Session 2

The Impact of Non-Synchronous Generation on System Inertia

Jon O'Sullivan
Michael Power
Sathees Kumar

The Impact of Non-Synchronous Generation on System Inertia

PROBLEM DESCRIPTION

Jon O’Sullivan

CIGRE

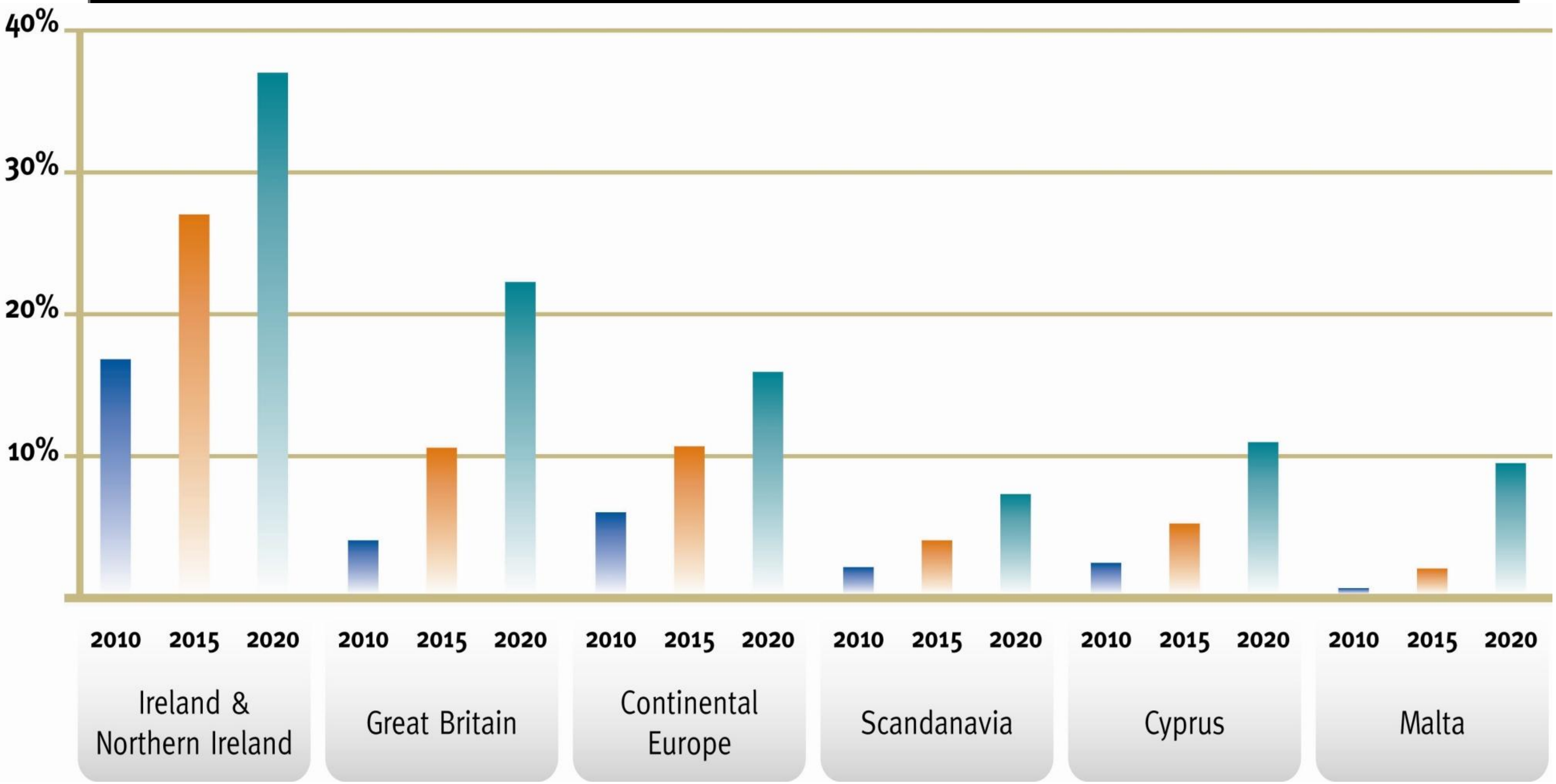
The Need for Frequency Response and Inertia in Power Systems with high RES

Jonathan O'Sullivan,
Manager Sustainable Power Systems,
EirGrid

European Targets

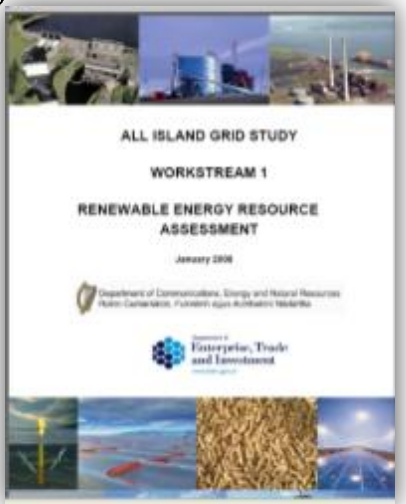
Ireland has ambitious targets for renewables, particularly wind

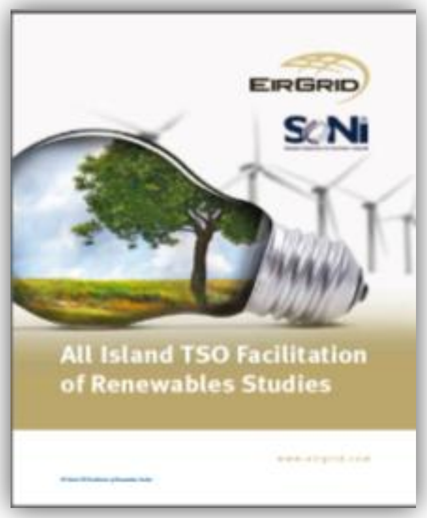
[redacted]

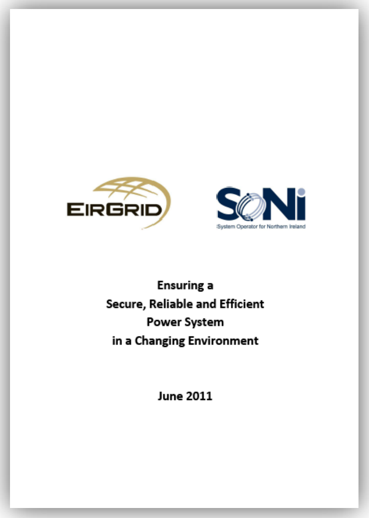


* Based on analysis of National Renewable Action Plans (NREAPs) as submitted by Member States

