

IEEE PES General Meeting, Washington DC, July 2014
Panel session on "Implications of large-scale wind energy on power systems and supporting measures for better integration"

Large Scale Wind Integration and its Impact on Dynamic Stability

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Emilio Gomez, Nickie Menemenlis

IEA Task 25 Collaboration



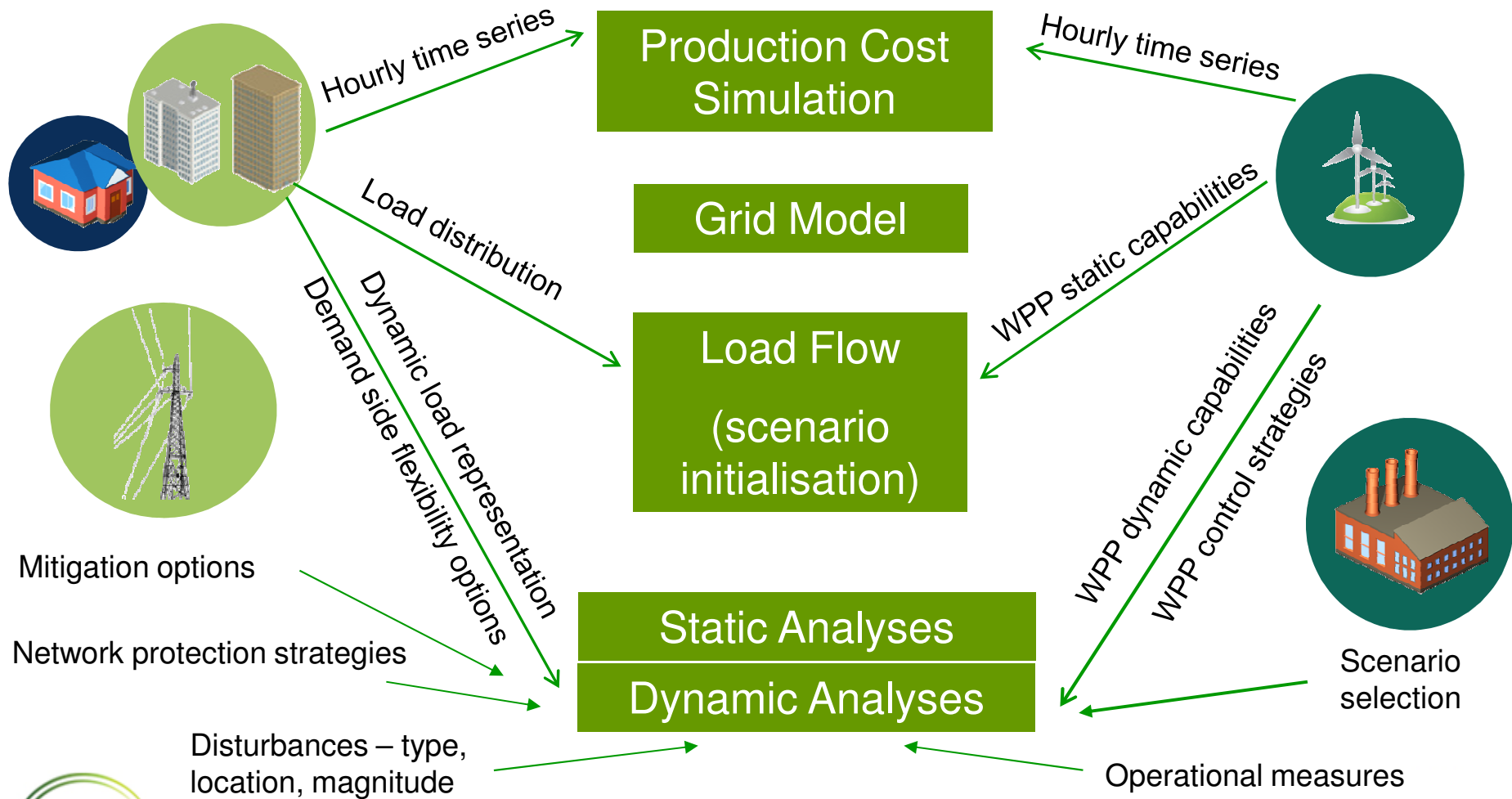
Overview

- Stability Concerns
- Assessment Methodology
- Inertial Support & Frequency Stability
- Fault Ride Through Capability
- Concluding Comments

High Wind Penetration Concerns

- Low ratio of synchronous machines on-line (voltage & frequency support)
- Transition to power electronics based controls
- Large exchange of surplus wind power across wide areas
- Validated simulation models of all grid components?
Grid code compliance?
- Transmission network development?
- (New) operational measures / ancillary services?

