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https://attendee.gotowebinar.com/recording/2434066267766356994

JWG C2/C4.41: Impact of High Penetration of Inverter-based Generation on System Inertia of Networks

Convenor: Mpeli Rampokanyo, Study Committee, C2

Webinar, 10 Dec 2020

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Agenda

Item	Topic	Time	Presenter
1	Introduction & Background (Chp 1)	5 min	Mpeli Rampokanyo (CSIR) -**Convenor**
2	Role of Inertia and Technical Definitions (Chp 2) & Quantification of Frequency Containment Reserves (Chp 7)	15 min	Dr. Julia Matevosyan (ERCOT)
3	Survey from different utilities (Chp 3) & Inertia Constraints Challenges in Ops Environment (Chp 4)- Why do we face the constraints / challenges of inertia?	10 min	Dr. Nilesh Modi (AEMO)
4	Inertia Constraints / Challenges in Ops Environment (Chp 4) - how are these constraints being managed? & Inertia providing technologies (Chp 5)	10 min	Dr. Diptargha Chakravorty (TNEI)
5	Inertia as an Ancillary Service (Chp 8) & Existing Grid Code / Policies (Chp 9)	10 min	Adham Atallah (Siemens)
6	Concluding Remarks	5 Min	Dr. Papiya Dattaray (EPRI) - **Secretary**
7	Q & A	5 Min	Pamela Kamera (ESP) - **Secretary**

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Introduction and Background to the Power System Inertia Phenomenon

Mpeli Rampokanyo, JWG Convenor

(Principal Engineer, CSIR, South Africa)

Background and Introduction to Inertia Phenomenon

The worldwide drive to reduce carbon emissions on the environment

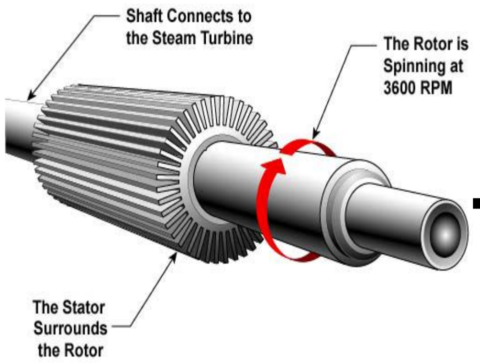
- Alternative sources of energy that are less polluting
- Introduction of non-synchronous or inverter based generation.

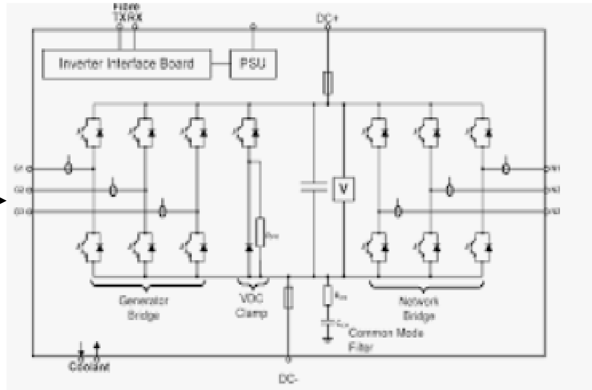
Erosion / depletion of power system inertia

- Natural inertial response from synchronous generating sources helps in damping frequency excursions during system disturbances

The rate of change of frequency (RoCoF) increases

- Leading to a lower frequency nadirs
- Primary Frequency Response (PFR) systems and even defence schemes such as Under Frequency Load Shedding Schemes (UFLS) may fail to protect the system during major frequency excursions.