Technical Analysis



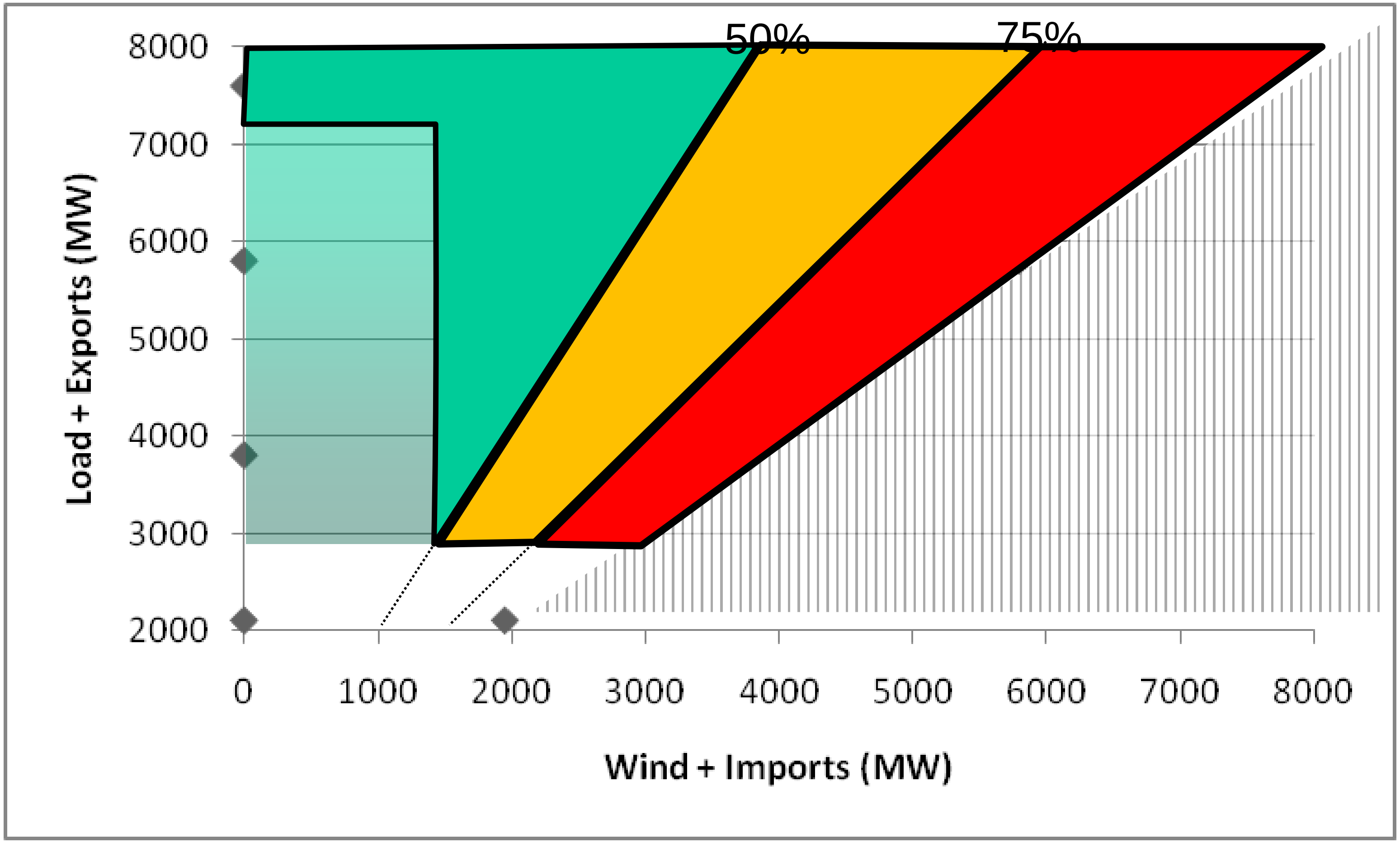




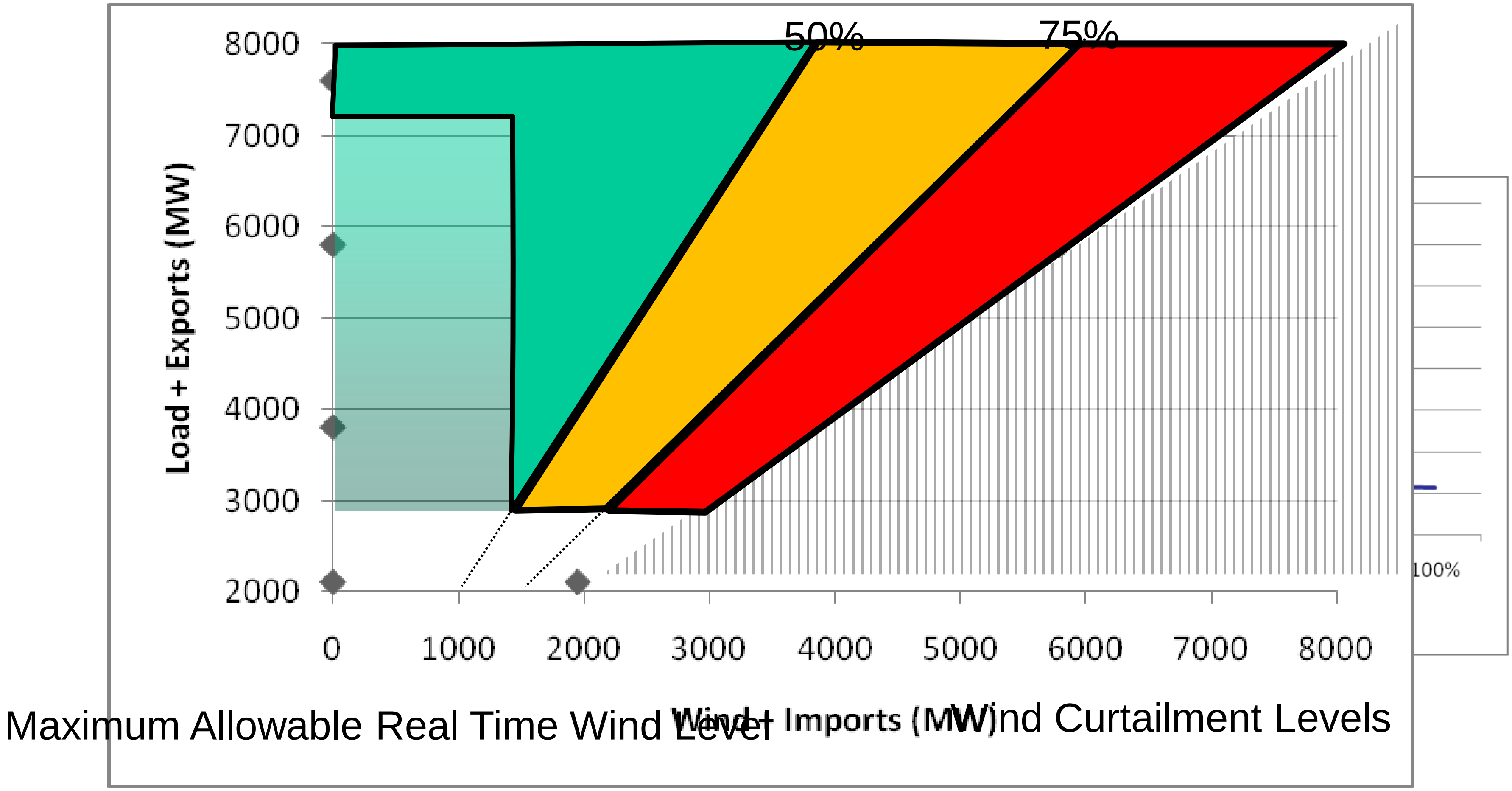
Detailed Technical Analysis

2008 - All Island Grid Study
2010 - Facilitation of Renewables
2011 - Ensuring a Secure Sustainable System

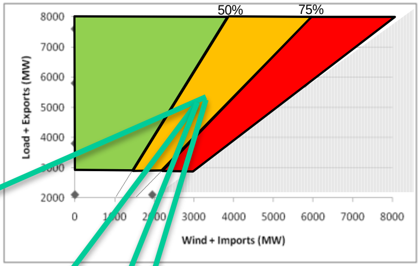
Real Time Operational Limits and Impact on RES-E



Real Time Operational Limits and Impact on RES-E

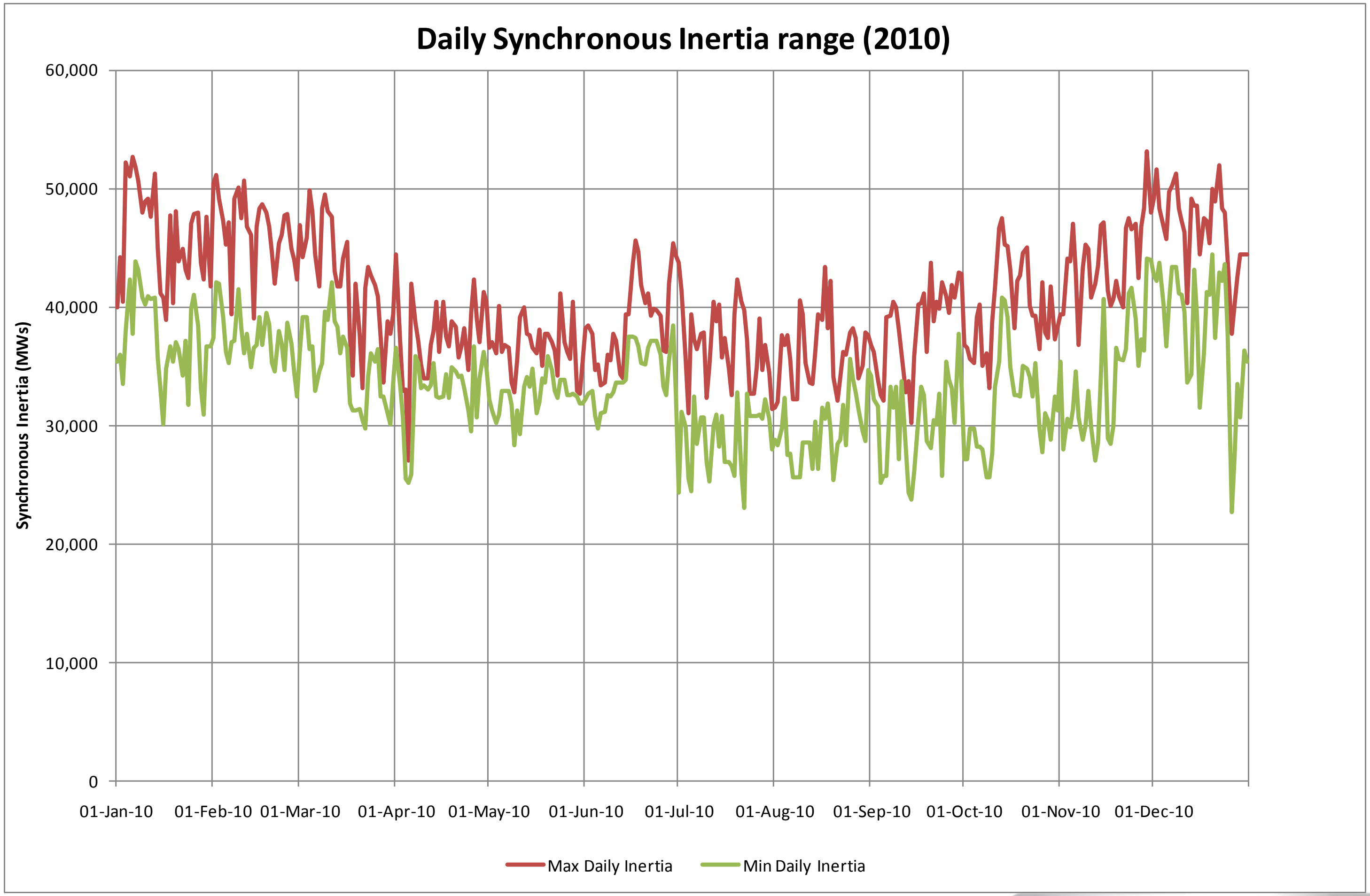


Tomorrow: achieving 75%.....