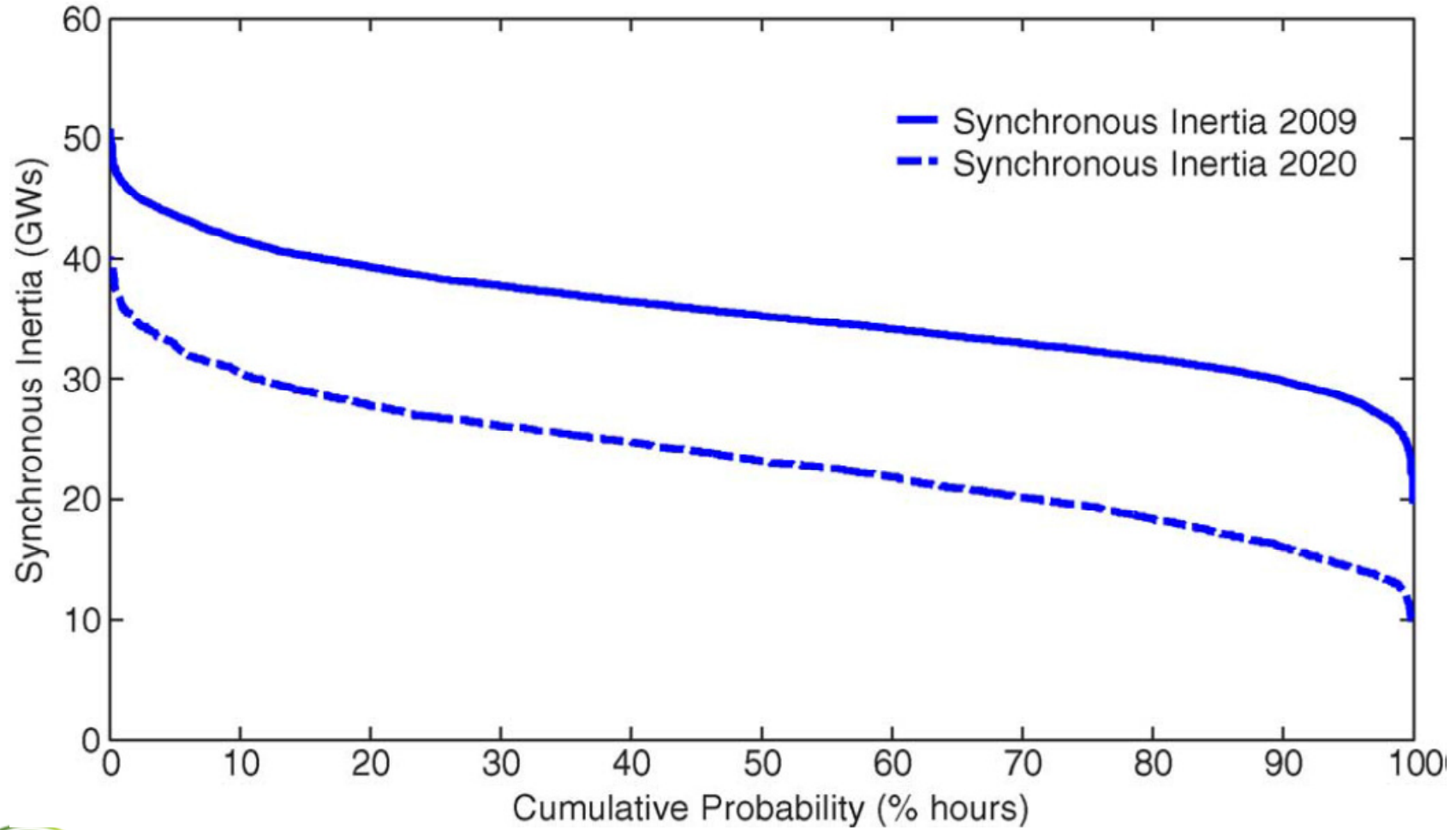
Methodology



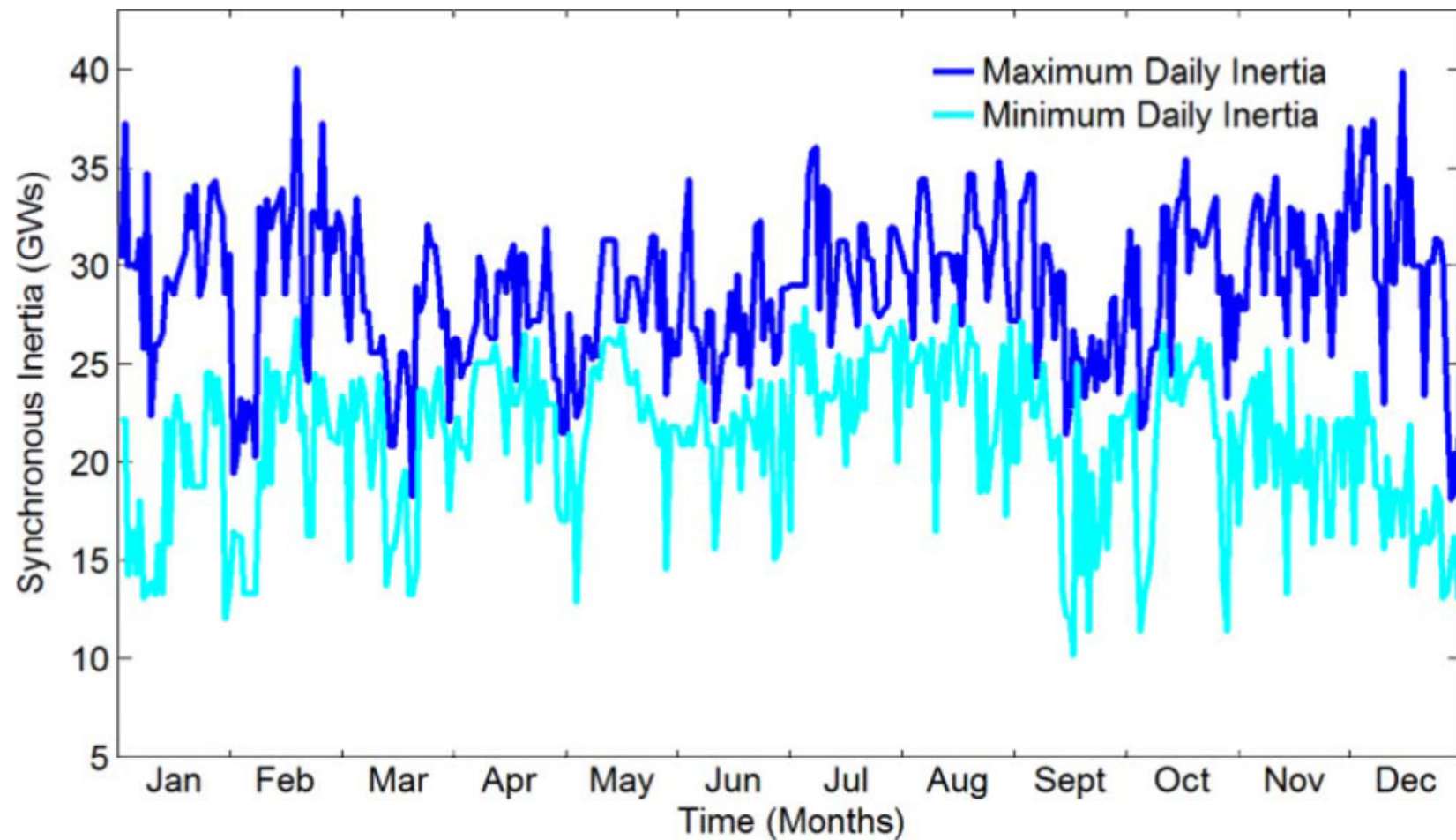


Large Scale Wind Integration: Inertial Support & Frequency Stability

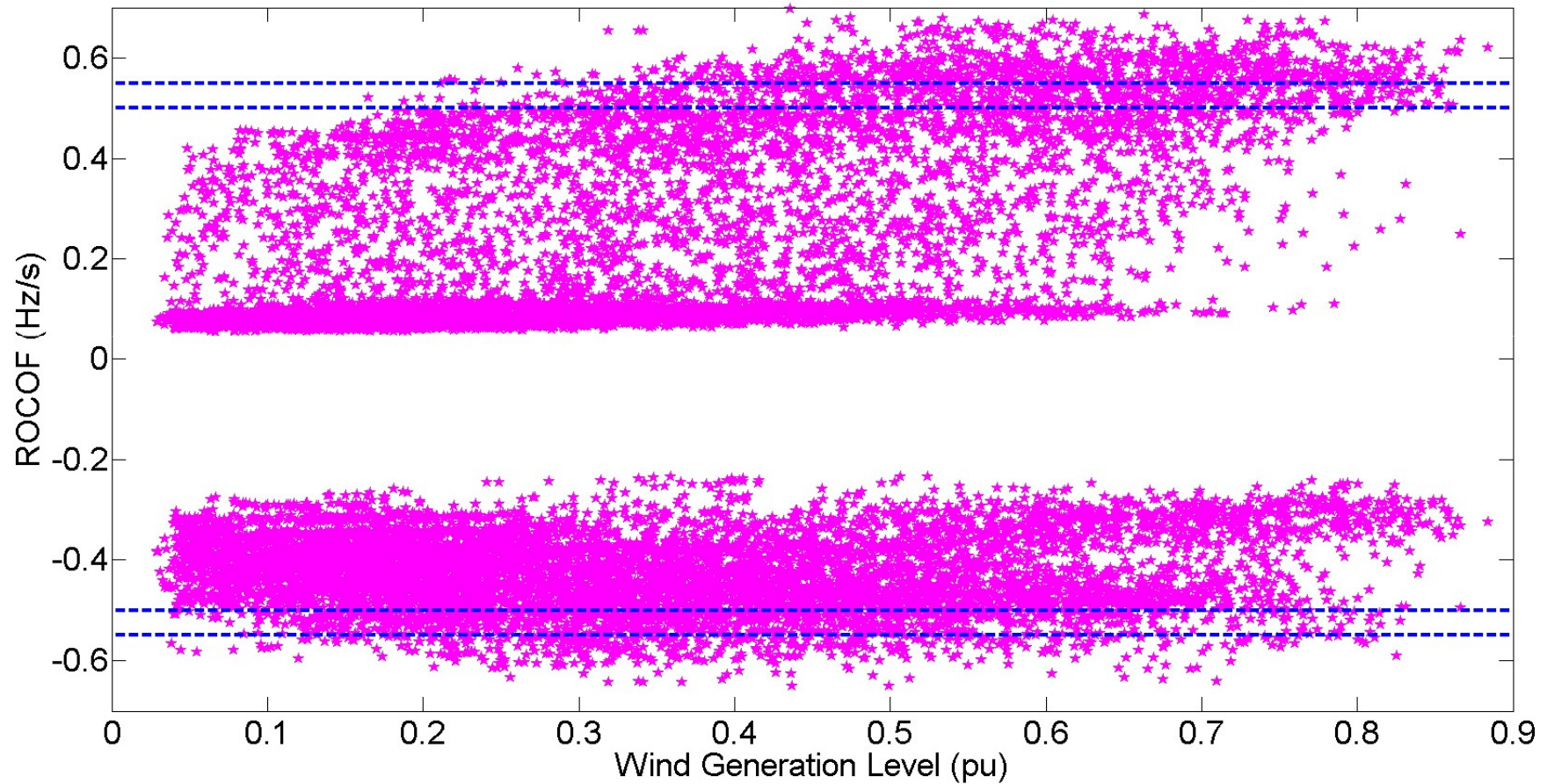
Ireland - System Inertia



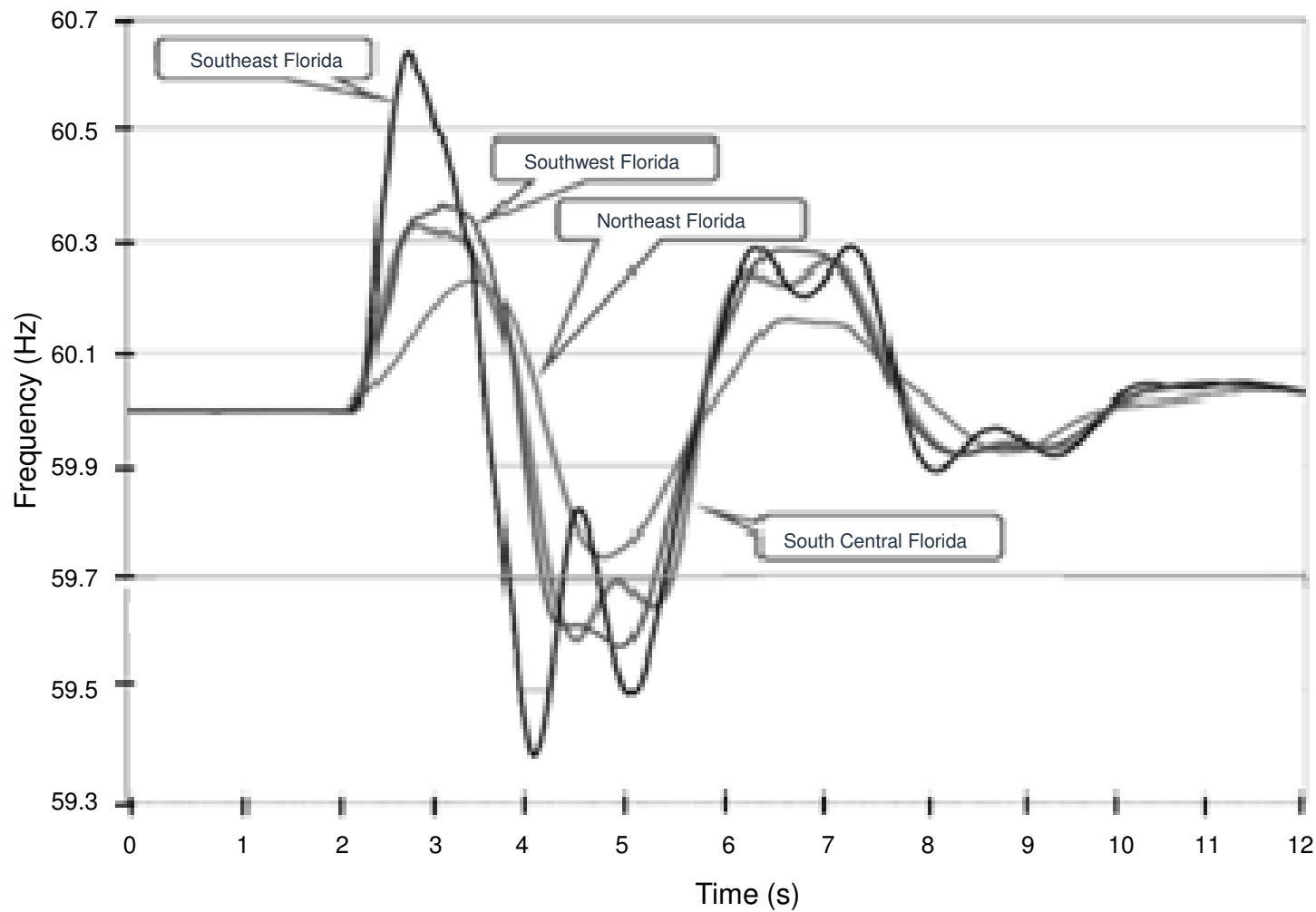
Ireland - Synchronous Inertia 2020



Ireland – RoCoF 2020



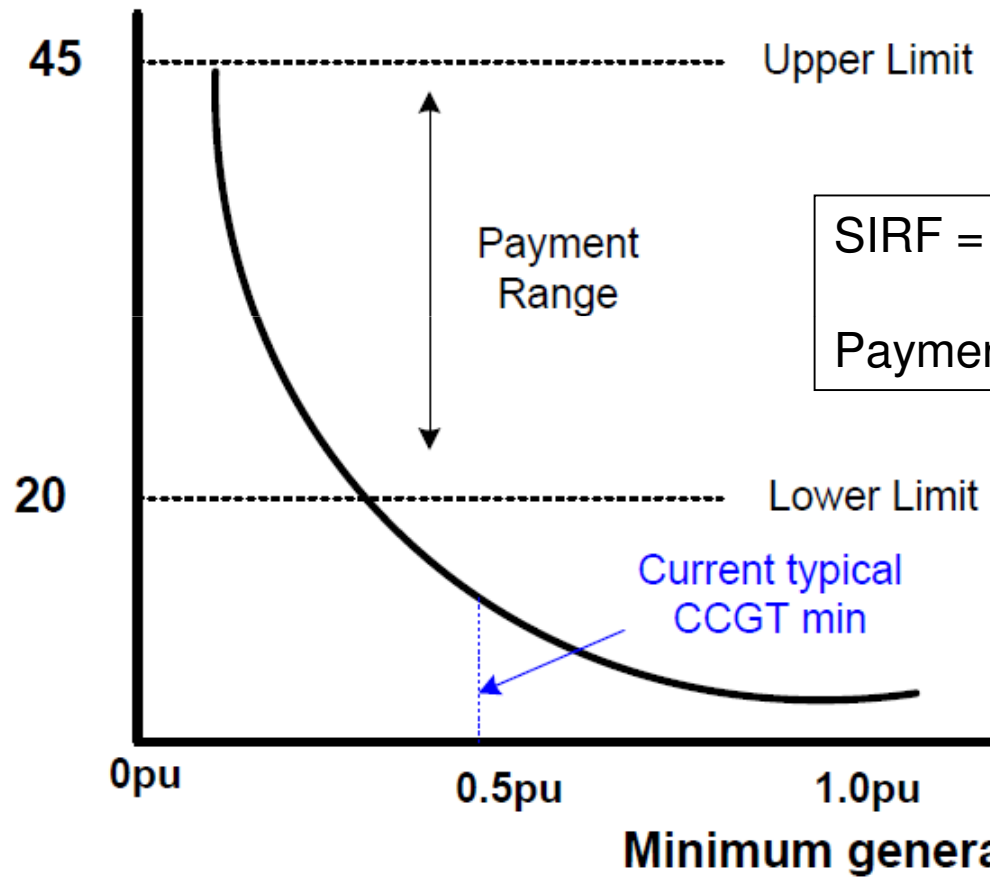
Florida – 26th February 2008



Synchronous Inertial Response



Synchronous Inertial Response Factor



$$\text{SIRF} = \text{KE} / \text{Min Stable Generation (s)}$$

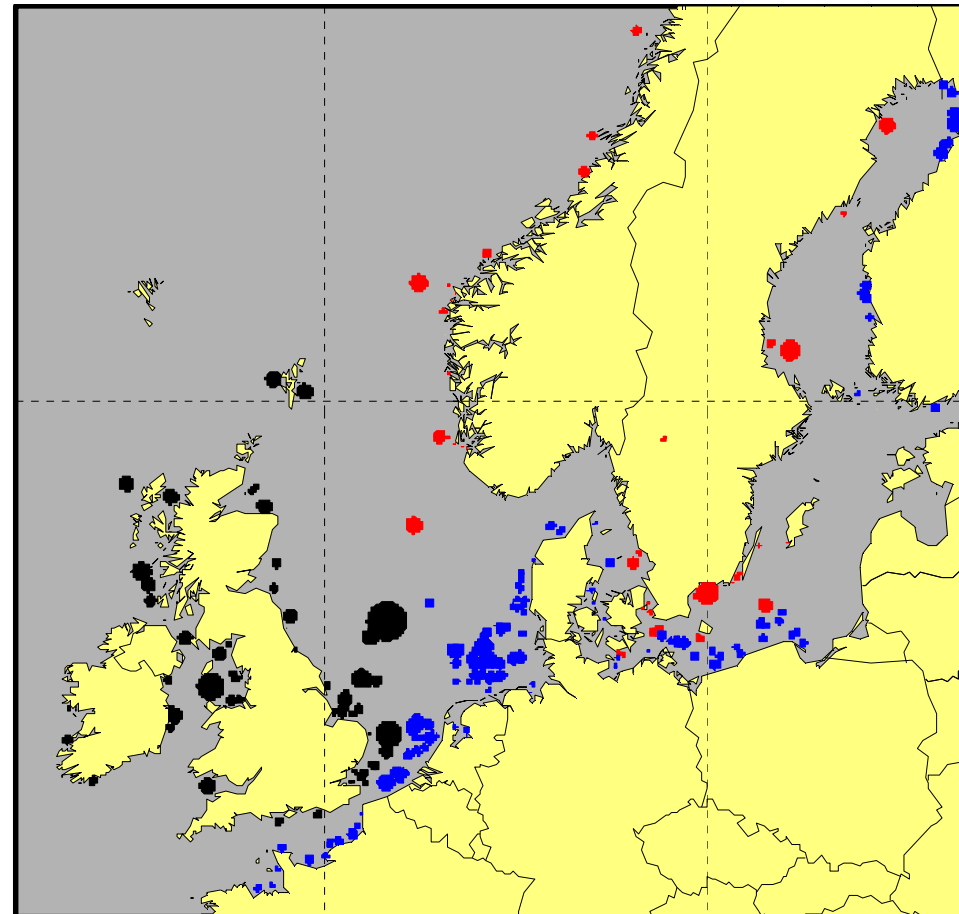
$$\text{Payment} \propto (\text{KE} \times \text{SIRF})$$

Offshore Wind Variability



Synchronous Area	2020	2030
	MW	MW
Continental	21,421	57,685
Nordic	4,924	14,669
GB	13,711	33,601
Ireland	1,419	3,219

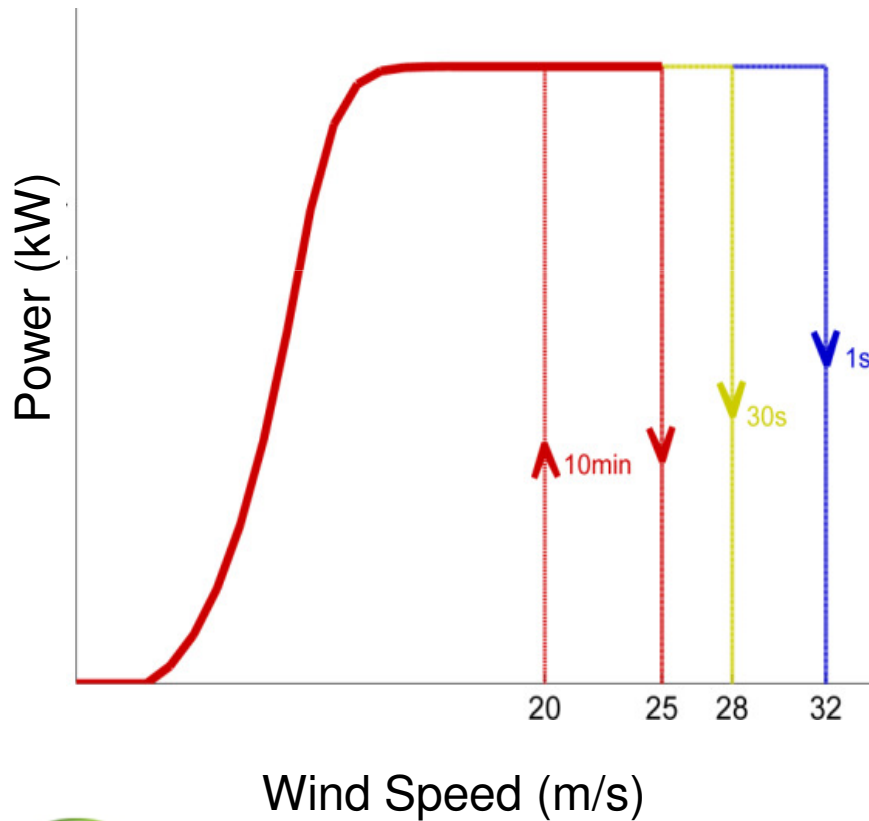
Synchronous Area	Dimensioning Fault
	MW
Continental	3,000
Nordic	1,200
GB	1,800
Ireland	500



