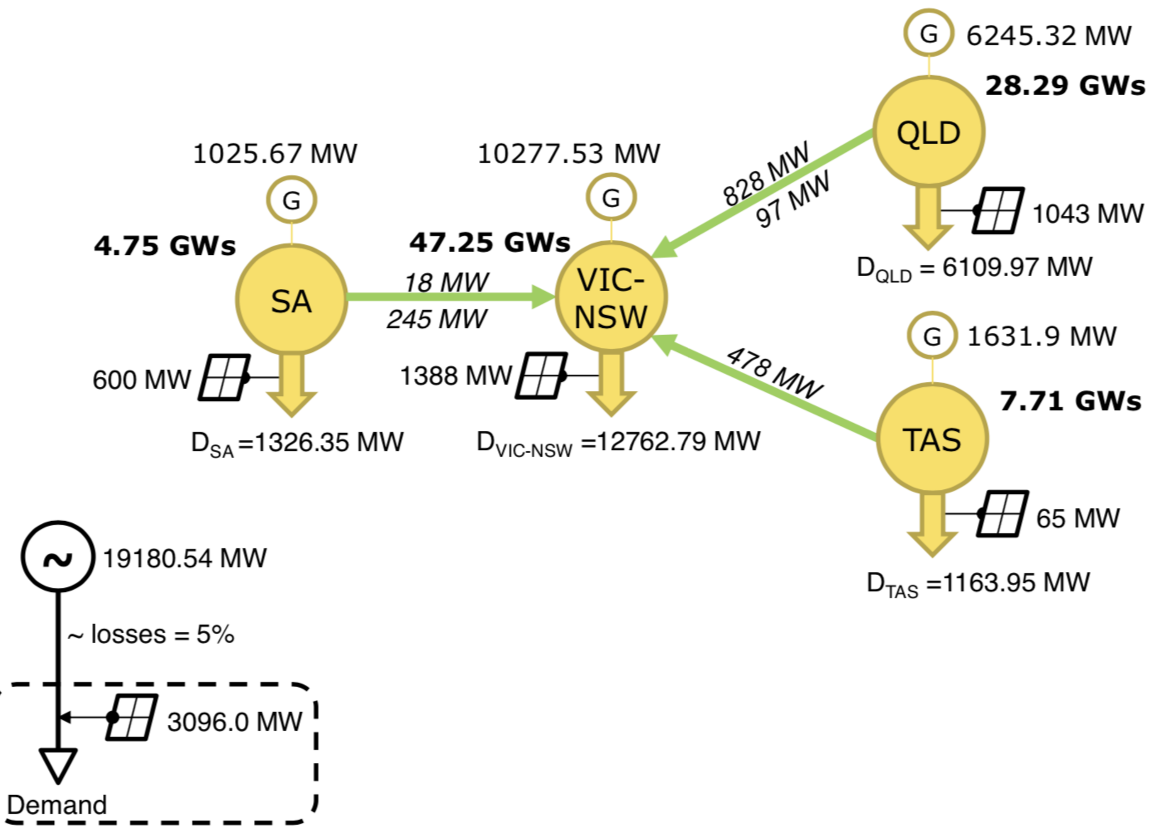
# Australian National Electric Market



# 28 September 2016 Event: Impact of