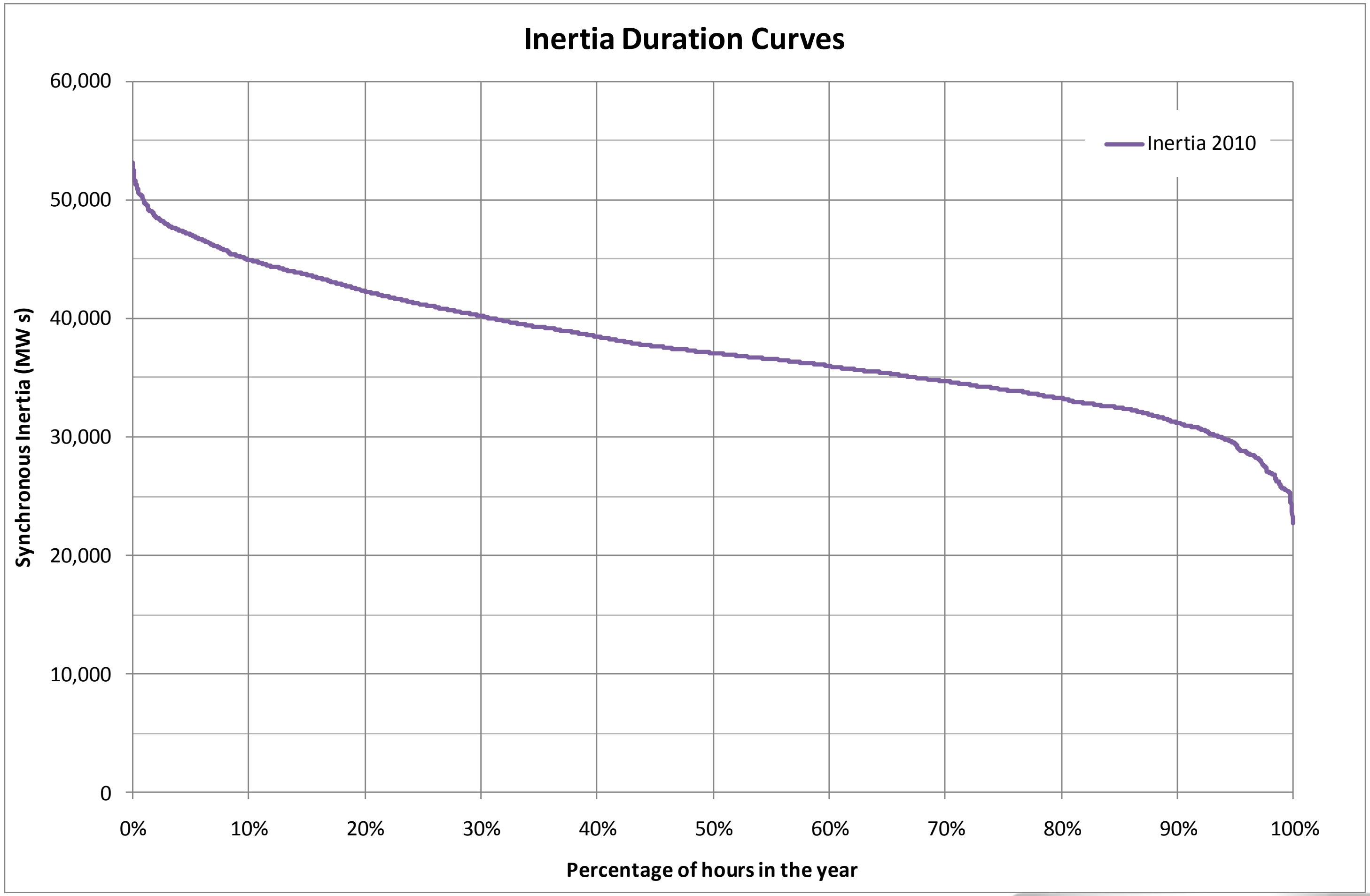


- RoCoF cascade failure
  - Loss of mains protection (G59)
  - Generator capability
- Ramping
  - Increased Variability and Uncertainty over hours
  - Require increased margin and performance to manage
- System Voltage Control (Reactive)
  - 25% reduction in Tx online reactive power by 2020
  - 50% of new windfarms in distribution including embedded generators
- Maintaining System Transient Stability
  - Increased electrical distance between remaining conventional gen
  - Require improved dynamic reactive response from windfarms