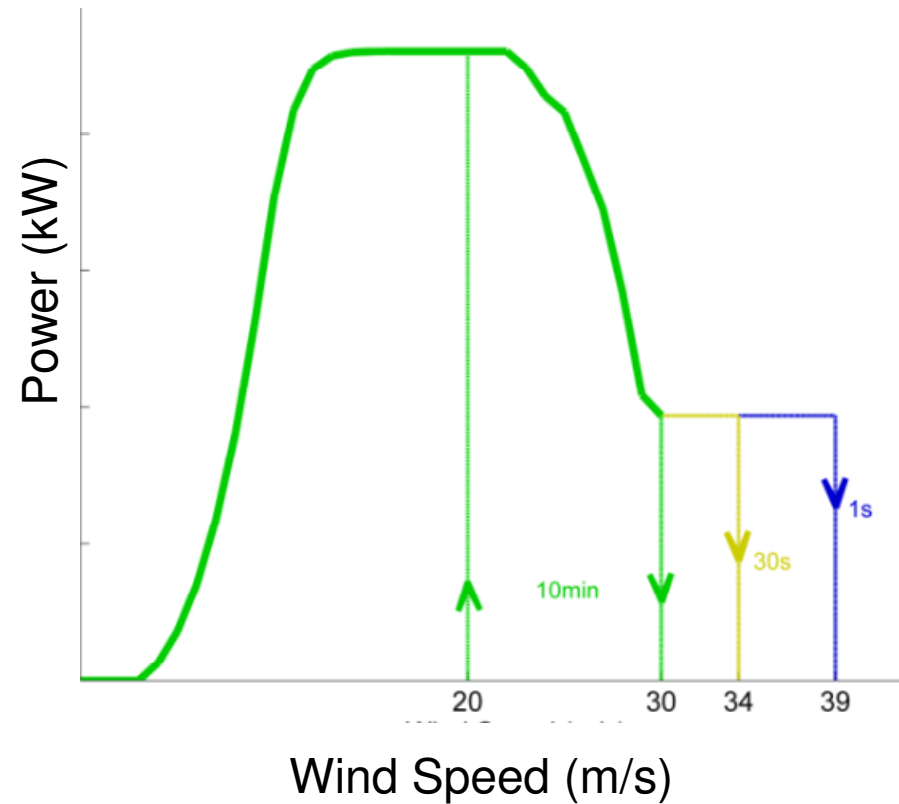
Wind Turbine Controls



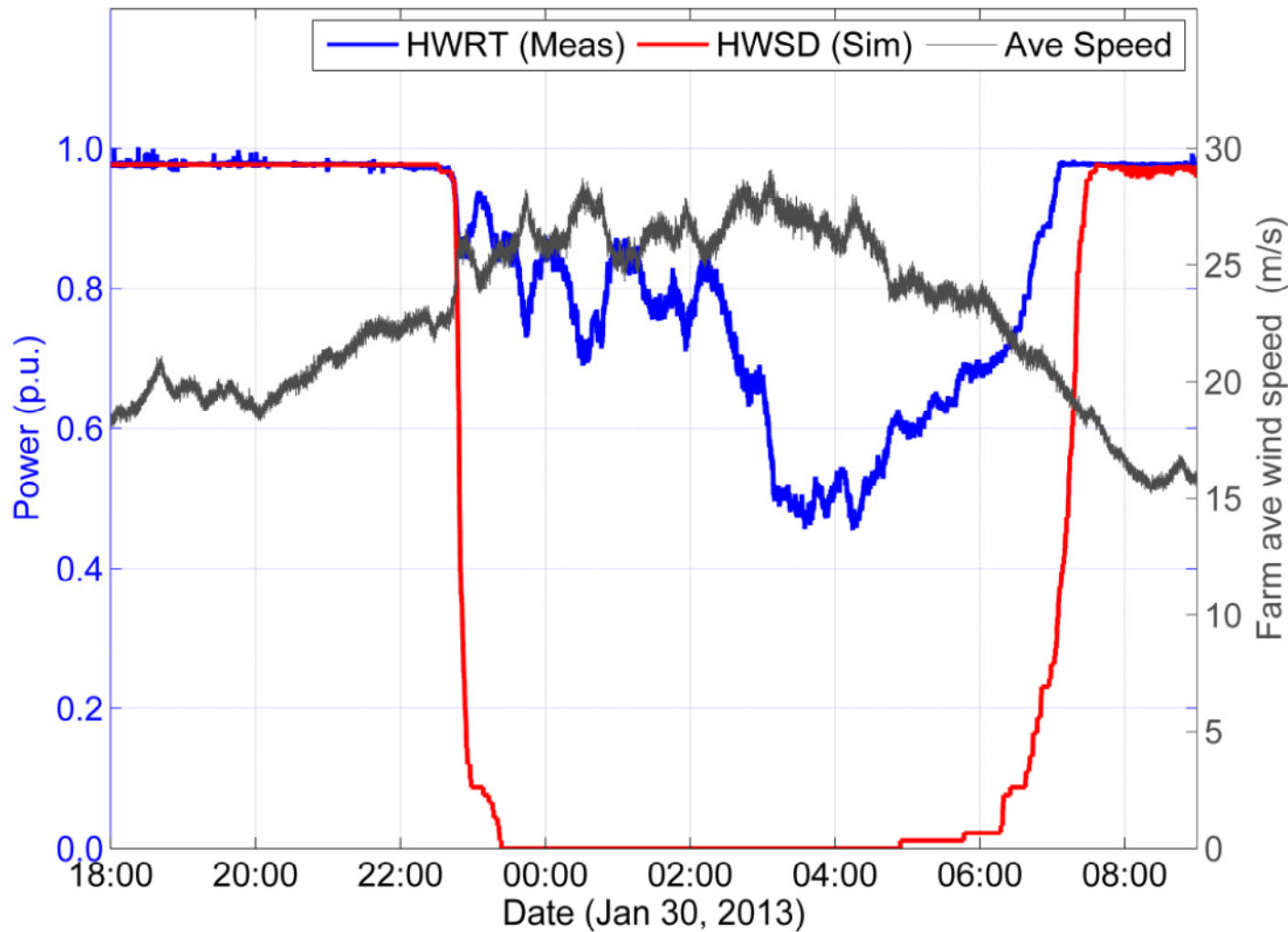
High Wind Shutdown



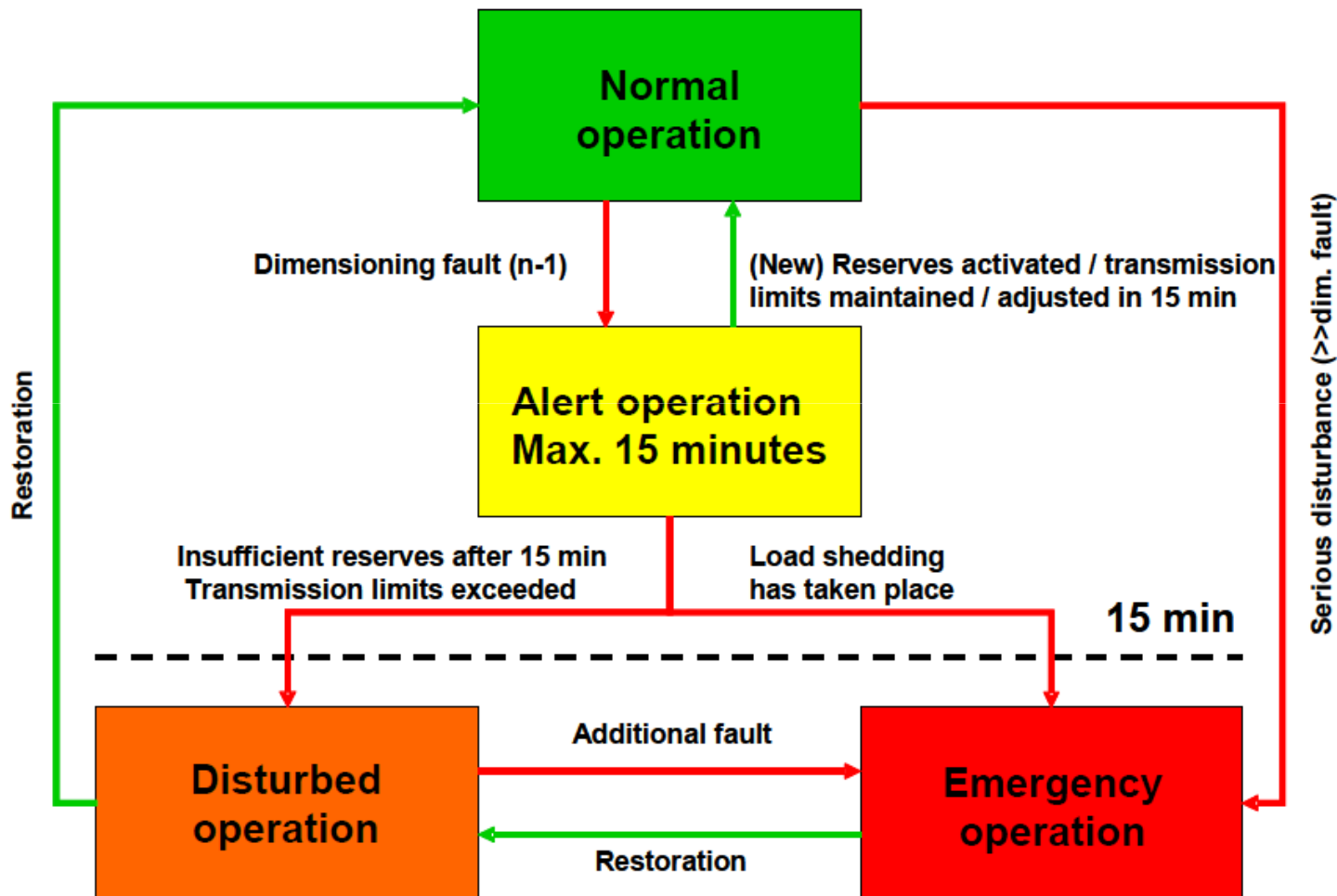
High Wind Ride Through



Horns Rev 2 – 30th January 2013



Primary Reserve Adequacy



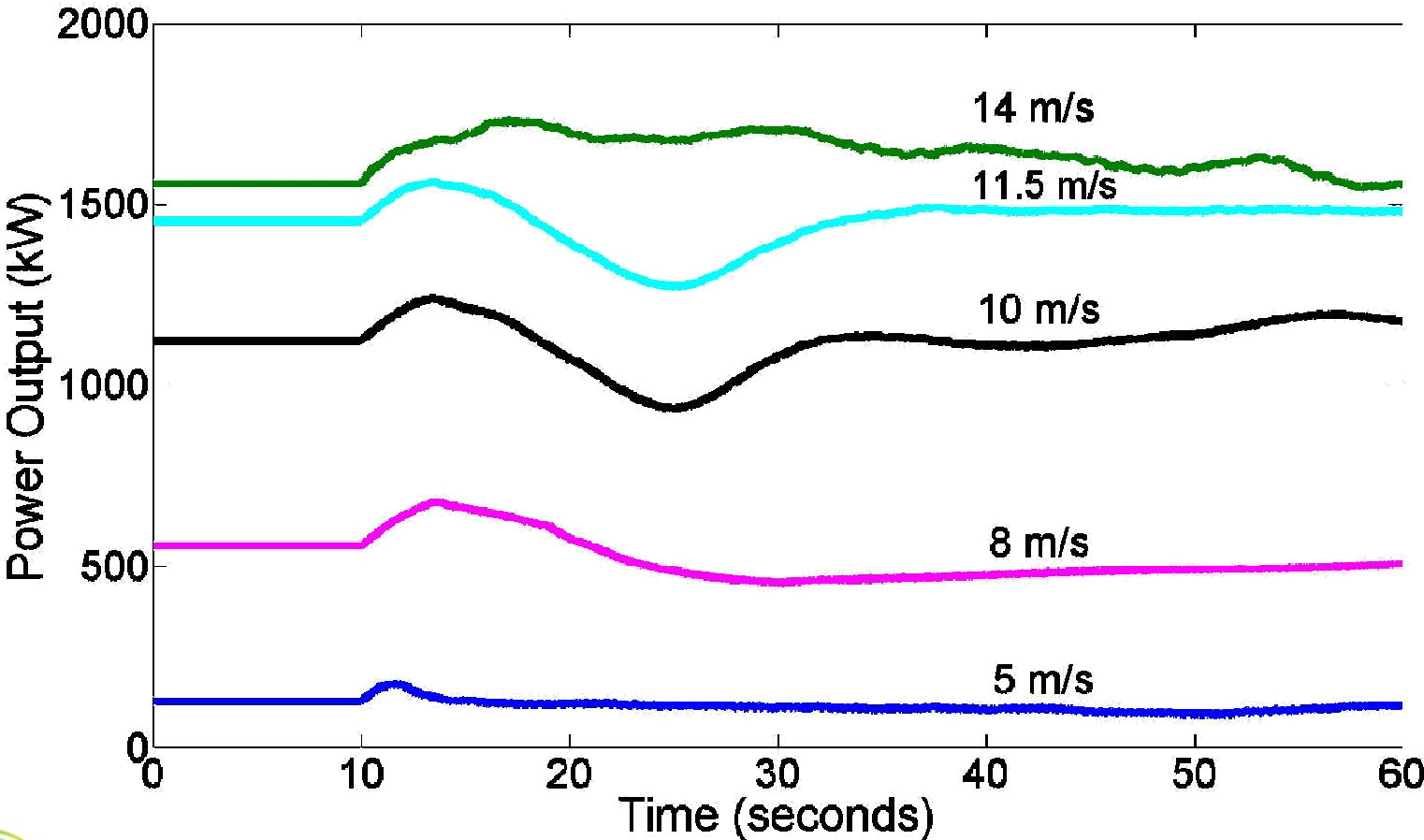
Primary Reserve Requirements



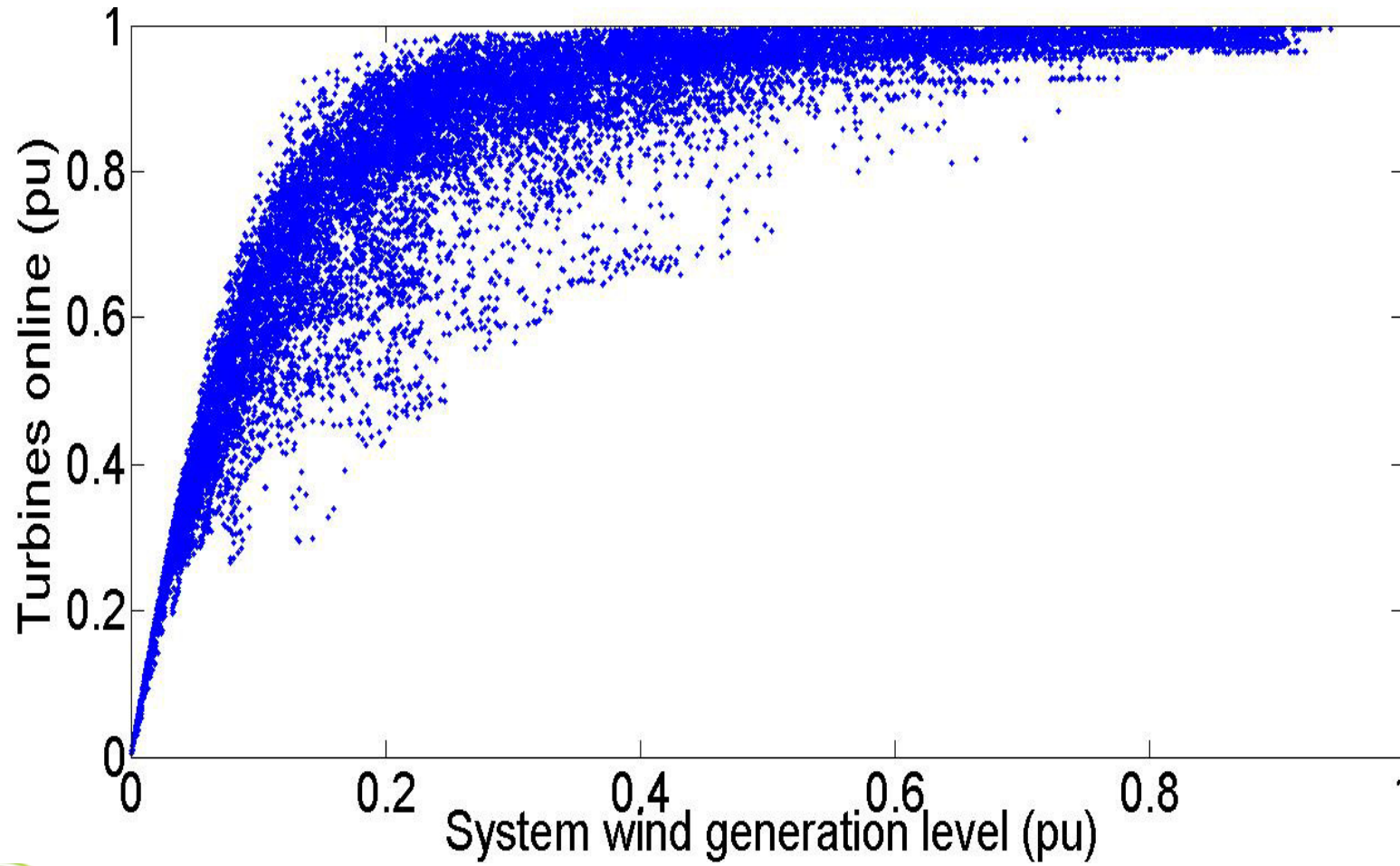
Synchronous Area	High Wind Shutdown	High Wind Ride Through	Dimensioning Fault
2020	MW	MW	MW
Continental	1,661	1,548	3,000
Nordic	480	483	1,200
GB	1,212	1,222	1,800
Ireland	224	224	500