the Tesla Battery



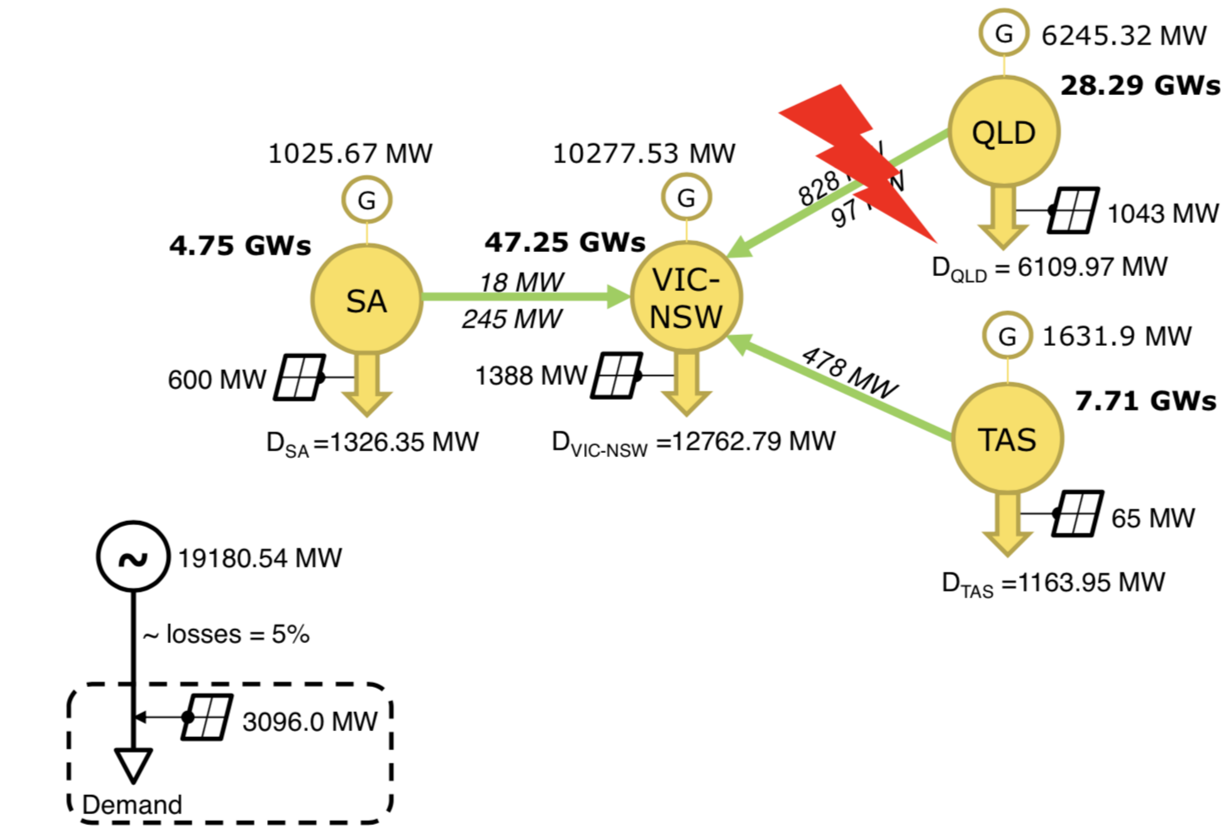
# 25 August 2018 Event: Pre-contingency Conditions