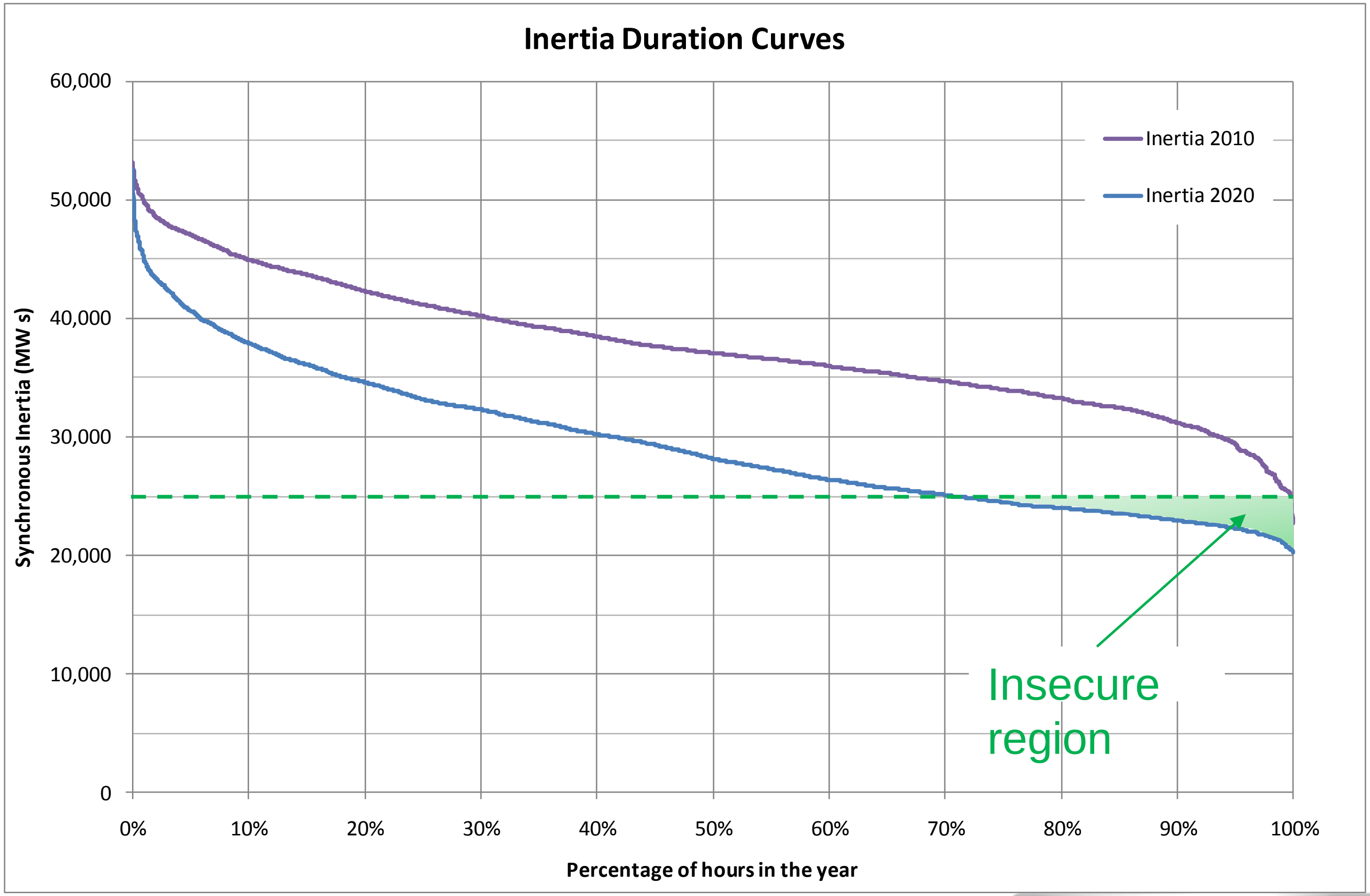
Frequency Control: Low Inertia



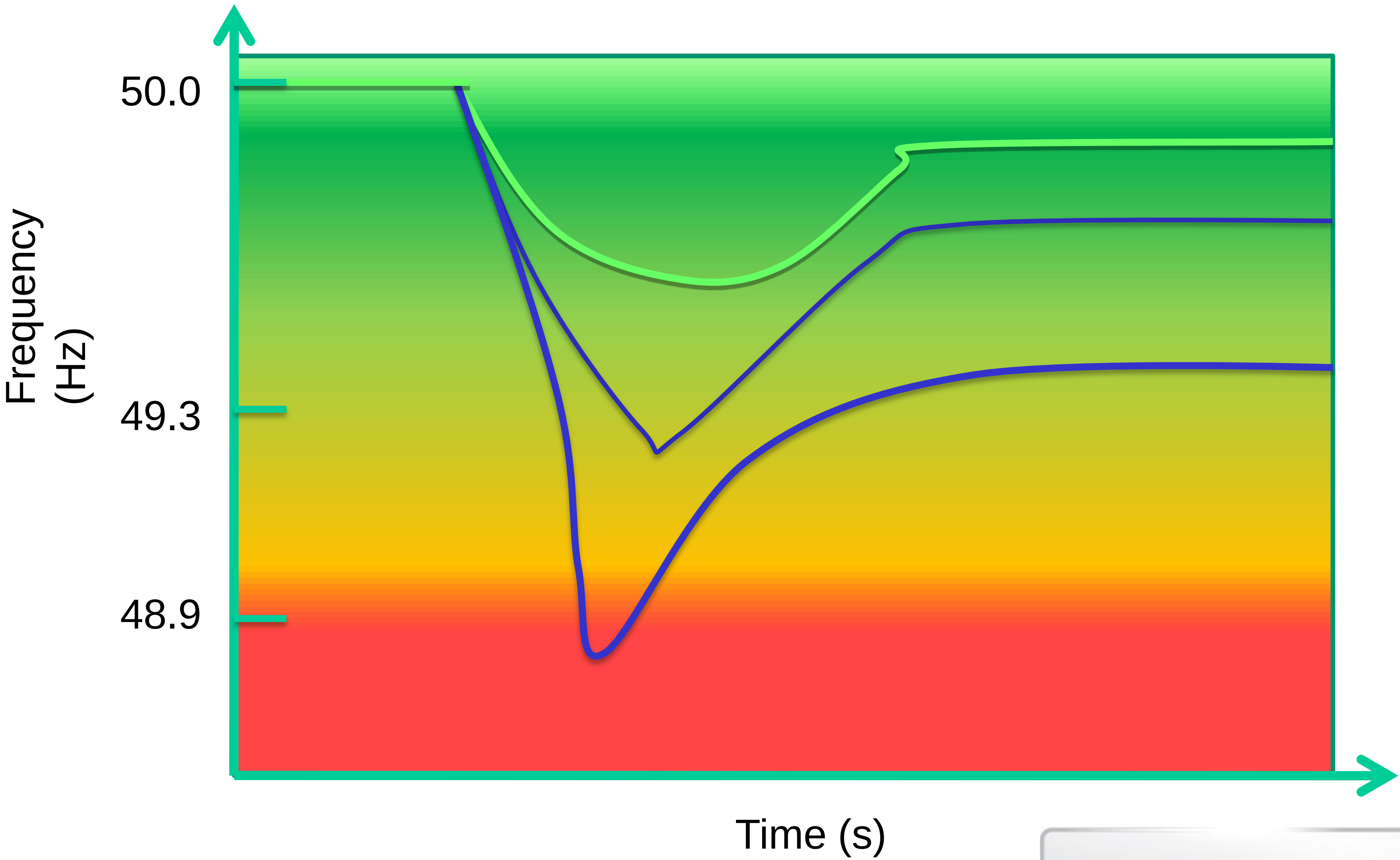
Frequency Control: Lower Inertia



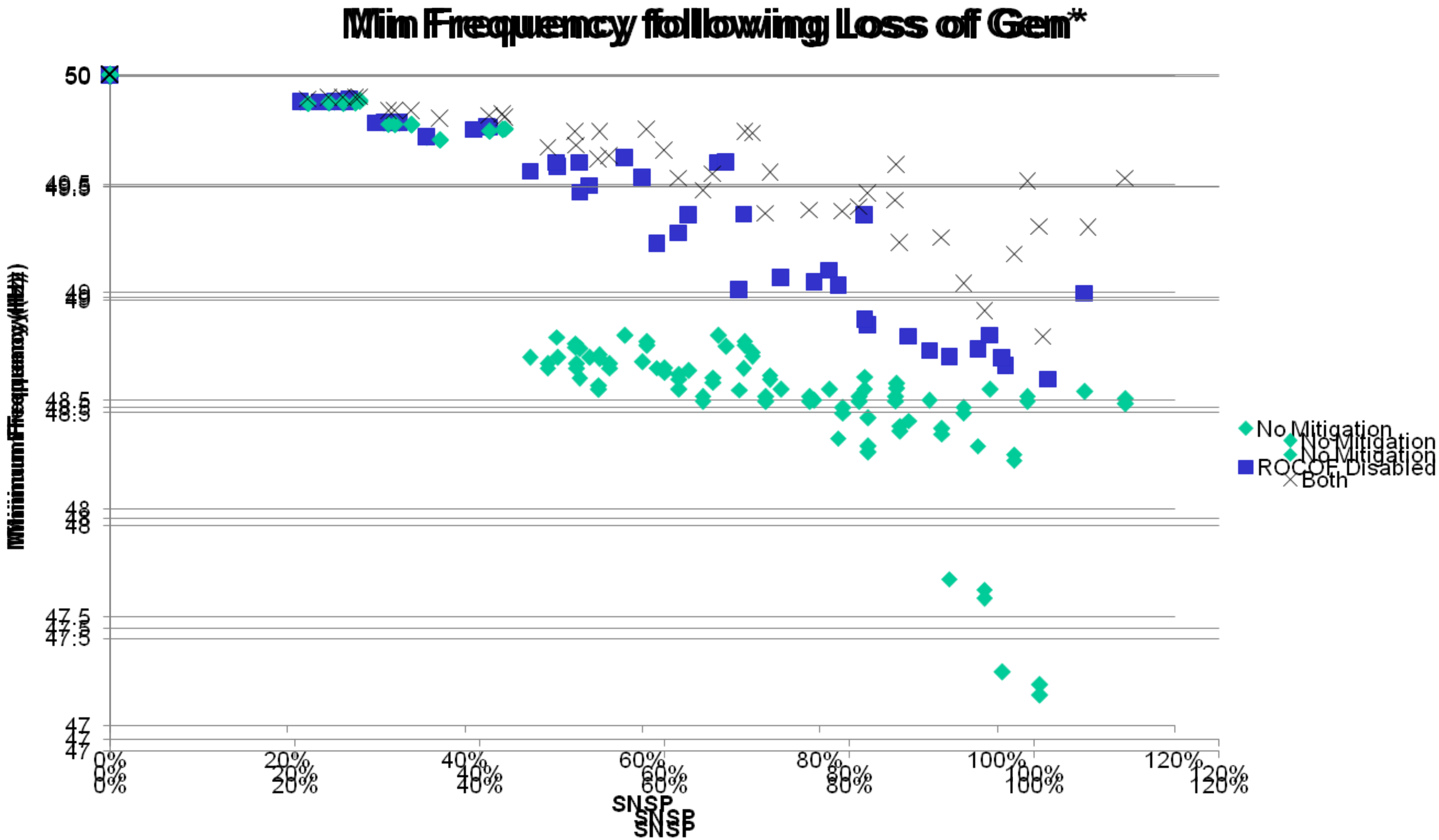
Frequency Control: Lower Inertia



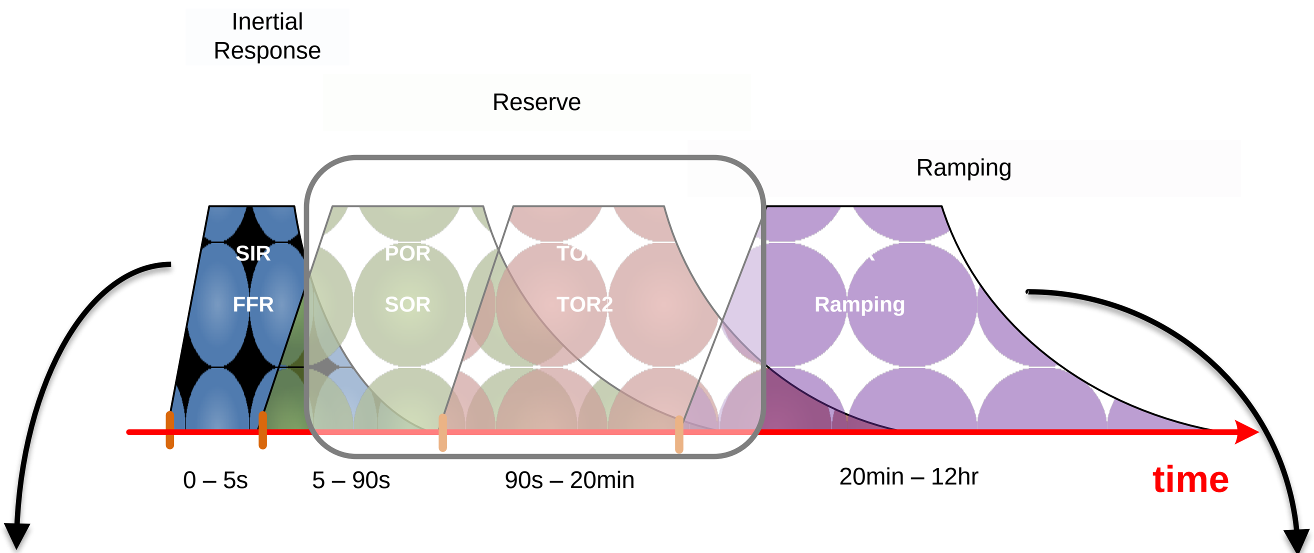
Frequency Concept



Frequency Control: Minimum Frequency following event



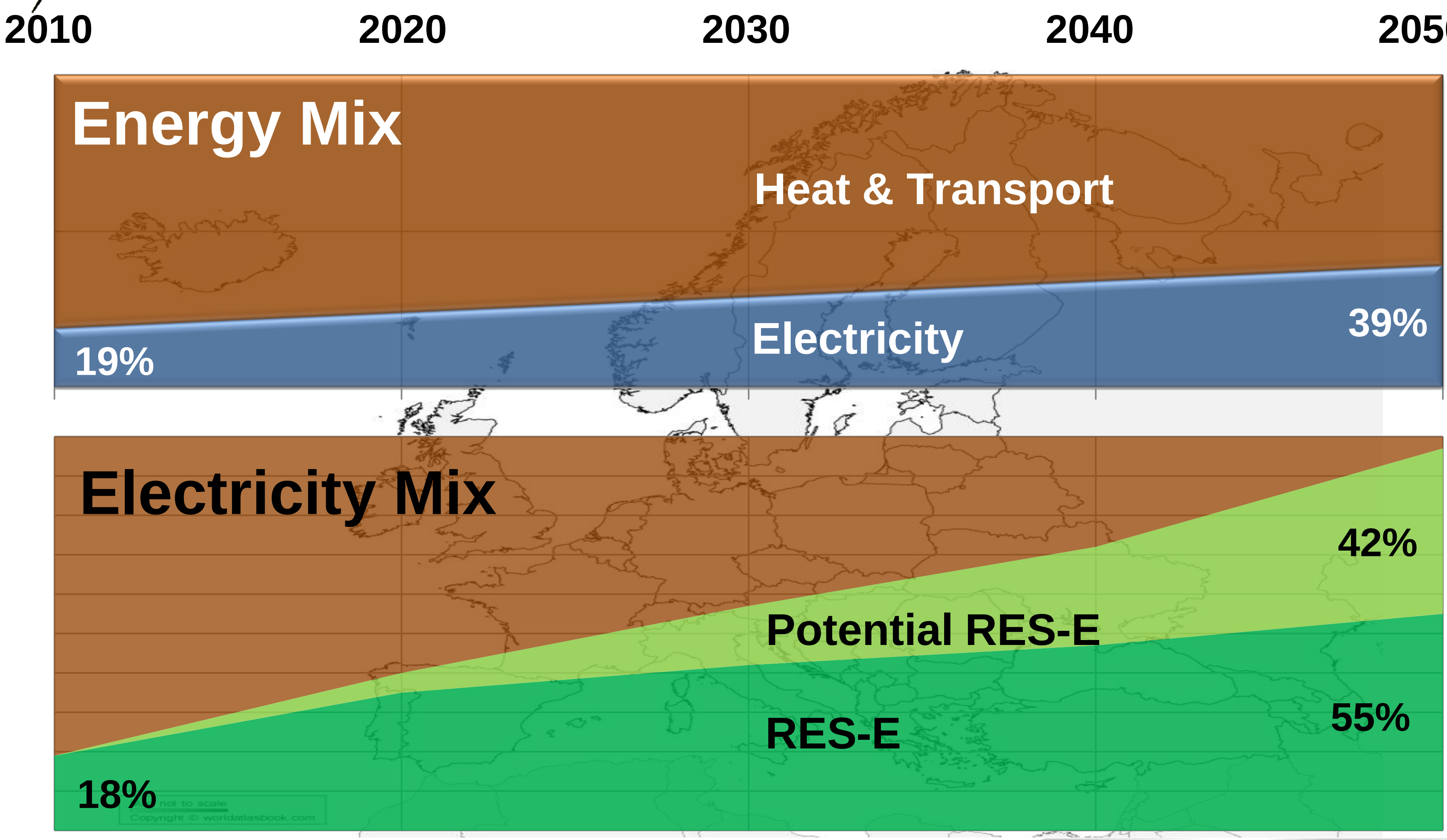
Frequency Control



- Synchronous Inertial Response
- Fast Frequency Response
- Fast Post-Fault Active Power Recovery