Synchronous Area	High Wind Shutdown	High Wind Ride Through	Dimensioning Fault
2030	MW	MW	MW
Continental	4,729	3,933	3,000
Nordic	1,096	1,082	1,200
GB	4,418	4,440	1,800
Ireland	439	438	500

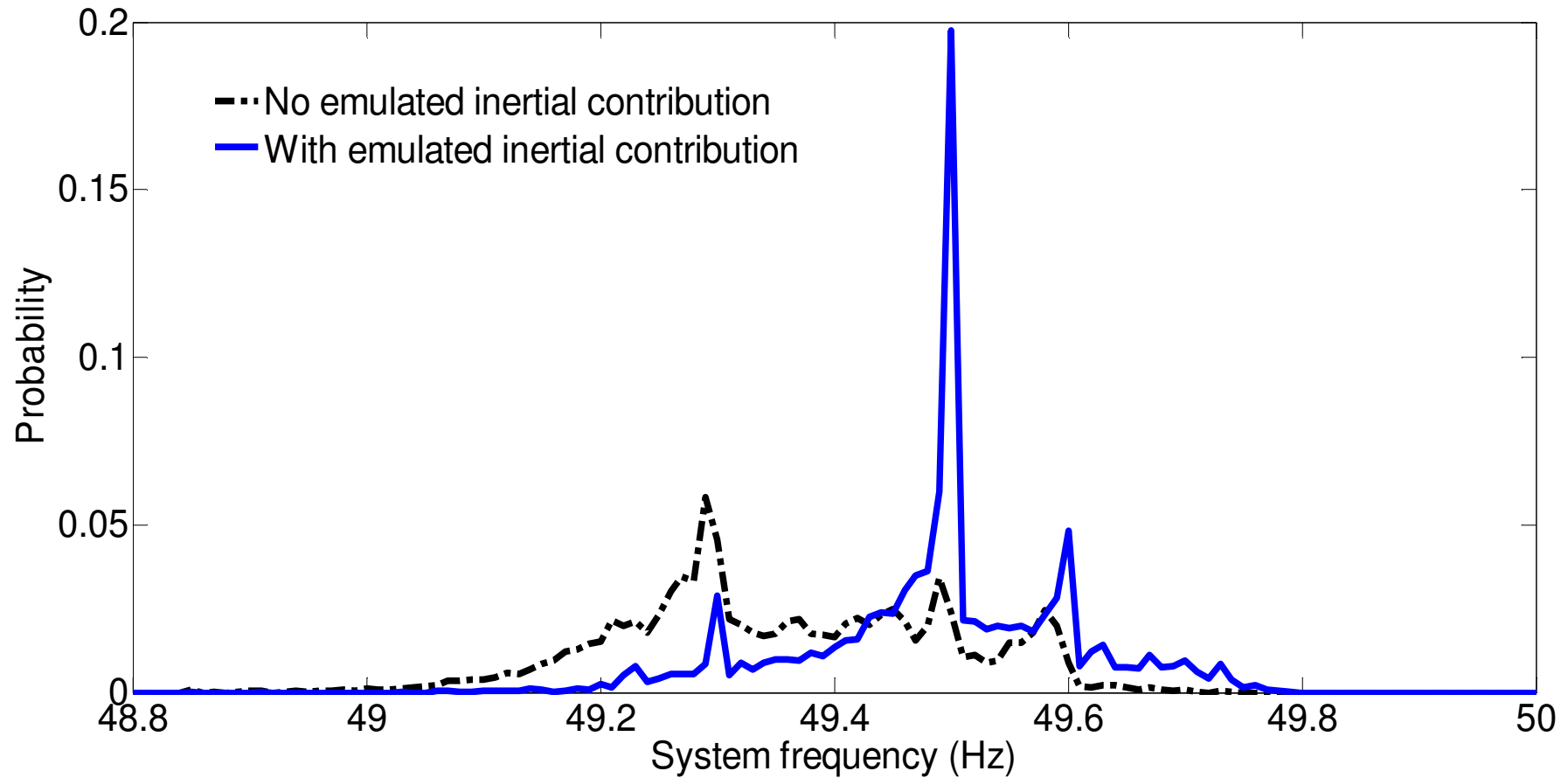
Wind Turbine Controls



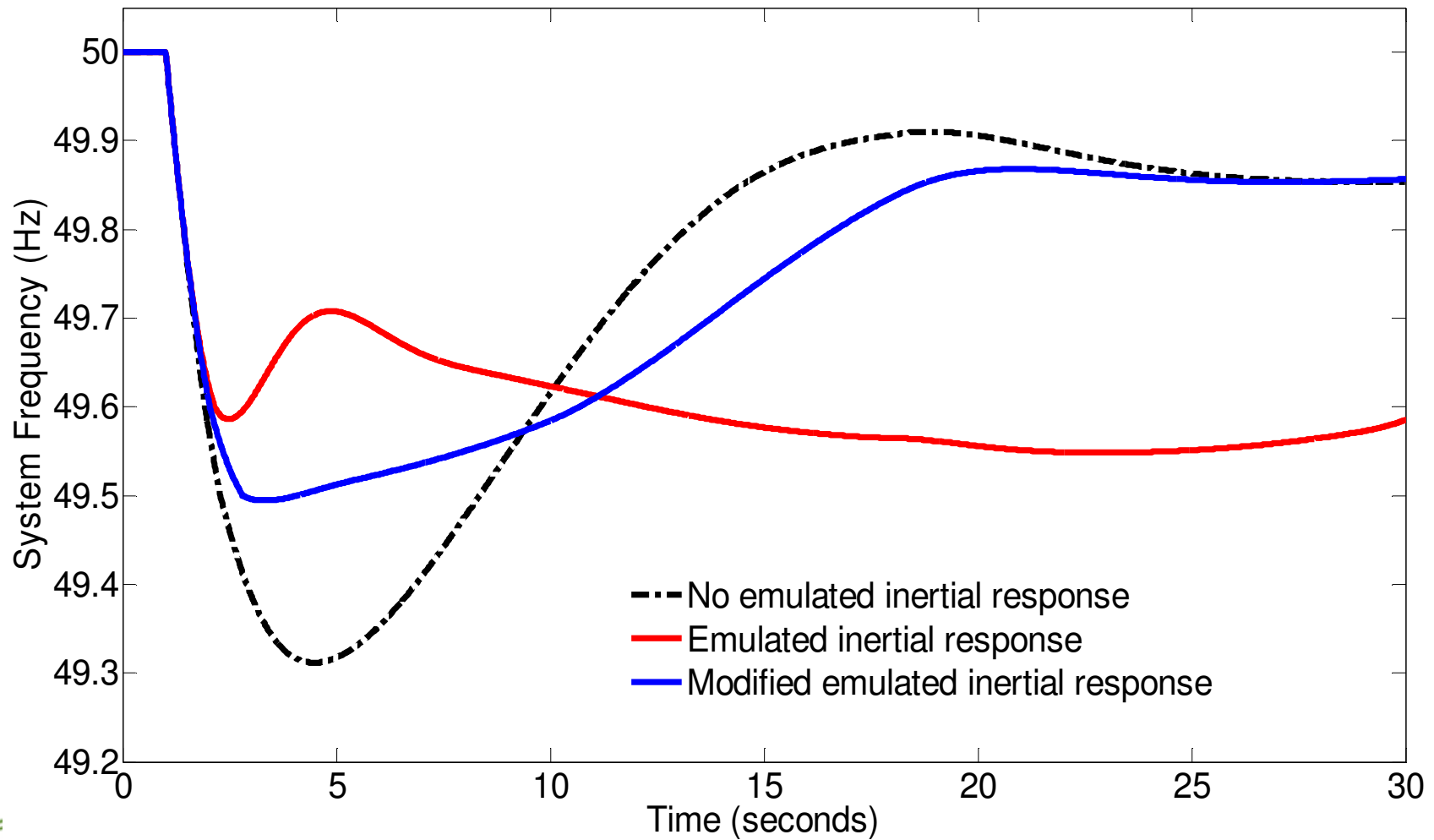
Turbines Online



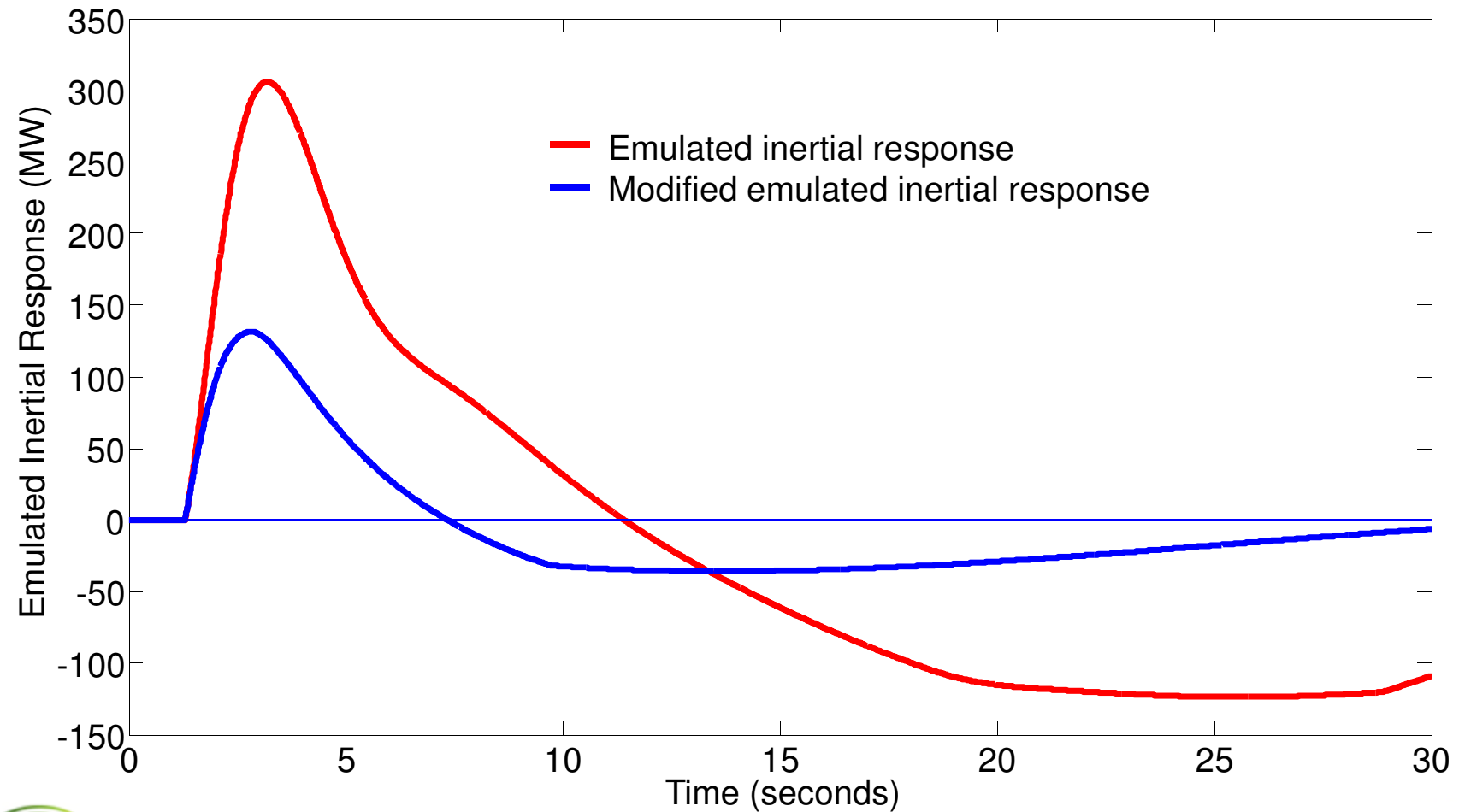
Ireland - Frequency Nadir 2020



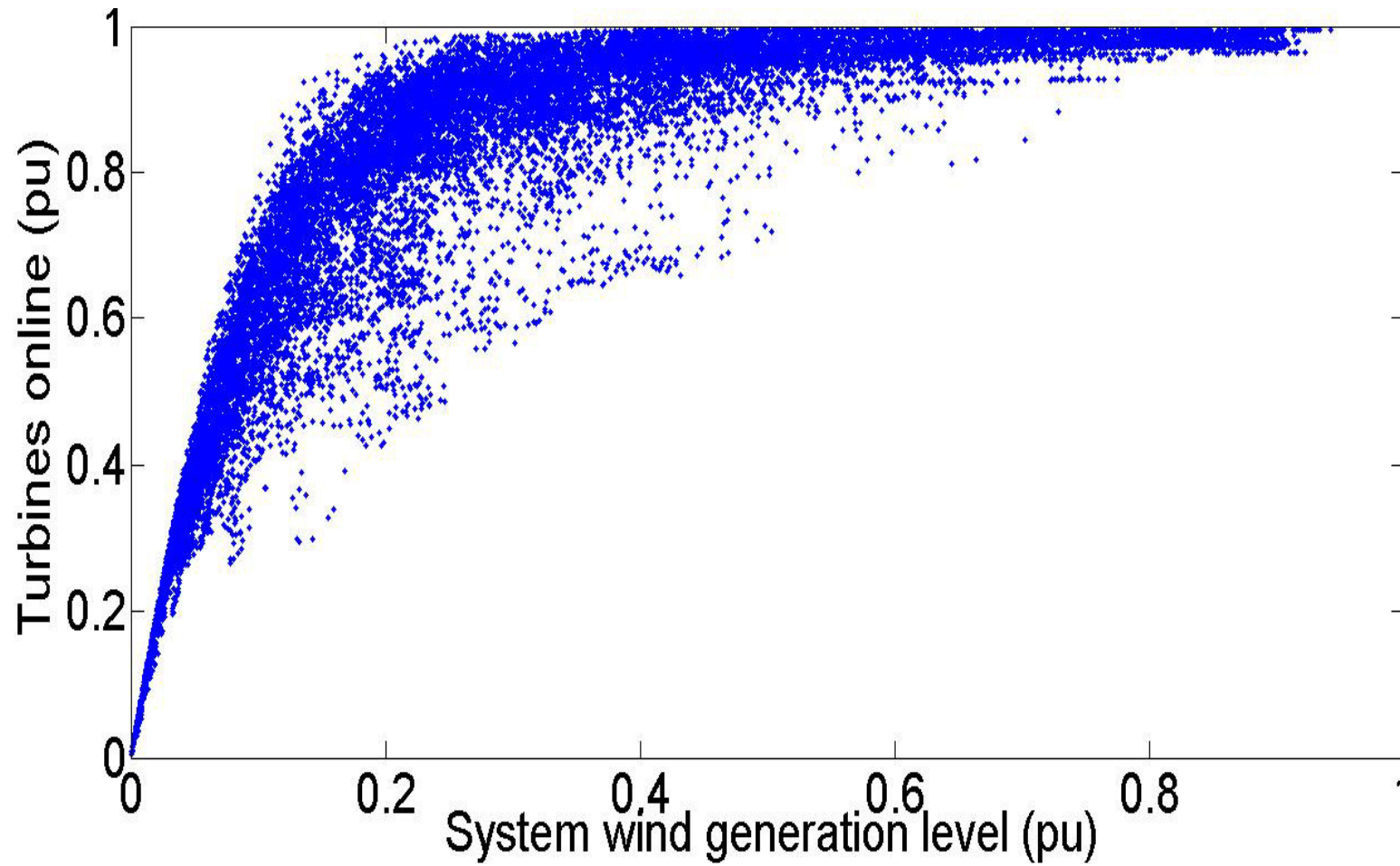
Response Tuning



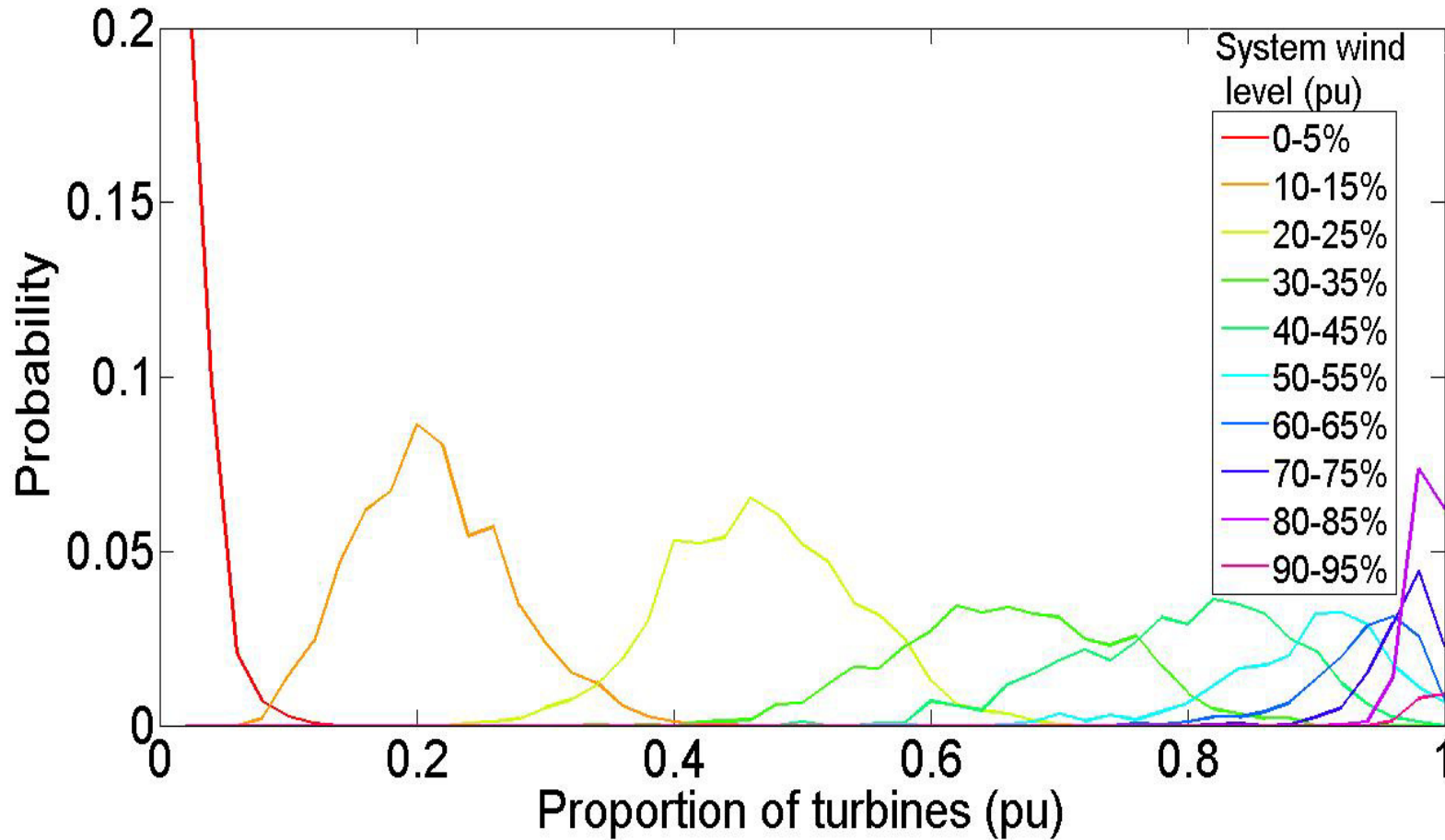