1.05 x (Demand – 3096.0) = 19180.54

Demand = 21363 MW

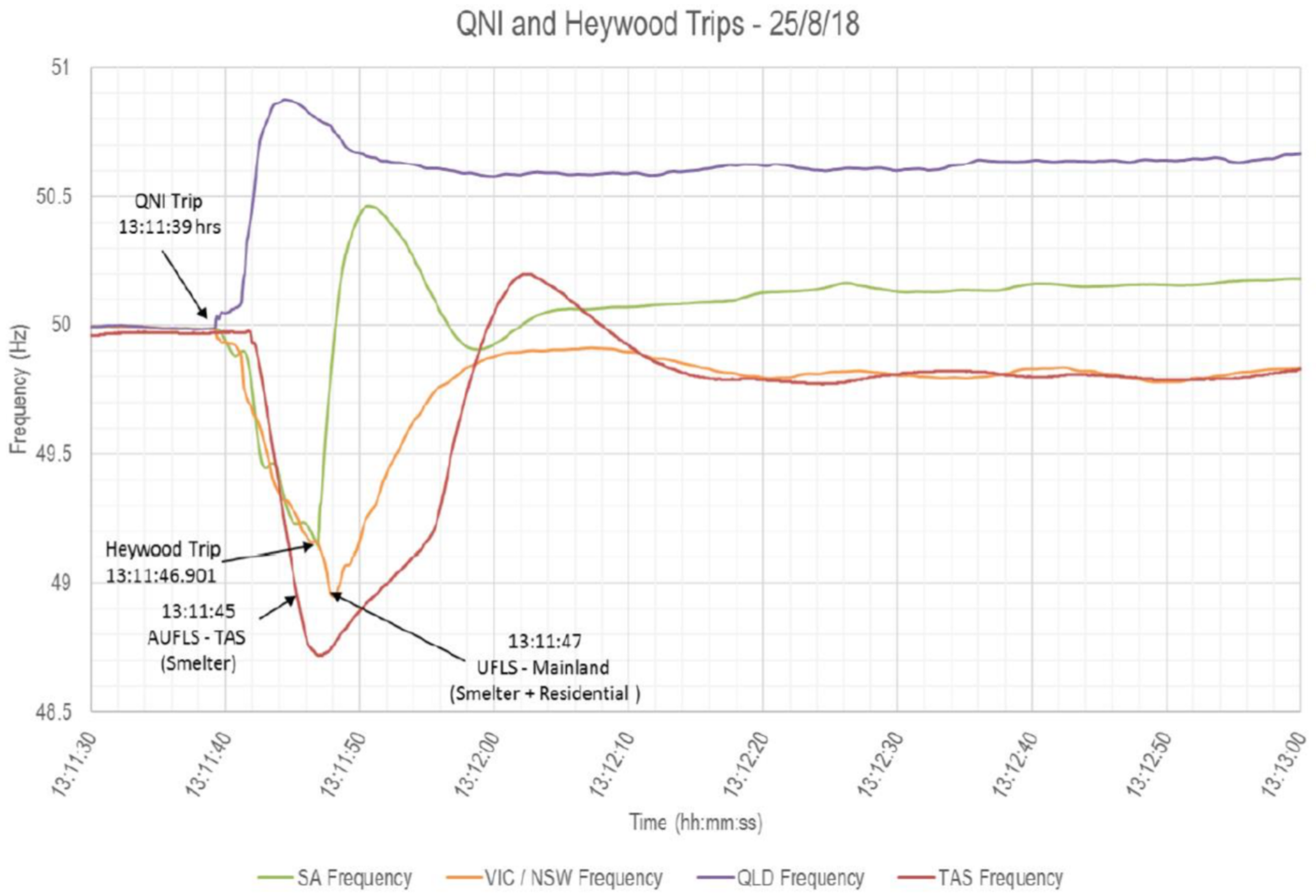
# 25 August 2018 Event: Post-contingency Conditions