- Ramping Margin

European Energy Roadmap 2050



EirGrid

semo
Single Electricity Market Operator

SONI
System Operator for Northern Ireland

The Impact of Non-Synchronous Generation on System Inertia

RANGE OF SOLUTIONS

Michael Power

CIGRE

Non-Synchronous Generation / Synthetic Inertia

Range of Possible Solutions

December 2013

Michael Power

Outline

- Generation Trends
- Denmark and Tasmania
- Synchronous Condensers and HVDC
- Synthetic or emulated inertia

Generation Trends

- From swing equation increasing H reduces angular acceleration.
- Stability is also improved by reducing machine transient reactance.
- Trend in manufacturing is to reduce H and to increase transient reactance.
- More dependence on controls especially excitation controls.
- HQ requires generators’ H to be compatible with inertia constants of existing plants in same region. (Min H for wind power is 3.5s)

Denmark

ENERGINET/DK

Danish perspectives on system support from different technologies

	Generator >100 kV	Generator <100 kV	WT >100 kV	WT <100 kV	Classical HVDC	New HVDC	SVC/ STATCOM	Synch. comp
Inertia	++	+	(+)	÷	(+)	(+)	÷	++
Short circuit power	++	+	(+)	÷	÷	(+)	÷	++
Black start	(++)	(+)	÷	÷	÷	(++)	÷/(+)	÷
Continious voltage control	++	(+)	(+)	÷	÷	++	++	++
Dynamic voltage support	++	÷	++	÷	÷	++	++	++
Damping of system oscillations (PSS)	+	÷	(+)	÷	(++)	(++)	(+)	÷

++	*Large contribution*
+	*Minor contribution*
(+/++)	*Conditionally available*
÷	*Unavailable*

Tasmania

- Tasmania is a small island system supplied by hydro-generators, wind farms and one HVDC link.
- Their ROCOF criteria:
  - Initial ROCOF to 49Hz is 3Hz/s
  - Delayed ROCOF from 49 to 48.6 Hz is 1.176Hz/s
- These have been used to define the maximum amount of synchronous generation using equations such as

$$\frac{Non\ Synchronous\ [MW]}{System\ rotational\ energy\ [MW.s]} \leq 0.17$$

Synchronous Condensers

- Both systems intend to use synchronous condensers.
- In Tasmania they will be based around their hydro generators – '*high inertia*'.
- In Denmark, synchronous condensers fitted with flywheels may also be considered.
- What is size of inertial contribution from a synchronous condenser?   Figures of 7.84 have been obtained from hydro units with vertical shafts.
- What will be the size of inertial contribution of a synchronous condenser with a flywheel be?

HVDC – 1

Inertia Emulation Control Strategy for VSC-HVDC Transmission System

This paper presents an inertia emulation control (INEC) strategy that uses the energy stored in the DC link capacitors of the VSC-HVDC systems to emulate inertia. This supports the AC network during and following disturbances, with minimal impact on the systems connected beyond the terminals of the HVDC system.

HVDC – 2

This can be realized by modifying the HVDC control systems. The proposed strategy is capable of emulating a wide range of inertia time constants using relatively small constant capacitances connected to the DC circuit. Additionally, the proposed strategy does not rely on df/dt measurement.

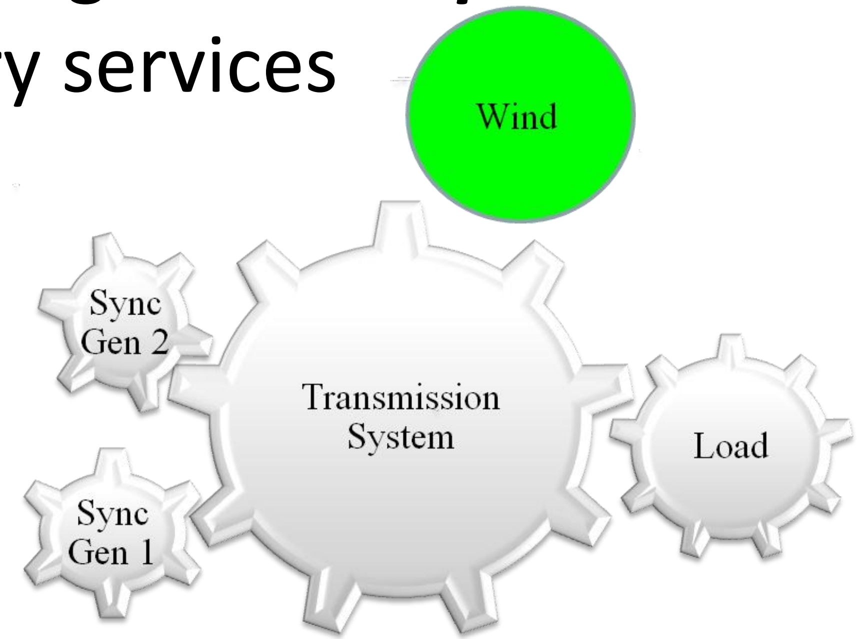
Inertia Emulation Control Strategy for VSC-HVDC Transmission Systems

Zhu, J. ; Booth, C.D. ; Adam, G.P. ; Roscoe, A.J. ; Bright, C.G.
Power Systems, IEEE Transactions on
Volume: 28 , Issue: 2
Digital Object Identifier: 10.1109/TPWRS.2012.2213101
Publication Year: 2013 , Page(s): 1277 - 1287

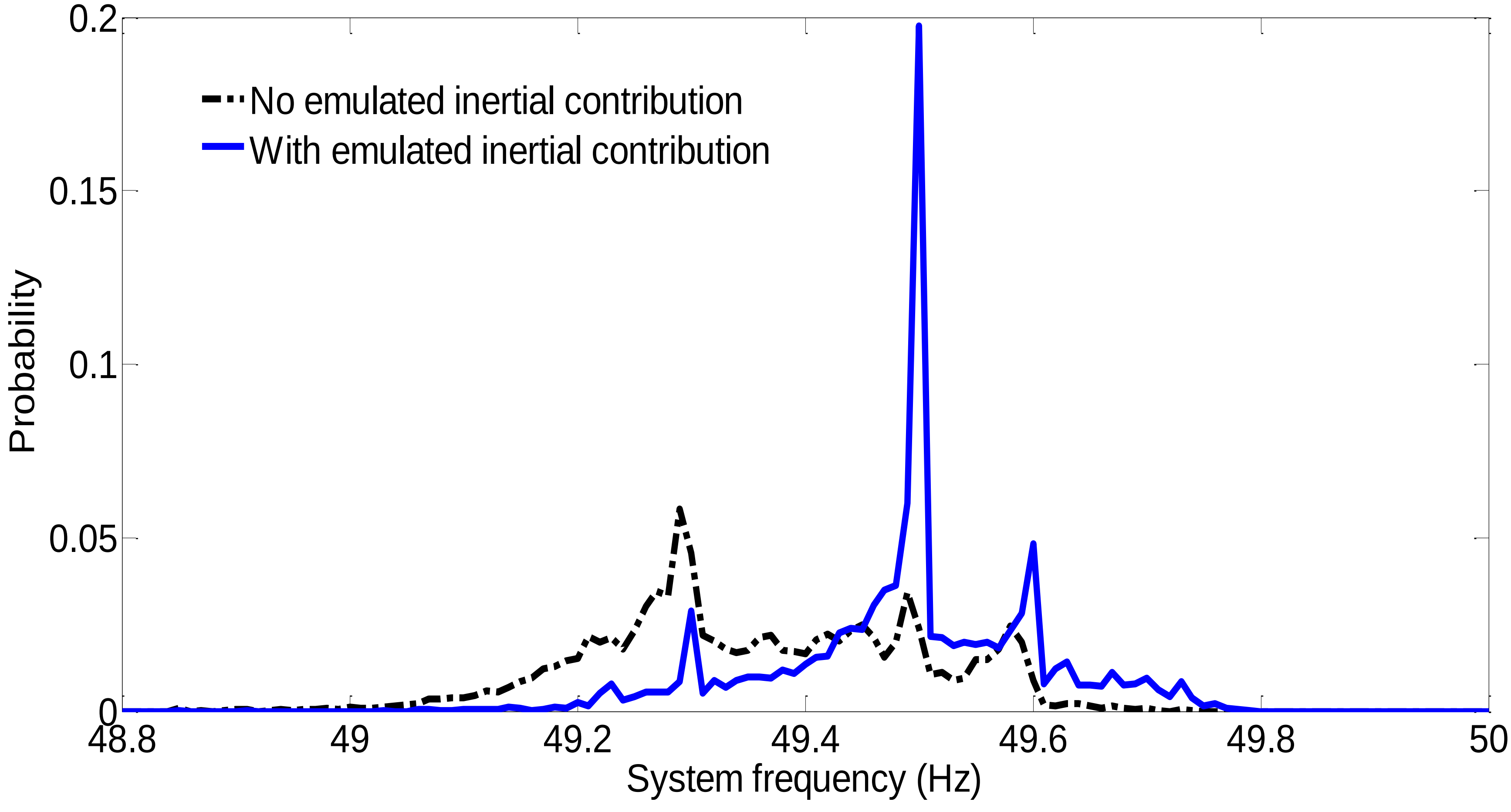
WT Emulated Inertia

The problem:

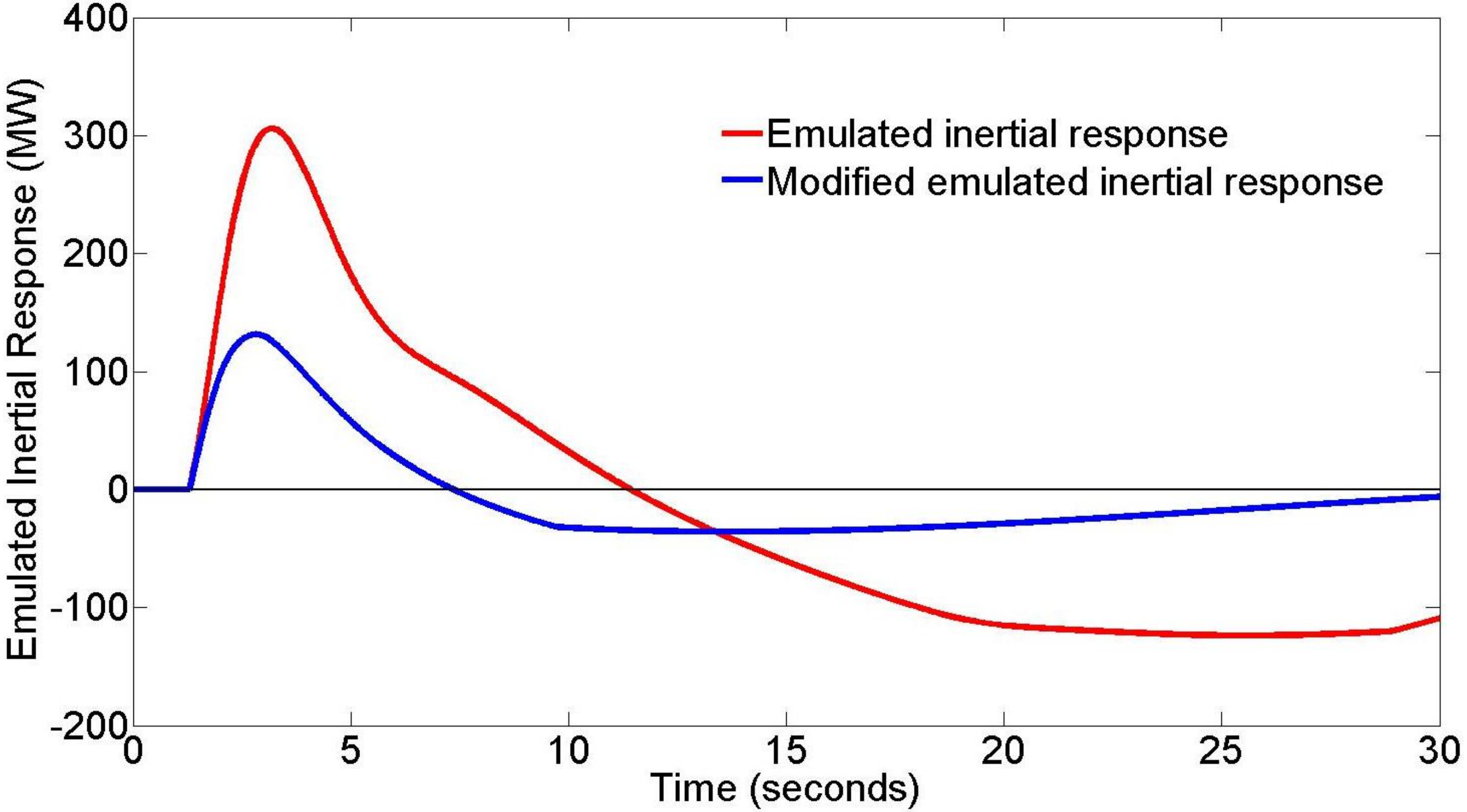
- Power balance on conventional systems well understood
- Higher wind penetration levels
- Fewer conventional generators ***plus*** associated ancillary services



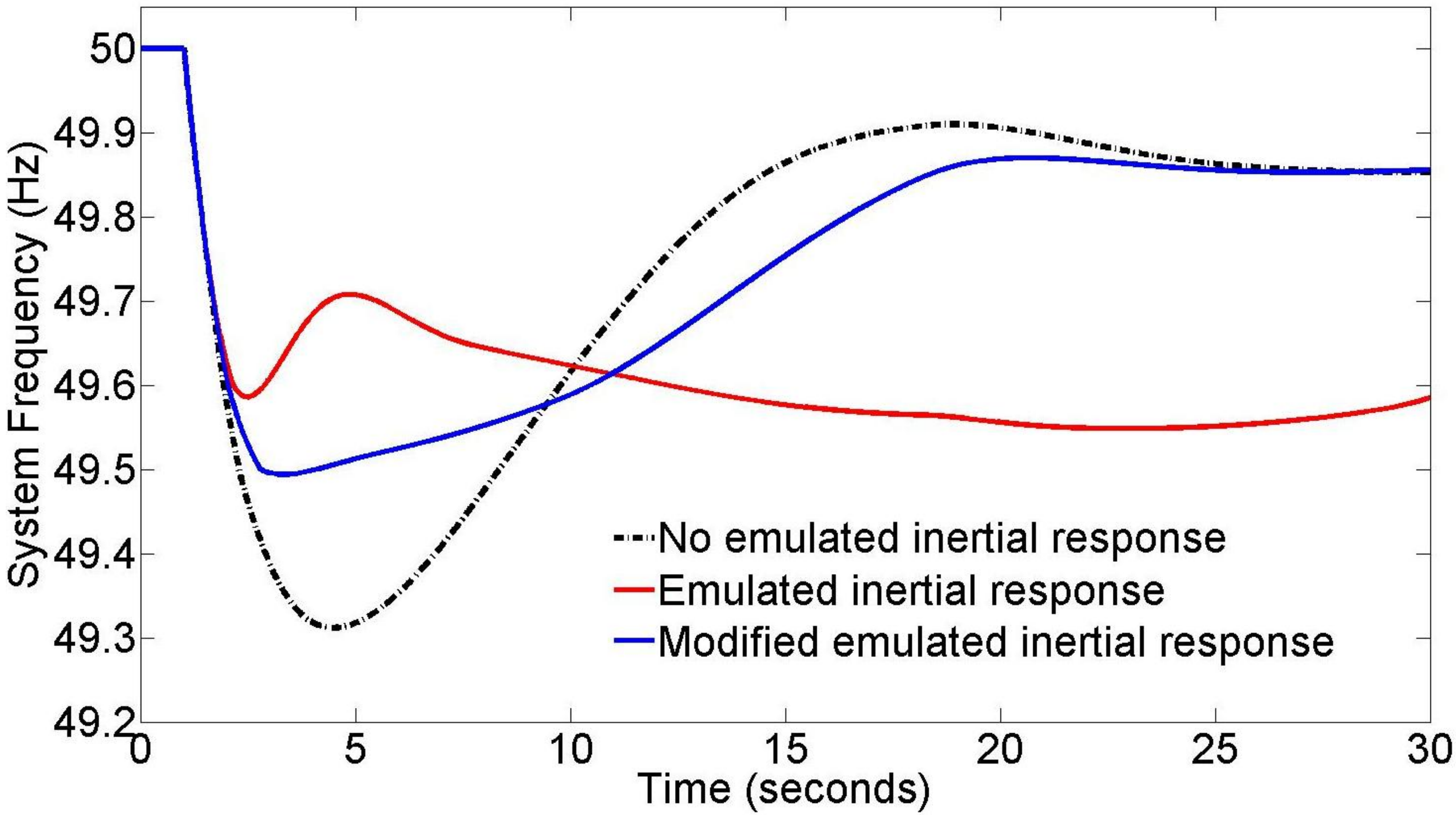
Frequency Nadir Distribution



Response Shape



Frequency Response Shape



Thank you for your attention.

The Impact of Non-Synchronous Generation on System Inertia

SOLUTION CASE STUDY

Sathees Kumar

CIGRE

Siemens Wind Power Inertia Response

December 2013

Sathees Kumar, Power System Engineer

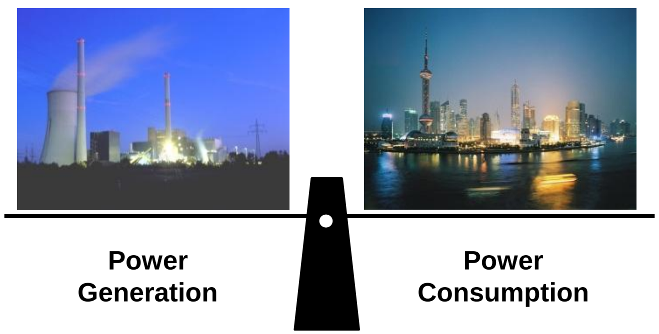
Executive summary:

- Delivering a fast over production of active power by extracting energy from rotor system.
- Continuous estimation of total wind power plant power boost capacity.
- Functional operation on park level and SWP Inertia Response is functional with the existing frequency control (LFSM and FSM).
- Configurable system for grid demand and properties through WPS User Interface
- Traditional safety systems employed to guard against instabilities and hazardous operation.