Modified Inertial Response



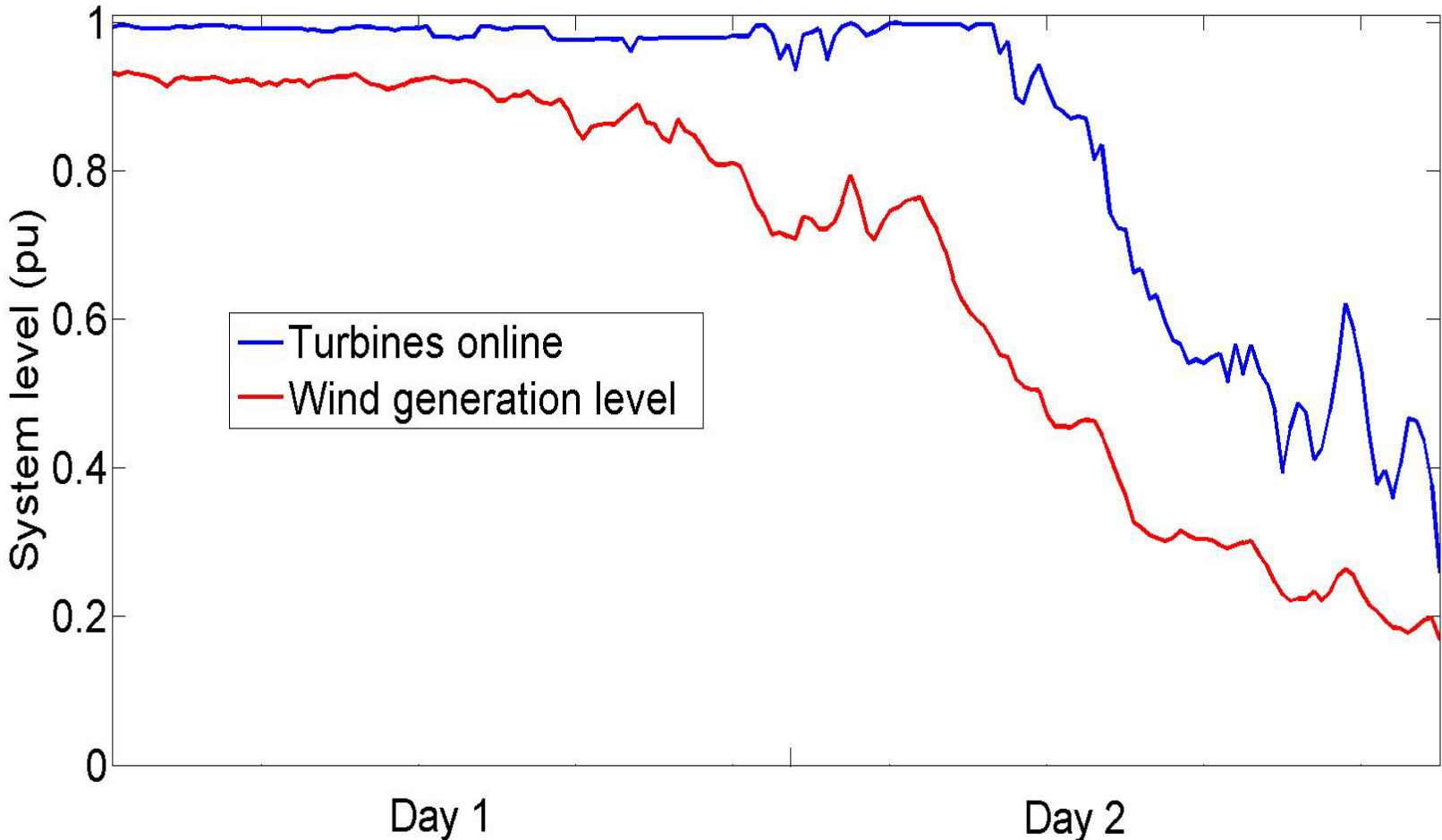
Turbines Online



Turbine Distribution

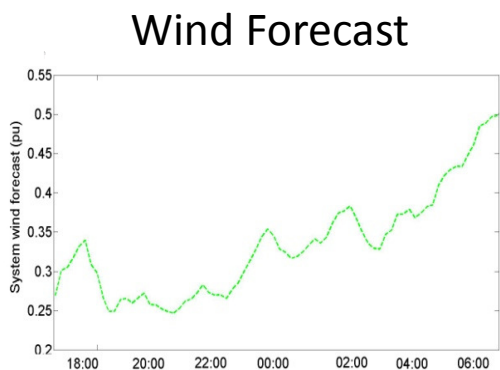


Resource Forecast

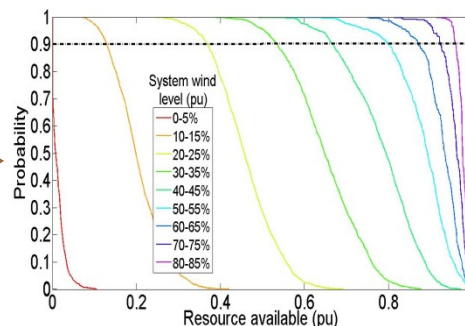


Resource Estimation

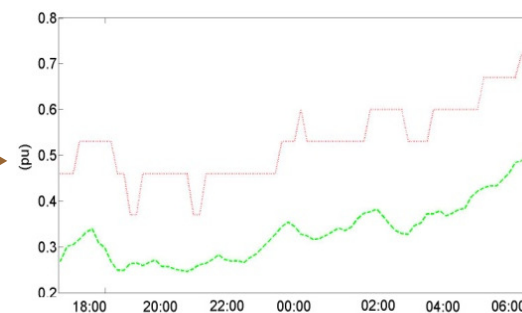
Unit
Commitment
Time Frame



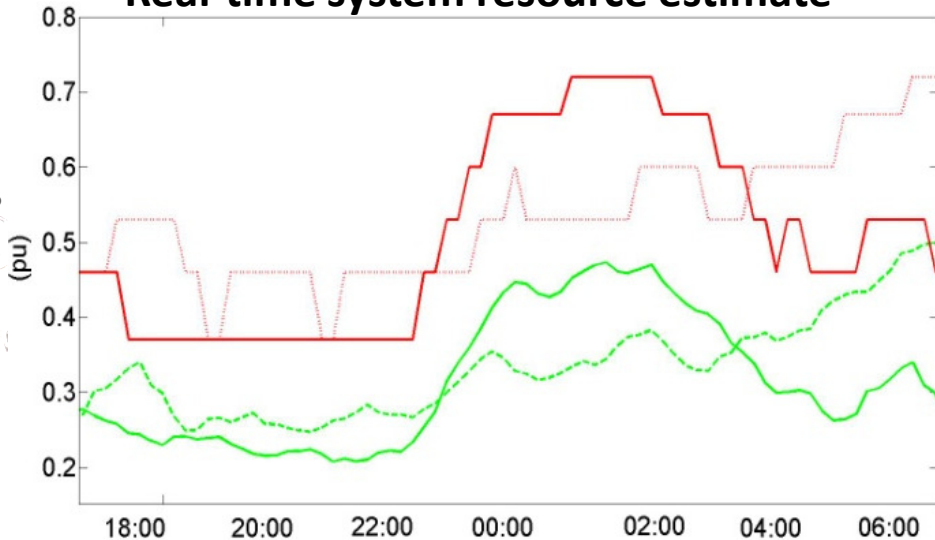
Statistical analysis



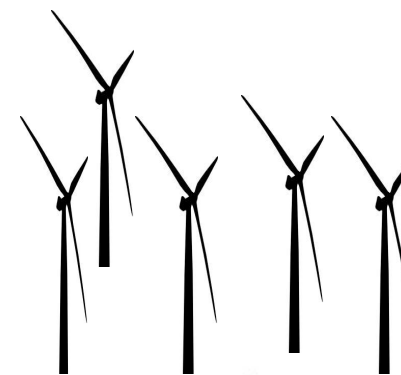
Resource estimate for UC