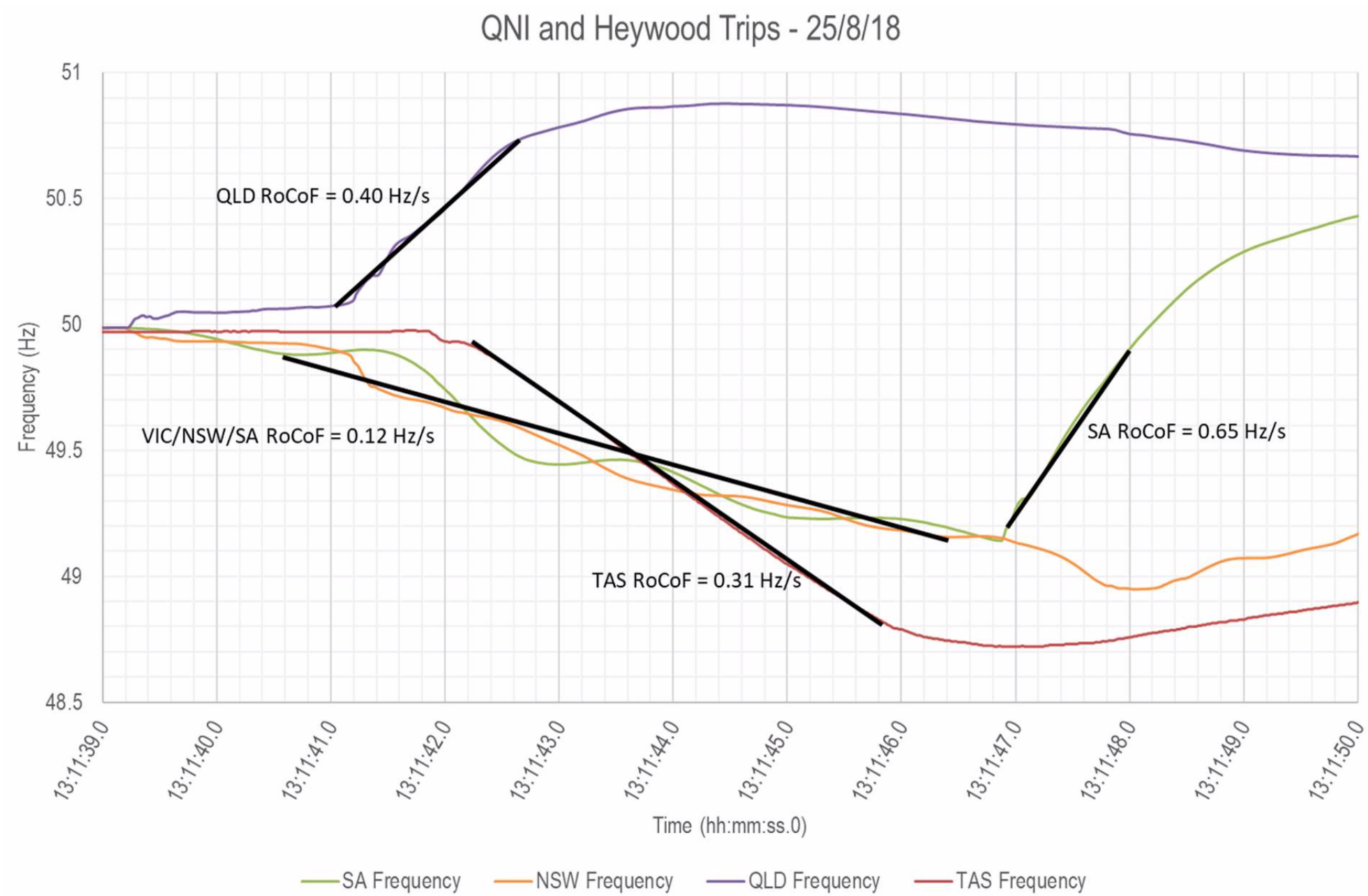

1.05 x (Demand – 3096.0) = 19180.54

Demand = 21363 MW

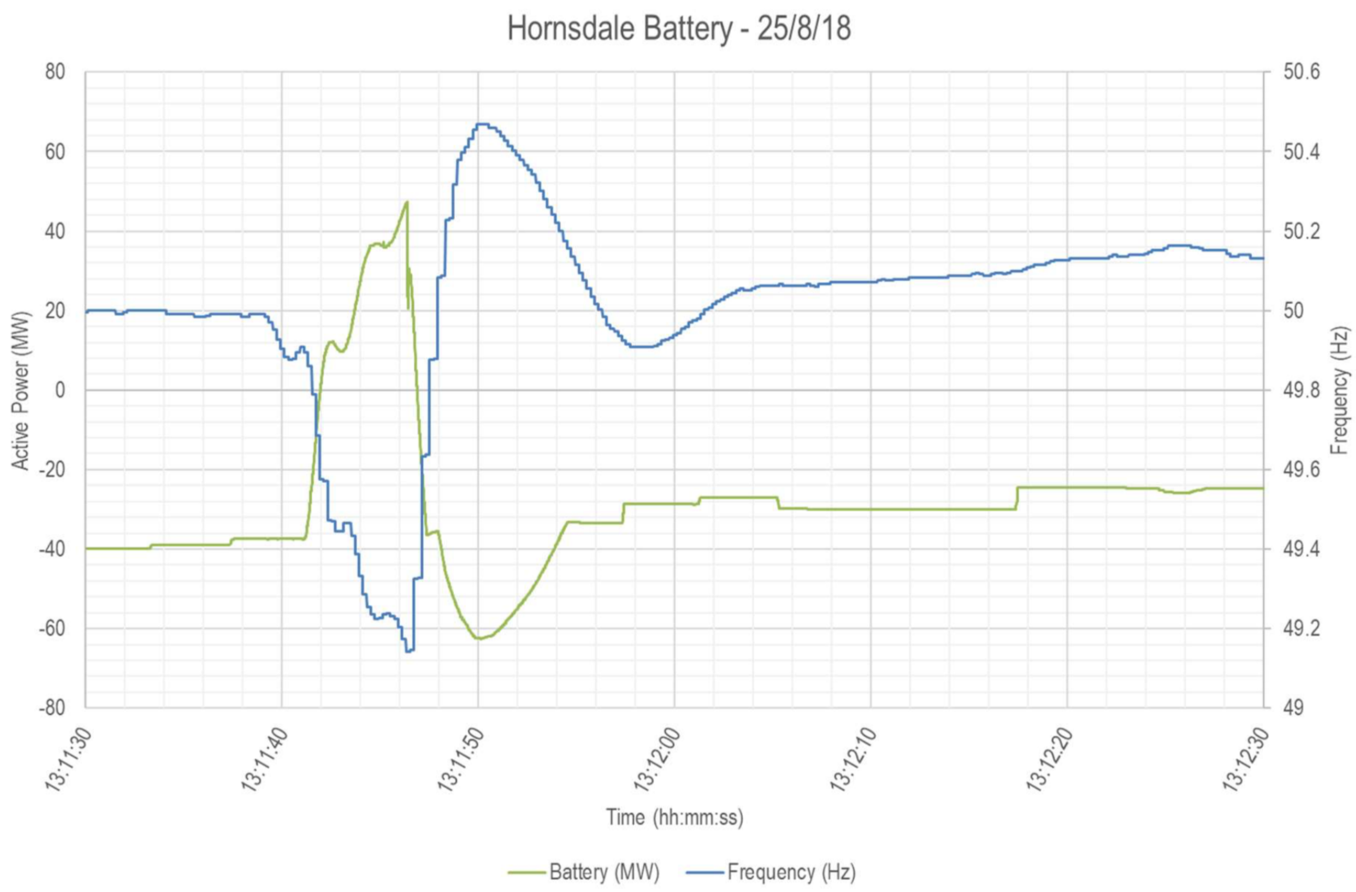
# 25 August 2018 Event: Regional Frequencies



# 25 August 2018 Event: Regional RoCoFs during the Event



# 25 August 2018 Event: Tesla Battery Response



# Pros and Cons of the Battery Dynamic Response

- The battery has a very fast response and is able to recover the frequency drop but . . .
- . . . there is a catch: fast transfer through interconnectors require headroom and ramp constraints
- The fast power ramp due to the battery has caused the intervention of the protection
- The tuning of such protection was again based on the assumption of a “slow” frequency control response by conventional generation.

# Conclusions

# Overall Remarks

- Low-inertia system often show new kinds of instability, that are not well-known to system operators.
- Stability depends on both system dynamics and topology (see events in Australia)
- Power electronic dynamics (possibly very fast, $< 5$ ms) might have an important role and should be modelled accurately.
- There is no satisfactory solution to predicting and arresting cascading collapse; beyond a certain tipping point the blackout is inevitable, and recovery became the priority.

# Recommendations

- Proper control of CIG is crucial.
- The role of large and fast energy storage systems (batteries) can be key.
- Retuning/rethinking existing protection schemes appears inevitable
- It might be necessary to fully rethink the entire model of power systems (what if frequency is not a relevant signal anymore?)

# The Challenge is to Look for Reliable Solutions . . .

**Thanks much for your attention!**