Facing the challenge of abrupt frequency drops in the grid

- Grid stability is attained by ensuring a balance between power fed into the grid and power consumed
- Abrupt changes to the power balance leads to sudden frequency changes, potentially having fatal consequences
- Maintaining a constant alignment between generation and consumption, requires urgent response-capabilities

Power balance in the grid



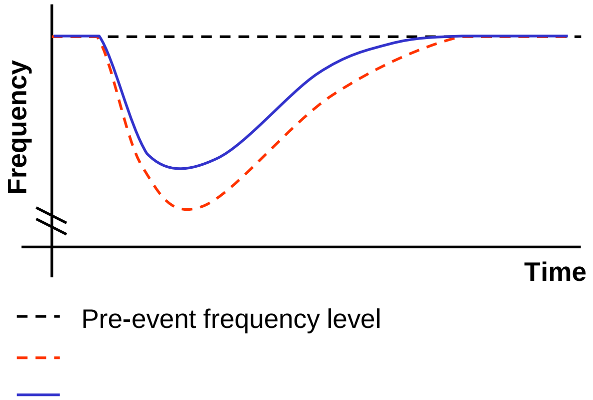
Power Generation **>** Power Consumption **=** Frequency Increase

Power Generation **<** Power Consumption **=** Frequency drop

Urgent delivery of active power by extracting kinetic energy from the rotor

- The most common challenge is frequency drops due to a tripping power plant, or sudden increases in power consumption
- Utilizing the inertia from the rotor of a wind turbine, allows for urgent delivery of extra active power
- This makes up an important support to conventional power plants, having a longer response time in comparison

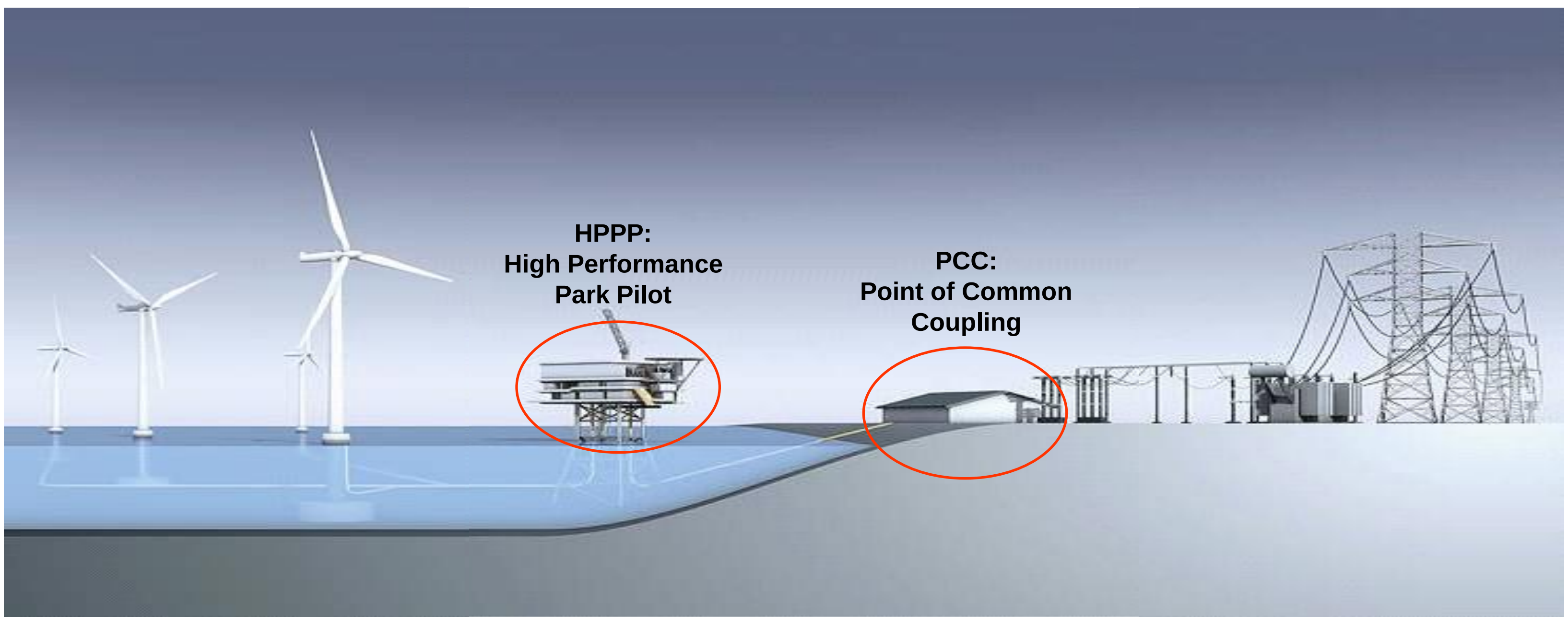
Power imbalances in the grid



Real time grid frequency monitoring allowing for urgent and accurate supply of over production

- The control strategy of SWP Inertia Response is based on three steps

Frequency drop monitored at PCC ➧ HPPP sends signal ➧ WTG responds



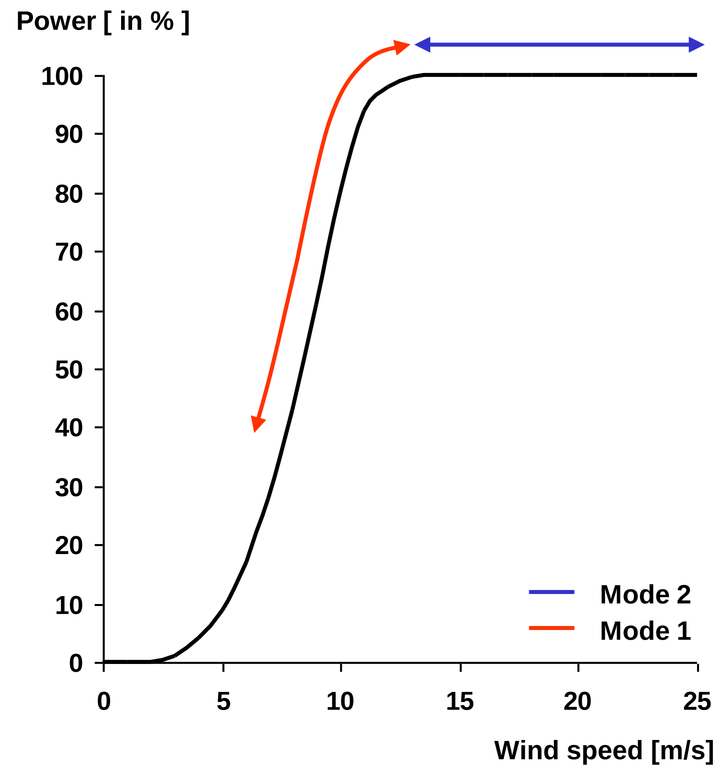
Inertia Response Control parameters, tailored according to wind speed

- Inertia response control mechanism features two operation modes:
  - Below rated power (mode 1)
  - At rated power (mode 2)

- At both modes, Inertia Response is the generated by an abrupt over production of active power

- In order to avoid turbine cut outs, a lower RPM threshold defines the lower limit for SWP Intertia Response operation

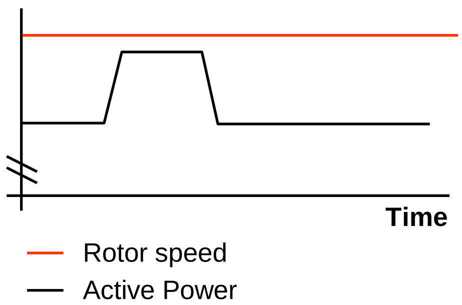
SWP Inertia Response operation modes



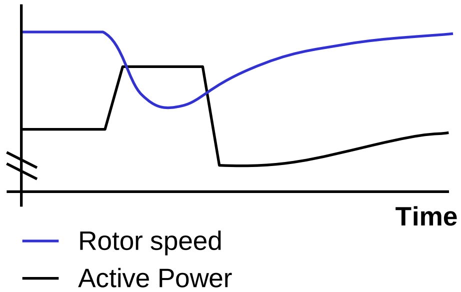
Intelligent adaptation to real time conditions for optimal supply of over production

- During operation at rated power, over production is generated by increasing the power reference
  - Variable pitch ensuring stable rotor speed
- During operation below rated power, over production is generated by increasing actual power reference
  - Leads to reduction in rotor speed
- Soft recovery function preventing uncontrolled undershoot and ensuring controlled ramp-in after ended over production

Operation at Rated Power



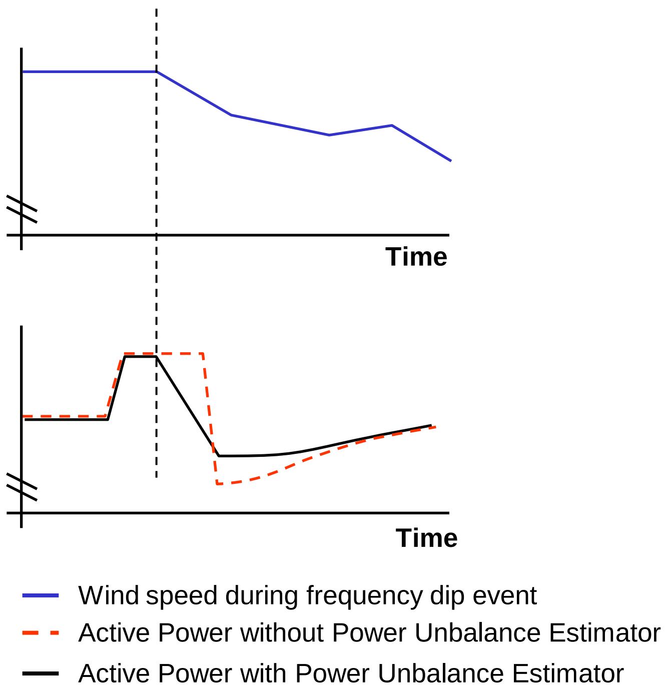
Operation below Rated Power



Intelligent functionality integrated for constant alignment to real time conditions

- Power Unbalance Estimator
  - Kinetic drop control for reduction in over production during significant drops in wind speed
  - Control for increasing of over production during significant increases in wind speed
  - Provides a stable operation of SWP Inertia Response, regardless of variations in wind speed

Operation during sudden drops in wind speed



User interface allowing for customization of Inertia Response control configuration