Real-time system resource estimate



Updated forecasts/
real-time wind data



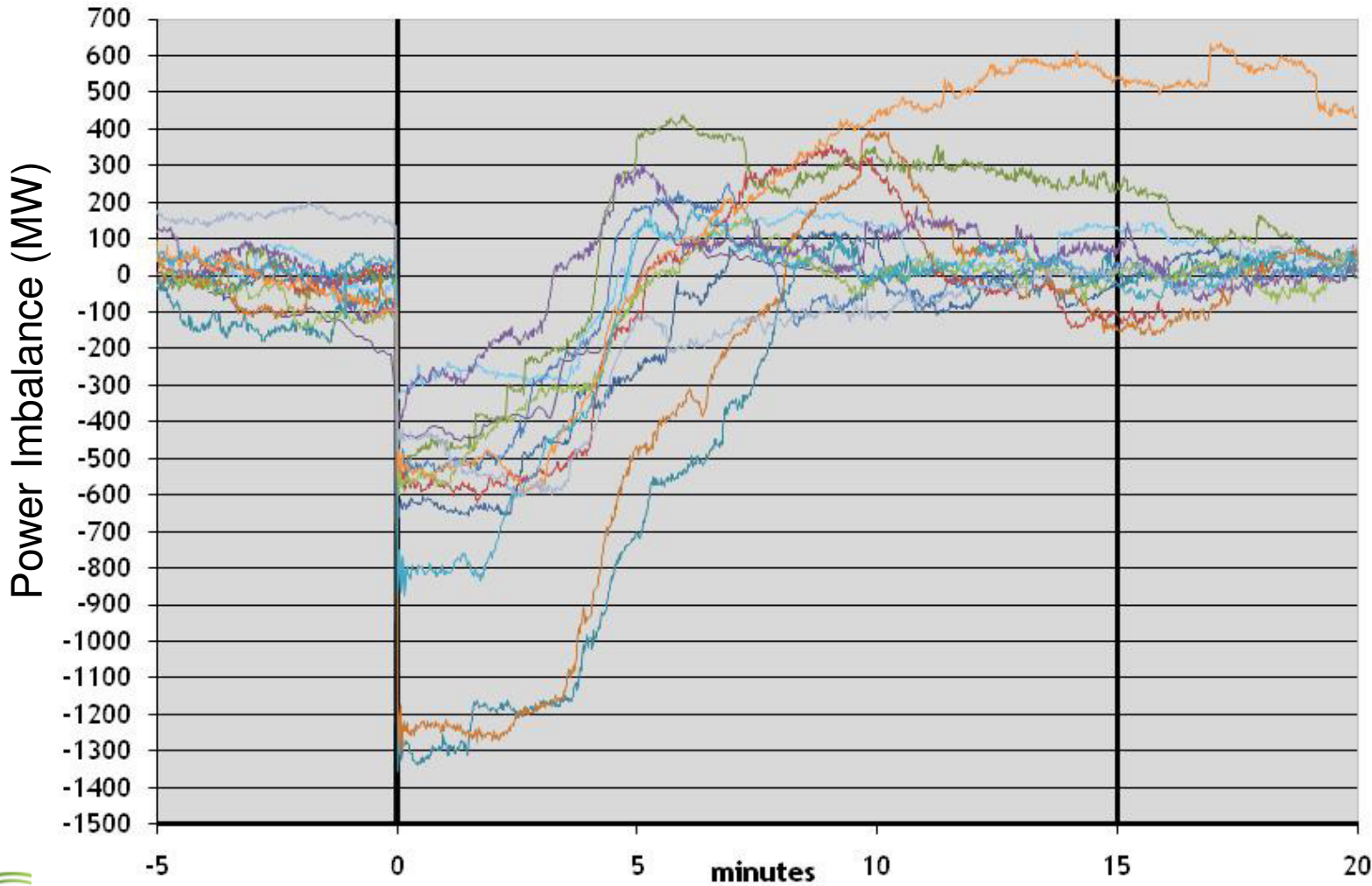
Real - Time



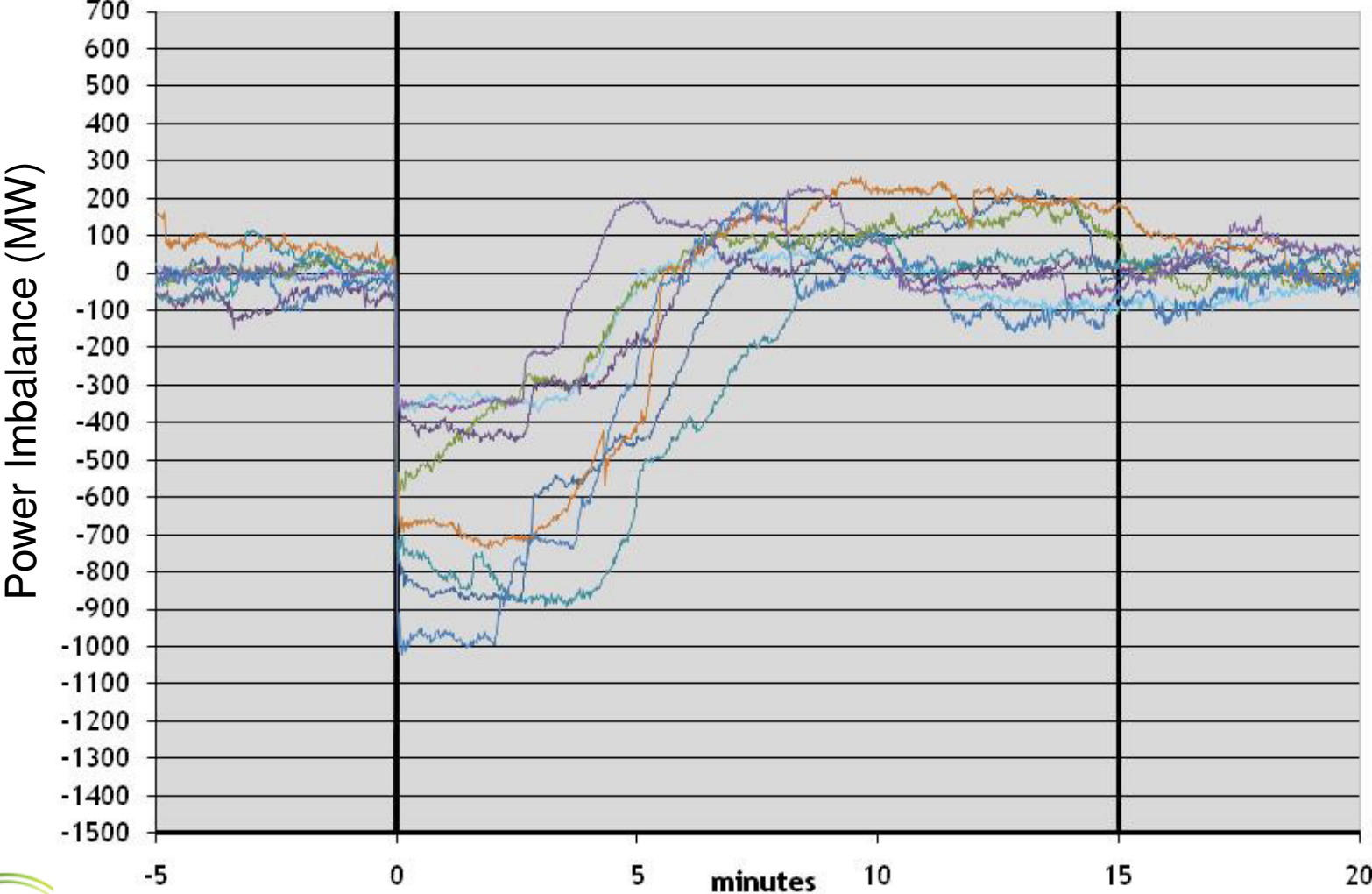


Large Scale Wind Integration: Fault Ride Through Capability

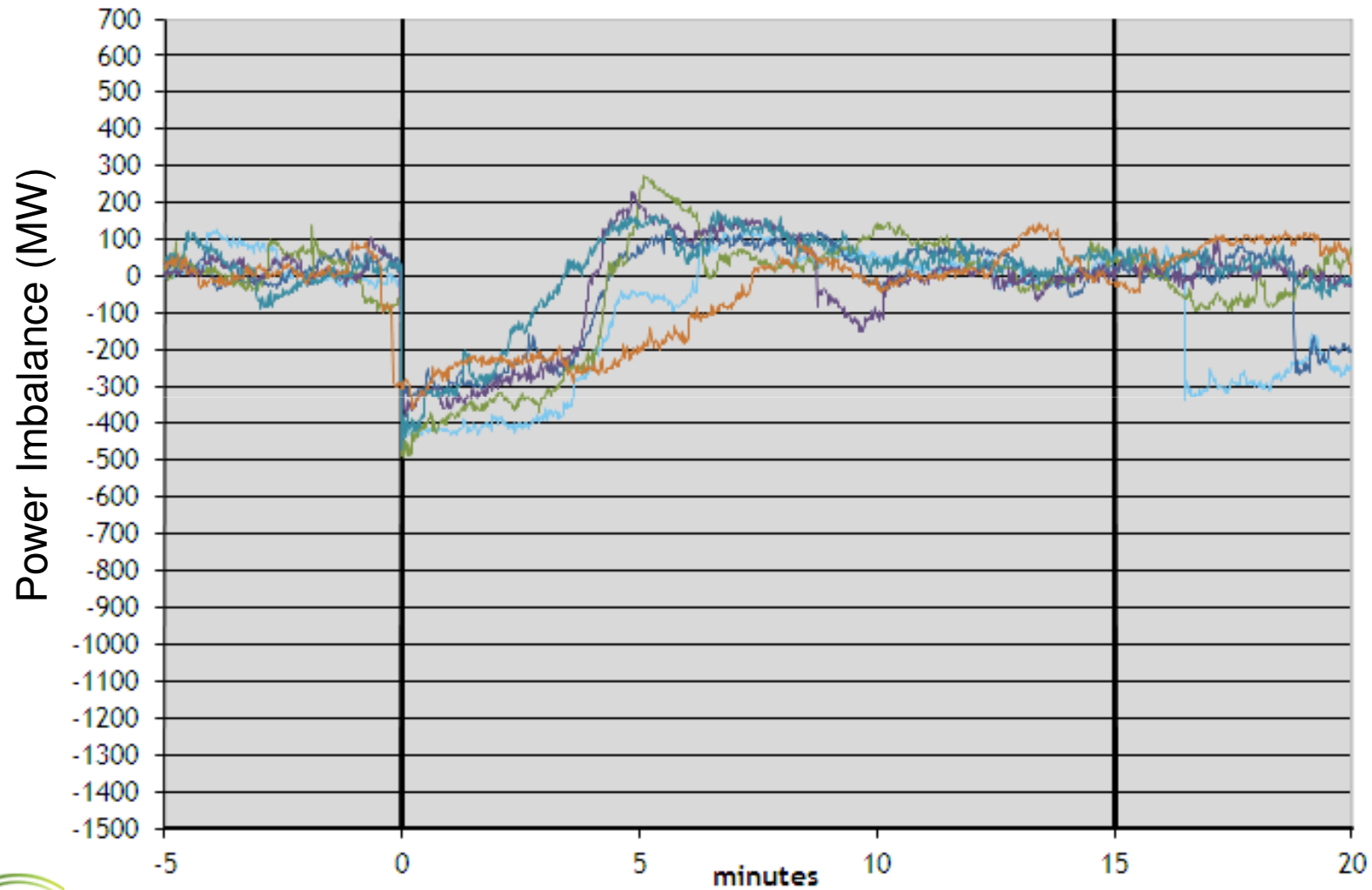
Portugal – Wind Generation Trips (2009)



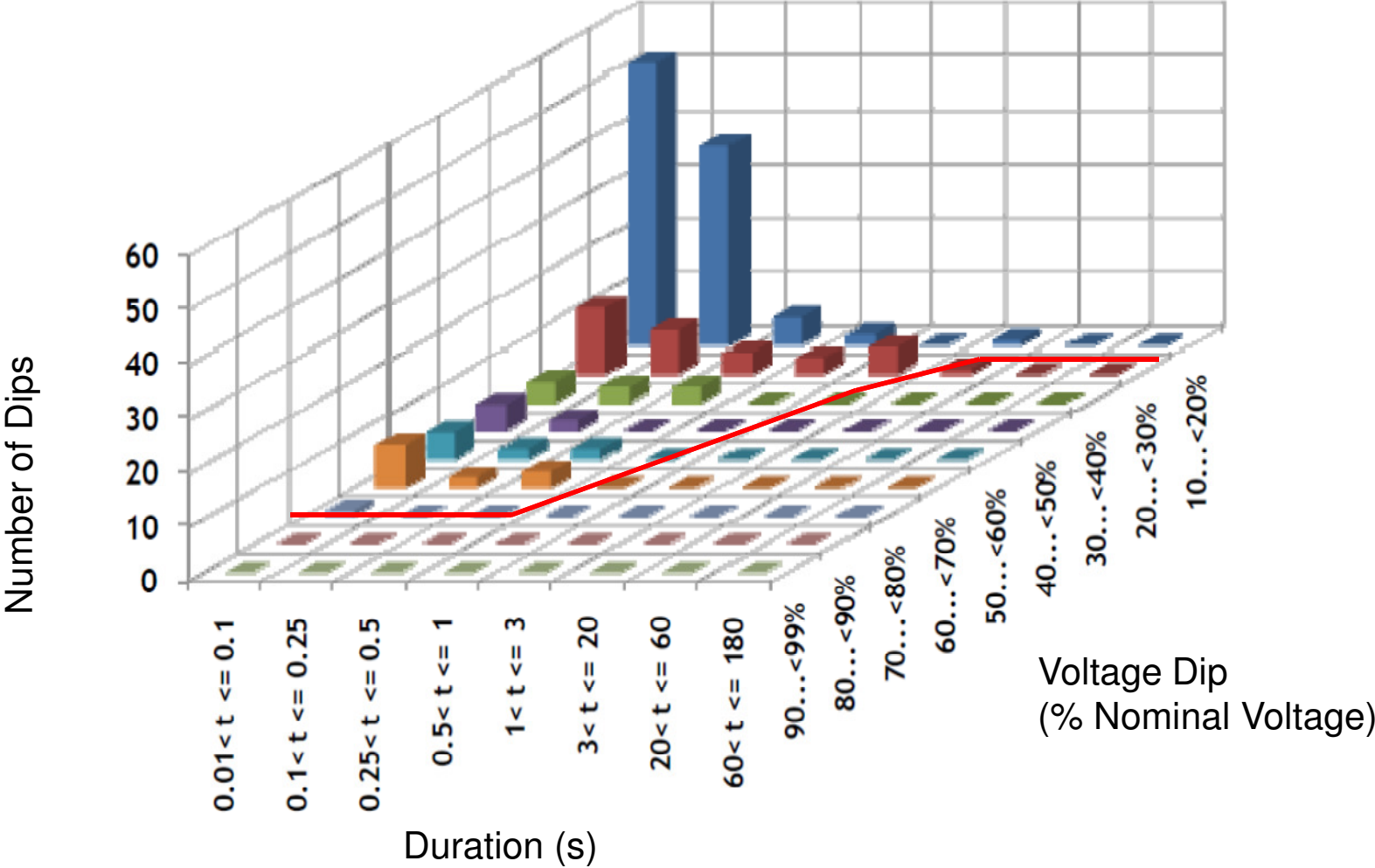
Portugal – Wind Generation Trips (2010)



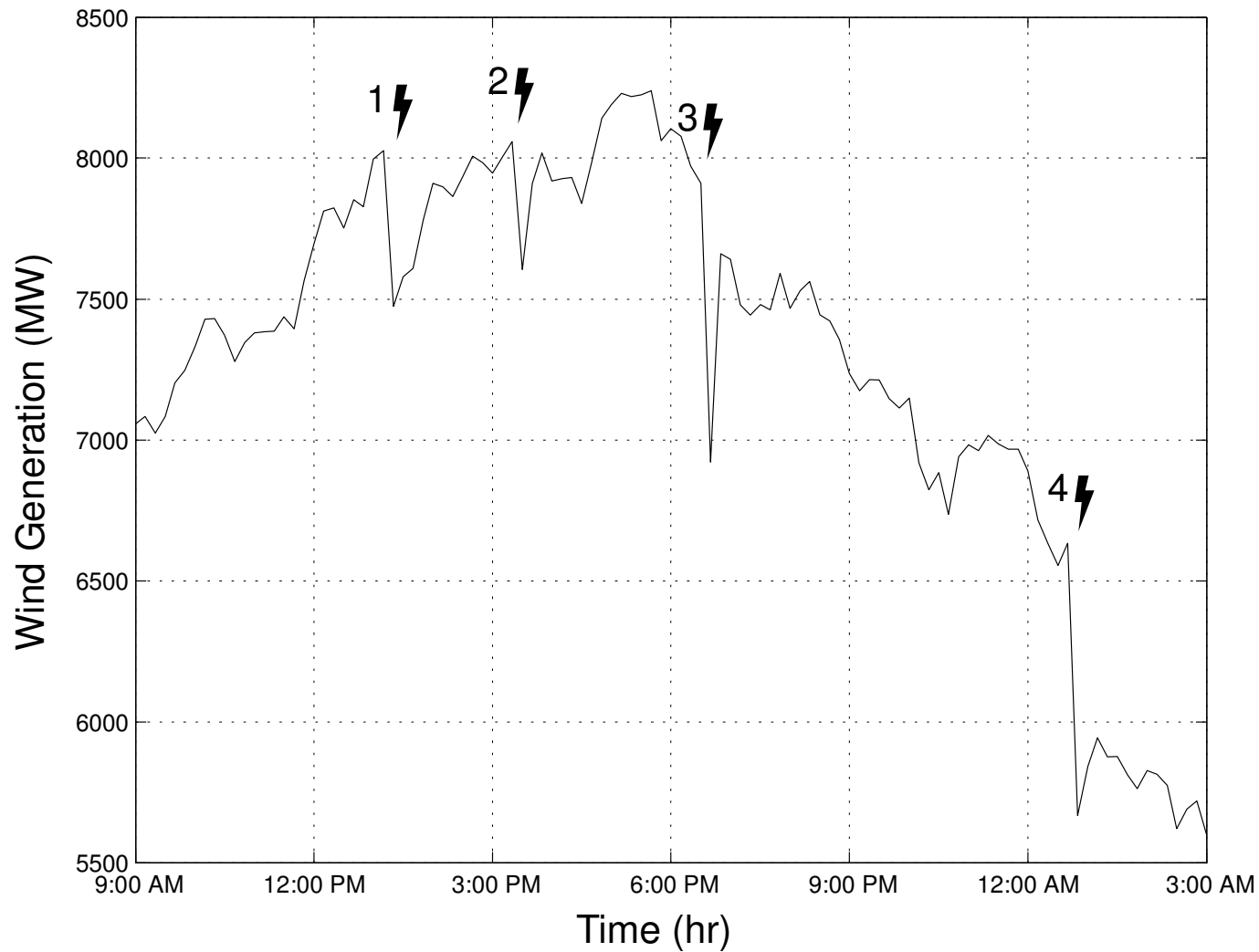
Portugal – Wind Generation Trips (2011)



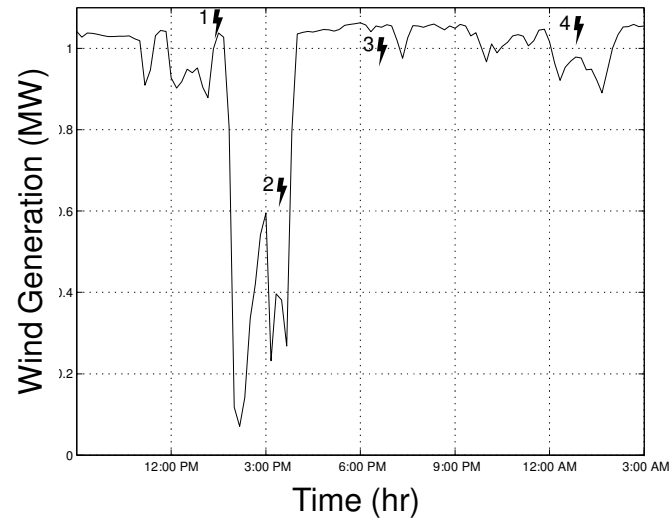
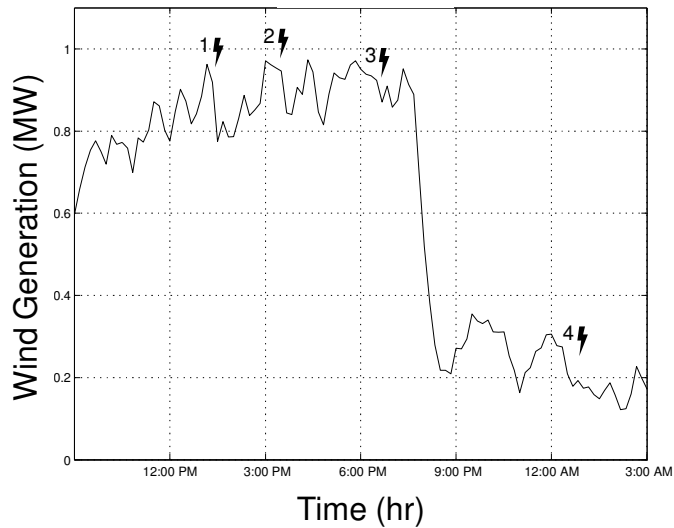
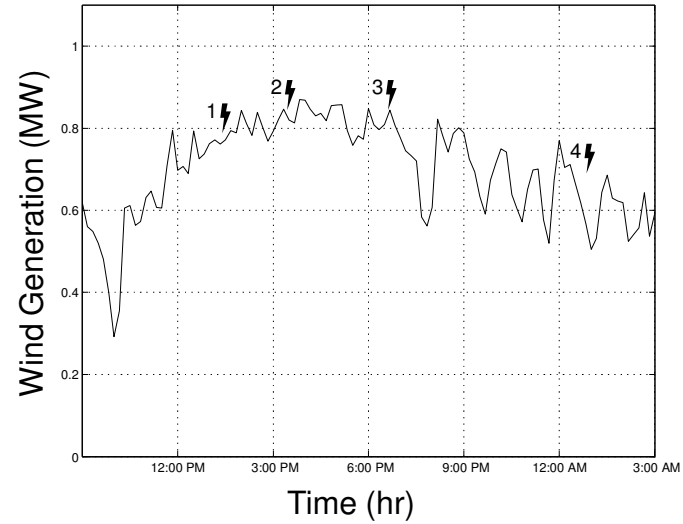
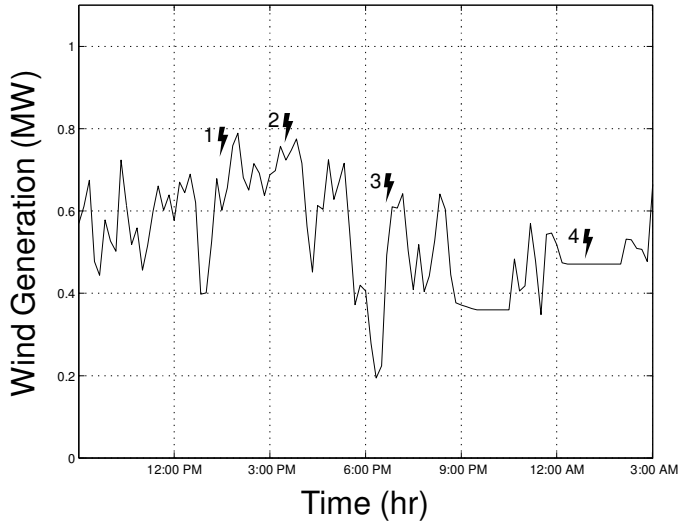
Portugal - Fault Ride Through



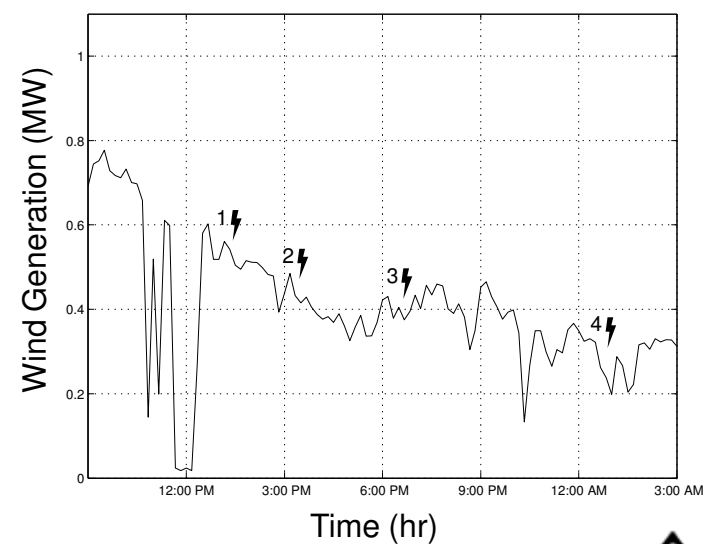
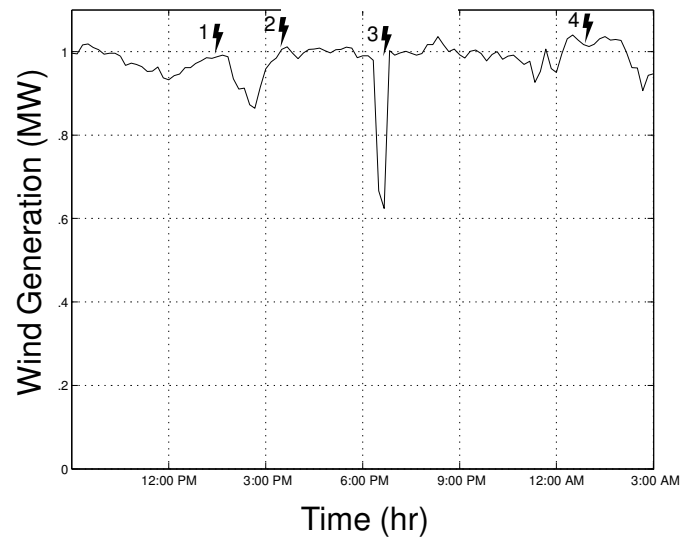
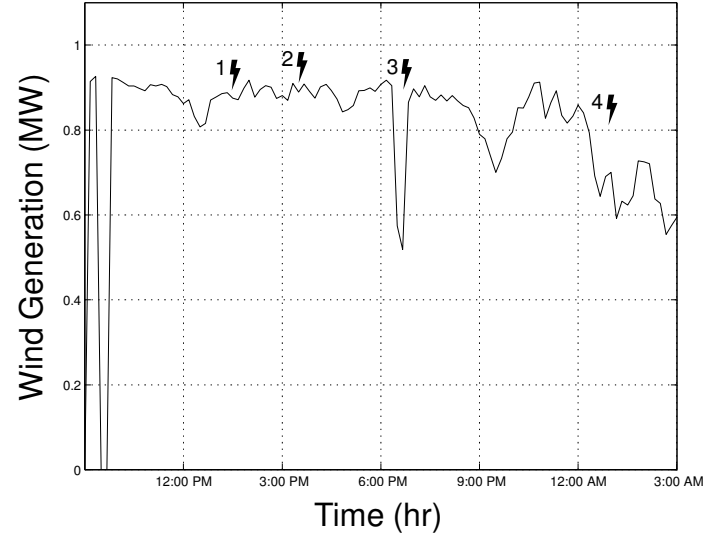
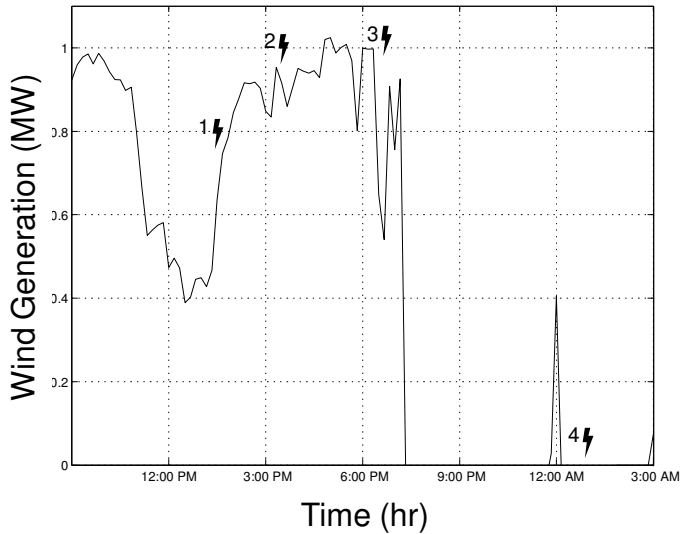
Spain – 19th-20th March 2007