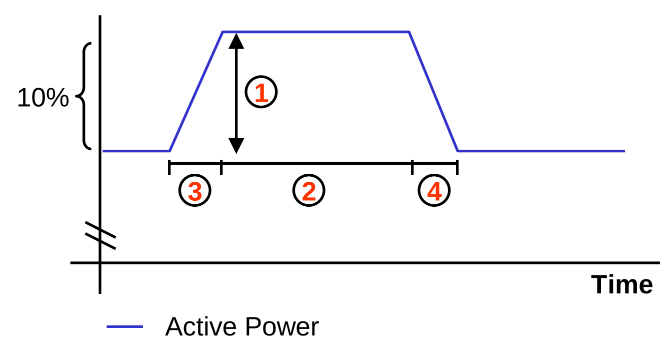
- SWP Inertia Response WPS user interface, allowing for individual configuration of SWP Inertia Response operation

- Facilitating tailoring according to Transmission System Operator specifications

Tailoring of WPS control settings

Inertial Response

Inertial Response Mode :	Frequency		Edit	
Amount release :	10	[% actual]	Edit	①
Duration :	10	[s]	Edit	②
Ramp Up rate :	1000	[% actual/min]	Edit	③
Ramp Down rate :	600	[% actual/min]	Edit	④
Repeat Time :	120	[s]	Edit	
Activation frequency offset :	0.9	[Hz]	Edit	
Abort frequency offset :	0.5	[Hz]	Edit	



Accurate and reliable monitoring ensuring constant overview of IR activations

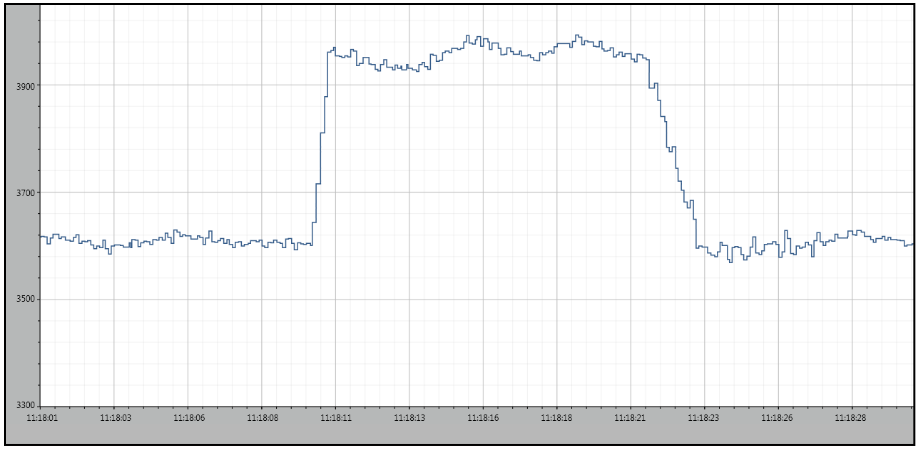
- Total available Inertia Response is available
- A log is shown for activation with time stamp

Park Pilot Status	HPPP01	Turbines	Controller
General			
Topology Selection		0	
Topology Turbine Count		4	
No Power Mode		Static	
Idle Requirement		0,0	%
ION7650_1Power - Active Power			
State		Automatic	
Reference Type		Absolute power (Scheduled)	
Reference		10,0	MW
Actual		6,2	MW
Available		6,7	MW
Curtailment	Total	0,5	MW
Curtailment		7	%
In Scope Count		4	
Frequency Controller		Disabled	
Actual Frequency		-	Hz
Turbine Fallback Power Reference Timeout		Disabled	s
Total Available IR		0,46	MW

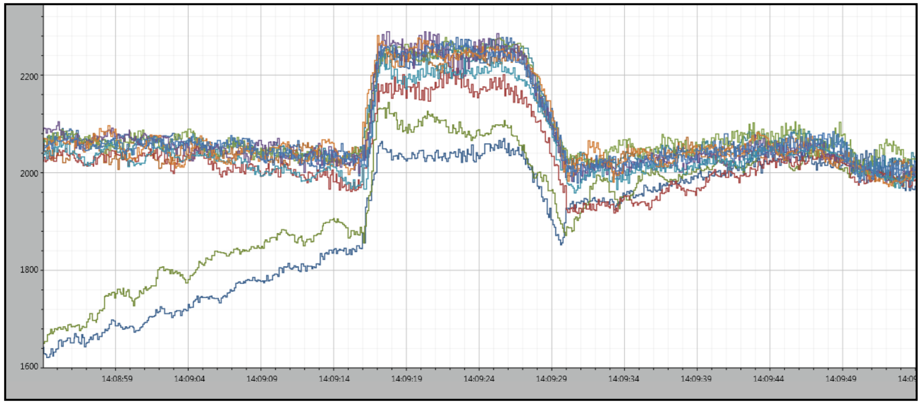
Inertial Response	
Number of IR Activations	31
Number of Remaining IR Activations	1969
Number of IR activations within the last hour	0
IR max activations per hour	10
Current Available IR	115
Date for last IR event	5/11/2012 - 2:40:57 PM

Power validation via field Measurements…

- Statements on the testing and validation process
- Testing and validation performed on individual as well as park level
- Test results indicate…



SWP Inertia Respons on a single SWT-3.6-120 operating at rated power



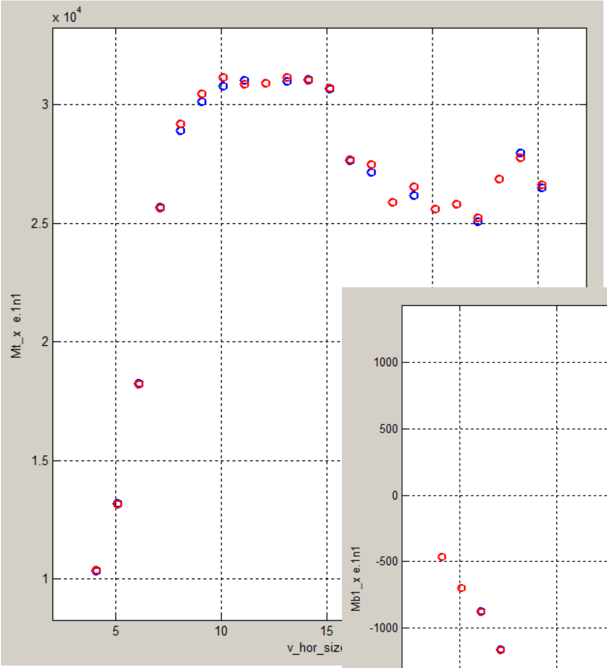
Inertia Respons on a park of SWT-2.3 turbines

Load validation via field measurements...

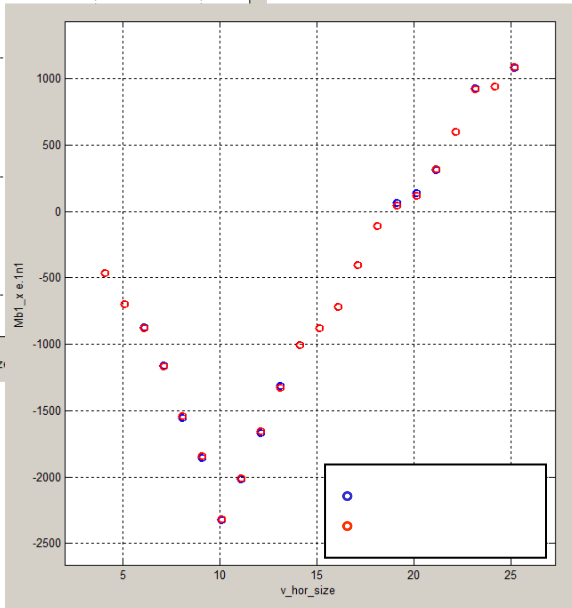
- Statements on the testing and validation of the WTG loading

- The most vulnarable parts of the WTG structureare blades and tower bottom section.

- Test data indicates…
- Transforming the inertia of the rotor into increased power factor, does nbot lead to excessive loading of the WTG structure…



Load measurements on tower buttom during inertia repsons operation



Load measurements on blade during inertia repsons operation


Thank You

Questions & Answers

The Impact of Non-Synchronous Generation on System Inertia

PUBLICATIONS

INTERNATIONAL COUNCIL
ON LARGE ELECTRIC SYSTEMS

Paris 2012

- **SC C2 System Operation and Control:**
  - **PS1 > Methods to overcome operation challenges caused by the combination of intermittent generation and changes in electrical loads behaviour from a TSO perspective**
    - Resource balance (day ahead and day at hand), maintaining frequency and uncontrolled excess generation in relation to system demand
    - Reduced inertia on the power system
    - Congestion management (power flow), voltage control and coordinated Phase Angle Regulator (PAR) settings
    - Information and control of dispersed generation

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INTERNATIONAL COUNCIL
ON LARGE ELECTRIC SYSTEMS

Paris 2014

- **SC A1 Rotating Electrical Machines:**
  - **PS1 > Developments of Rotating Electrical Machines**
    - Improvements in design, manufacture, efficiency, operation and
    - Influence of customer specifications and grid operator requirements on the operation, design and cost of machines. ·
    - New developments for extending the power rating of large generators

- **SC C2 System Operation and Control**
  - **PS1 > Managing new challenges in operational planning and real-time operation of Electric Power Systems**
    - Stability analysis, monitoring and control (i.e. voltage and frequency control, phase angle stability).
    - Ancillary services, including operational reserves

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INTERNATIONAL COUNCIL
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Publications

- **Technical Brochures**
  - TB 523 System Complexity and Dynamic Performance
  - TB 370 Integration of large scale wind generation using HVDC and power electronics
  - TB 450 Grid Integration of Wind Generation
  - TB 328 Modelling and dynamic behaviour of wind generation as it relates to power system control and dynamic performance

- **Session Papers / Electra**
  - Control of wind power generation with inertial energy storage system
  - Impact of wind power generators on the frequency stability of Synchronous generators
  - Supplementary Grid Functions in DFIG Wind Turbines to Meet Québec's Frequency Requirements