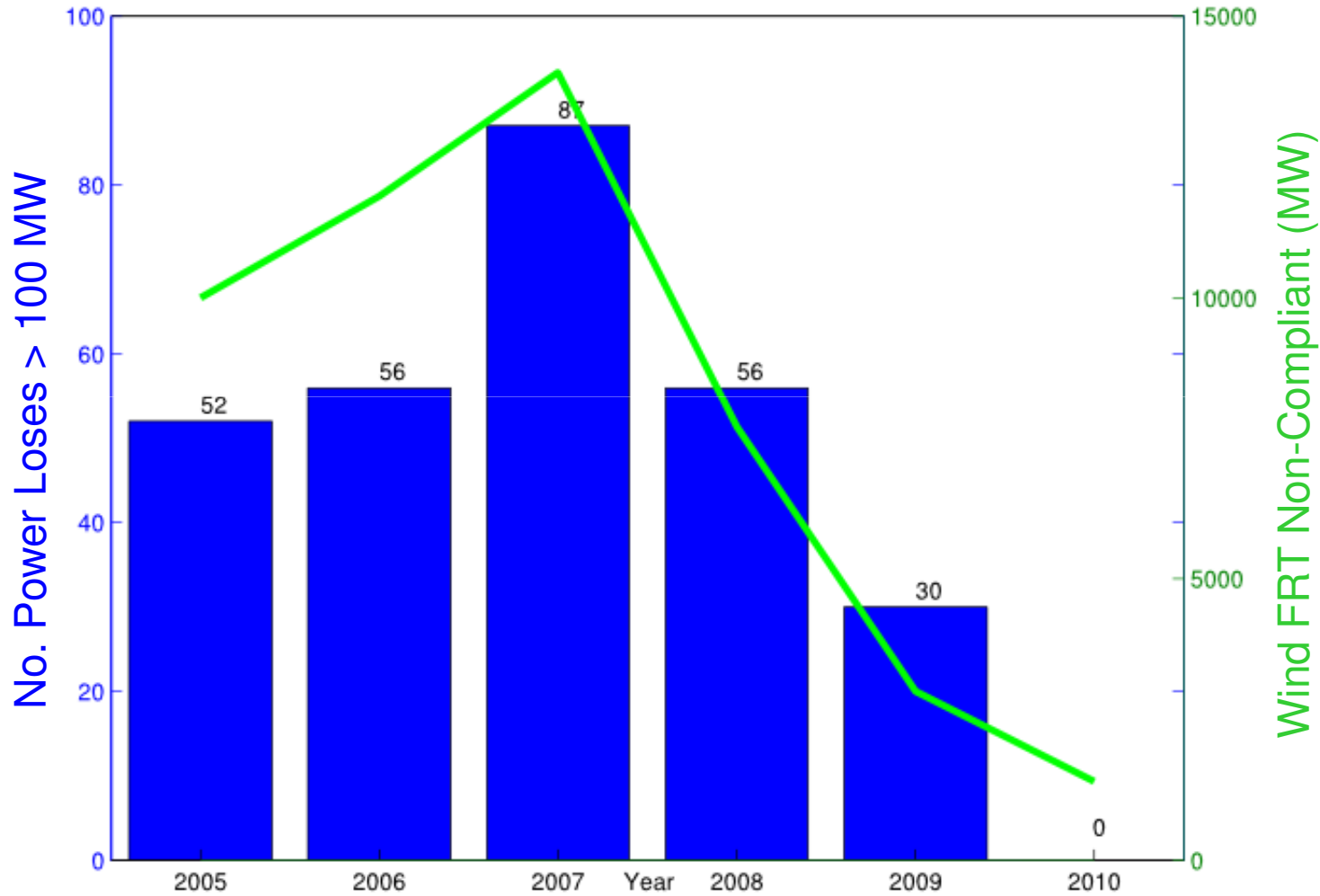
Spain – Individual Wind Farms



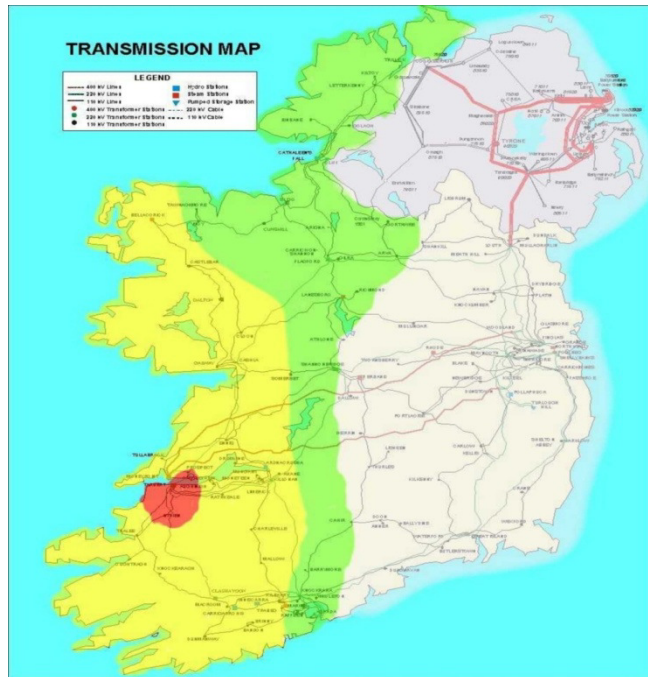
Spain – Individual Wind Farms



Spain – Grid Code Compliance

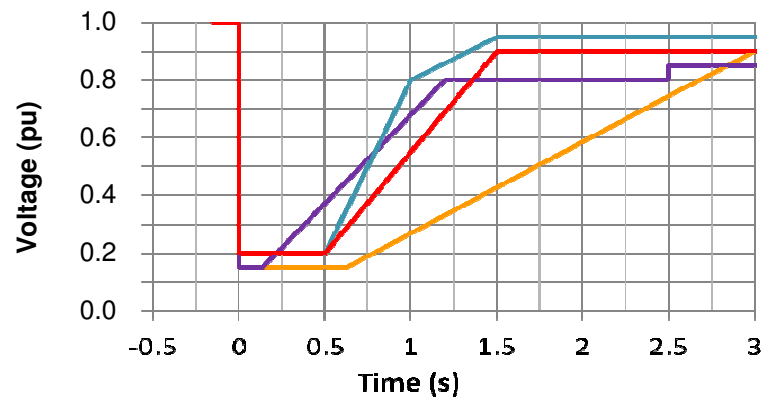
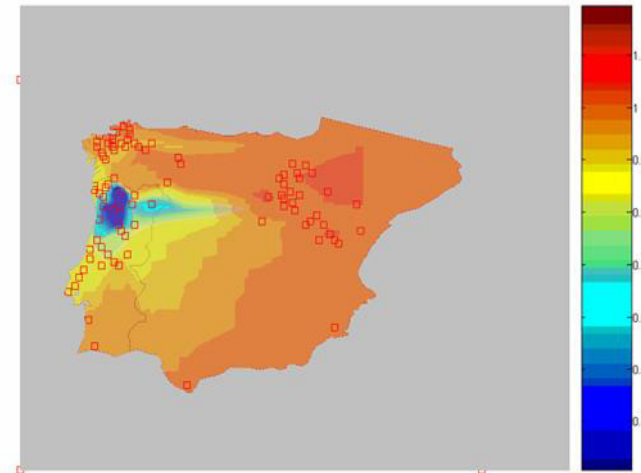


Voltage Dip-Induced Frequency Dips

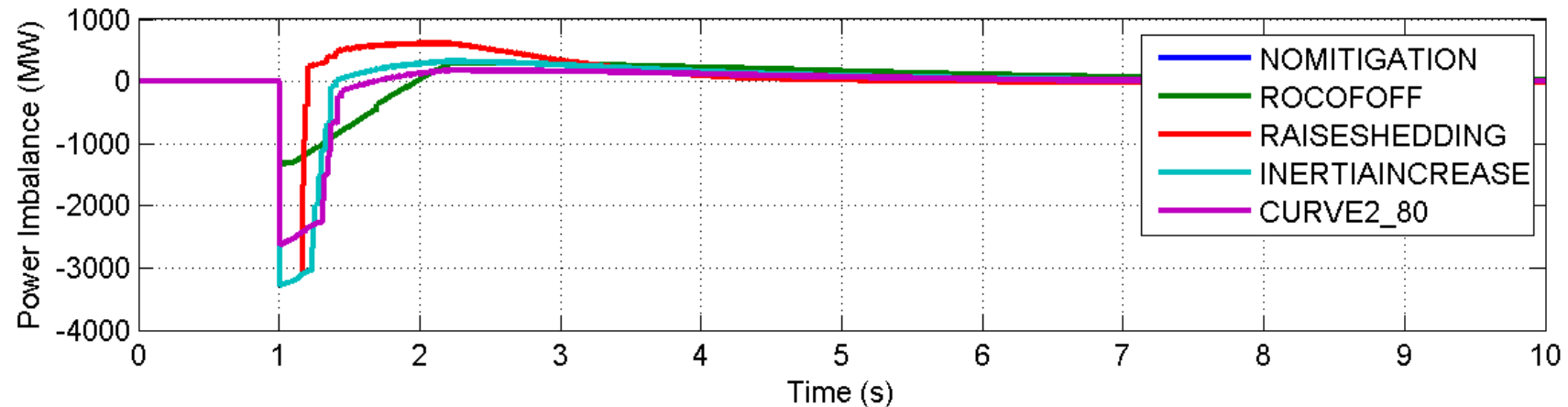
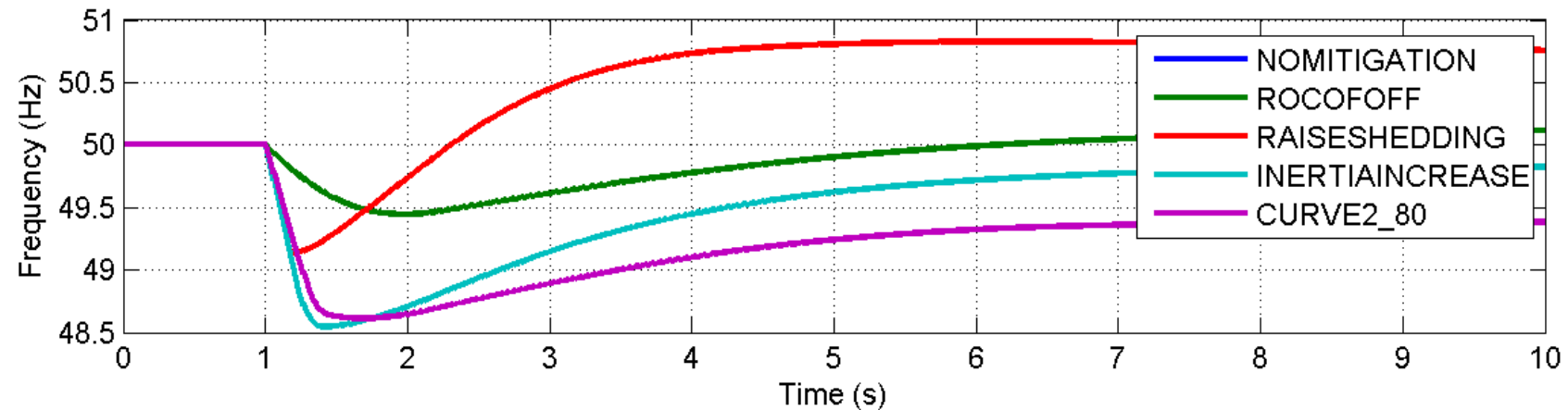


Voltage Profile

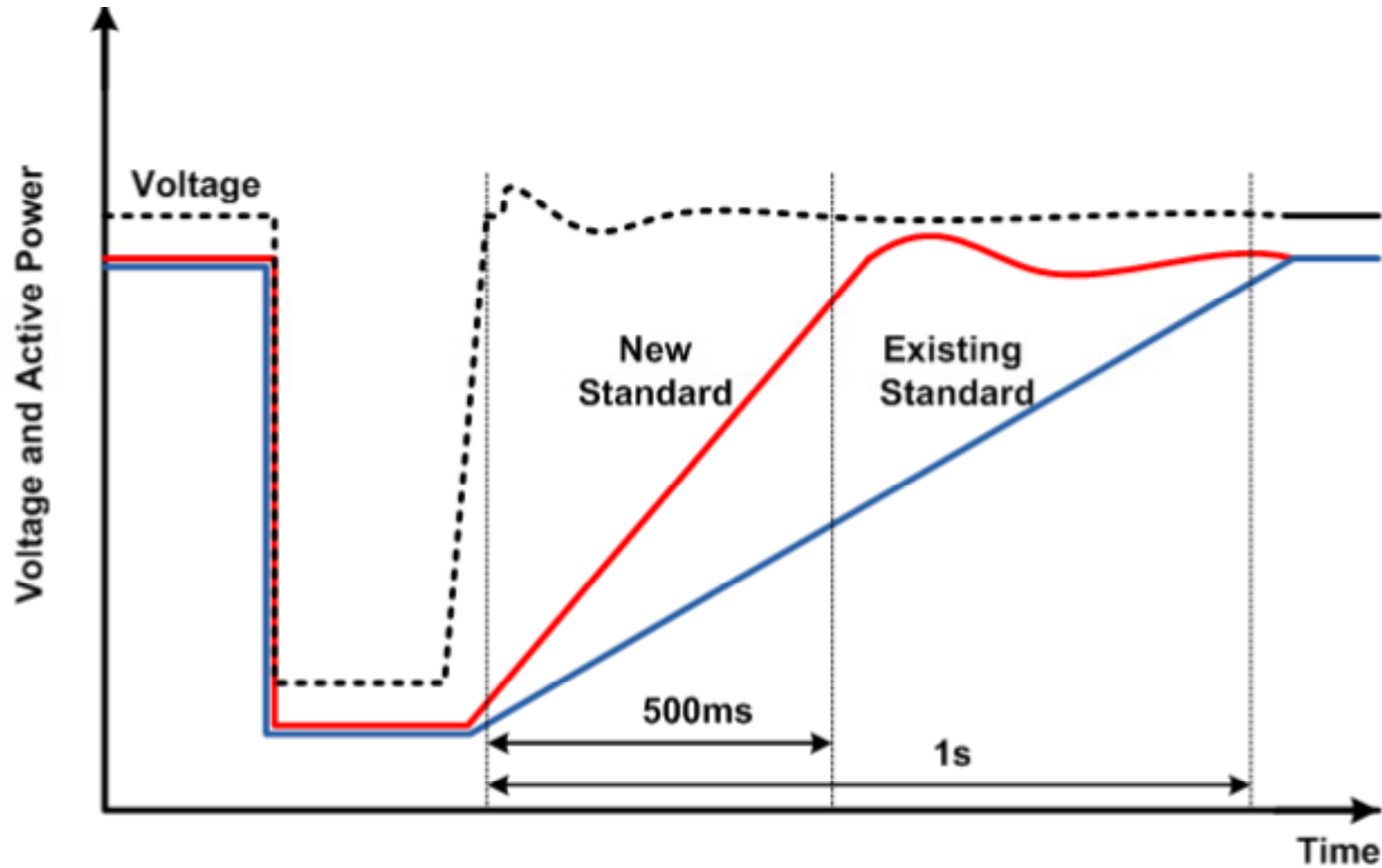
- Red < 15 %
- Yellow 15 – 50 %
- Green 50 – 80 %



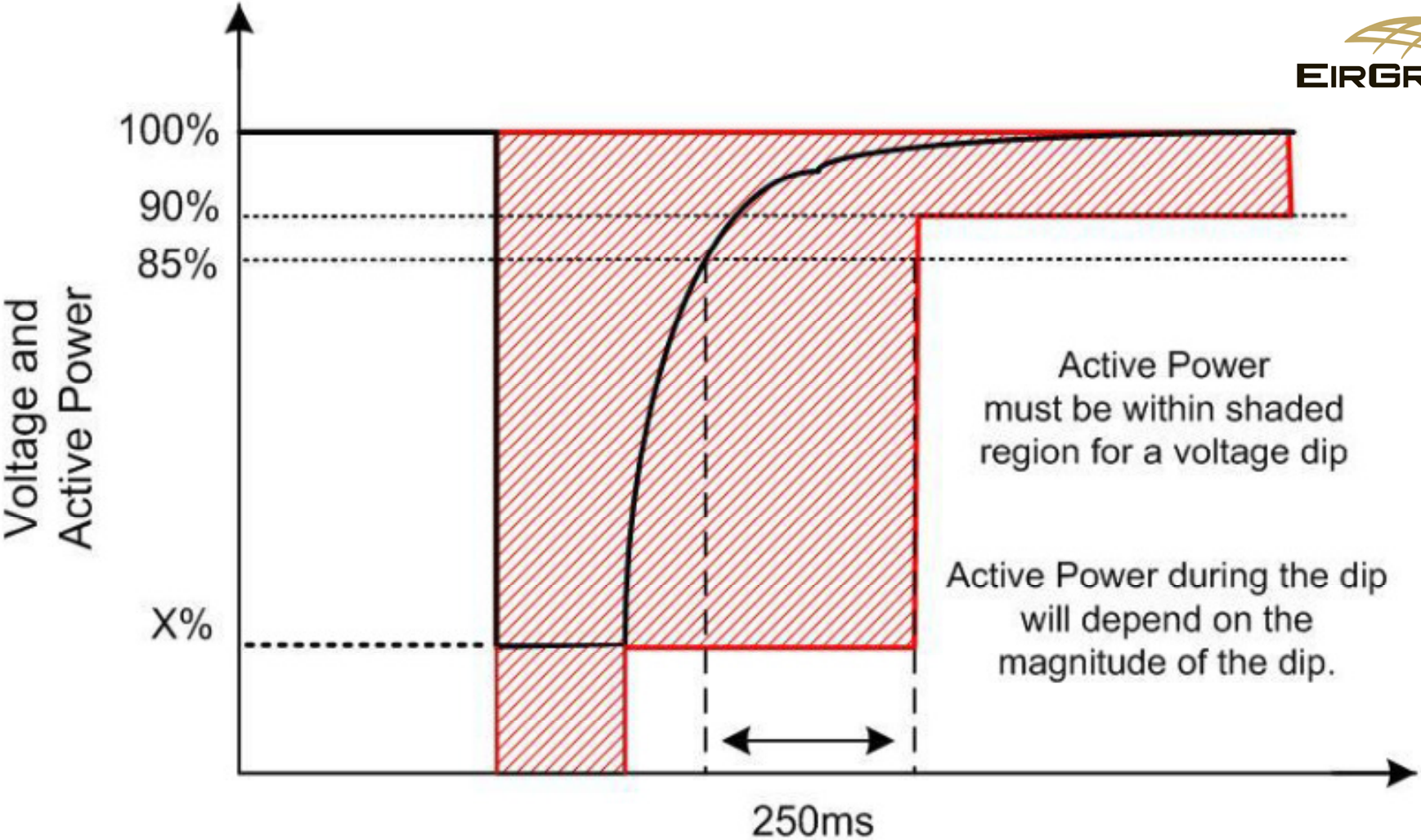
Voltage Dip-Induced Frequency Dips



Post-Fault Active Power Recovery



Fast Post-Fault Active Power Recovery



Concluding Comments

- Trade-off with transmission planning and operational policies requires multiple studies
- Accurate assessment requires validated wind turbine models + proposal of control strategies
 - Verification of conventional generation capabilities + dynamic load representation
- Relative importance of voltage / transient / small-signal / frequency stability issues system dependent
 - Network topology, underlying plant portfolio including other renewables, e.g. solar, wind turbine types + location, grid code requirements
 - Studies should evolve from "what are my problems?" to "how can I take advantage of my new control options?"

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