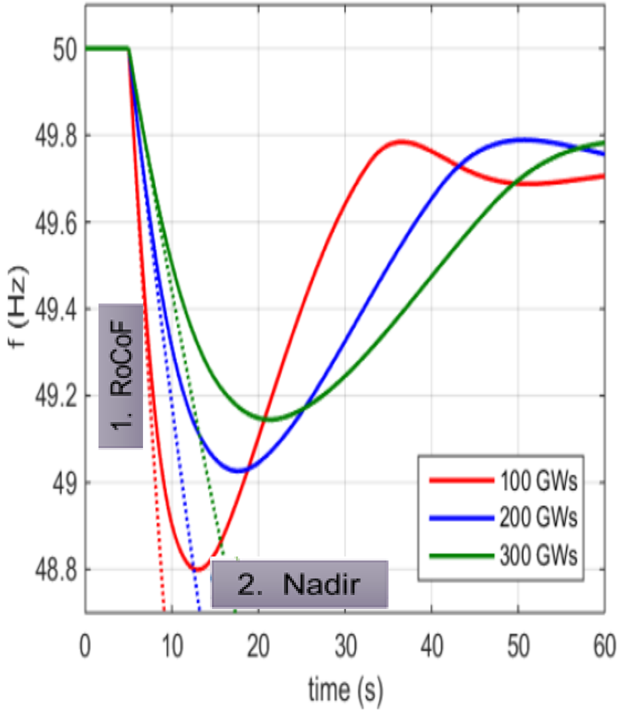
Source: EPRI Power System Dynamics Tutorial

Objectives and Scope of the JWG

Purpose: To advise and formulate philosophies for system operations in order to prepare the on-going energy transition. Primary Frequency Response studies will be carried out (or existing studies will be reviewed) in order to analyse and mitigate against the impact of the reduction of synchronous inertial energy on the power system as a result of integration of non-synchronous renewable generation using various networks around the globe as case studies.

Key objectives:

- Review of previous CIGRE work relating to the current and the connection with on-going work.
- Survey existing practises used to determine primary frequency response requirements.
- Define operational measures to manage the dispatch of inertia.
- Quantify Frequency Containment Reserves (FCR) with increasing RES penetration
  - ✓ Demand Response (DR) requirements
  - ✓ Primary Reserves requirements
  - ✓ Fast Frequency Response (FFR) techniques and requirements
  - ✓ Trade-offs between inertia and FFR /DR techniques



Source:
documents/Publications/SOC/Nordic/Nordic_report_Future_System_Inertia.pdf

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Objectives and Scope of the JWG contd.

- Methodology to establish rate of change of frequency (RoCoF) limits with increasing non-synchronous RES penetration levels, and the integration of the methodology into the operational environment.

- Review existing Grid Code policy around FCR requirements in light of higher penetration levels of RES.

- Investigate possible control strategies for inverter-based generation in order to provide wider future designs possibilities of inverters/converters and to achieve the most efficient way to use the technology.

- Survey possible/ existing mitigation techniques and increased system controllability

  - ✓ Synthetic inertia (including technologies based on voltage source converters)
  - ✓ FFR
  - ✓ DR
  - ✓ Other technologies

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Motivation from Different Countries

South Africa - Eskom

- The South African draft Integrated Resource Plan (IRP) 2019 is projecting 10.52% PV and 22.53% Wind of the total installed capacity by 2030.
- A suite of studies or technical assessments needs to be conducted to sufficiently determine the technical impact of integrating high levels of RE. This includes among others frequency control (low levels of inertia, RoCoF), voltage control, fault level, reactive power, electromagnetic transient (impact on equipment/ systems), power quality and reliability.
- The South African System Operator has to date done a sensitivity study to understand how the system would respond as instantaneous RE penetration levels increase up to about 60%. This study was aimed at understanding system response due to decreasing inertial levels but more thorough studies are proposed for future with appropriate mitigation strategies for the south African system.

Ireland - EirGrid

- The renewables that form part of the energy supply in Ireland are thermal, hydro, wind power generation which are 64% of the total power generation in Ireland as at 2020 which necessitates an investigation into the implications for its system inertia.
- The current Rate of Change of Frequency (RoCoF) standard for Ireland is 0.5 Hz/s as defined in the Grid Code, set by the standard used by RoCoF relays.
- RoCoF relays are used to provide protective function to distribution generation, and RoCoF values greater than 0.5Hz/s would result in loss of generation and lead to system instability.
- RoCoF values greater than 0.5 Hz/s are likely to occur when the power system exceeds a level of about 60 % system non-synchronous penetration (SNSP) or the synchronous inertia falls lower than 25 000 MW-seconds – 2017study.
- The goal currently is to ensure an operational policy which aims to operate a power system reliably at up to 75 % SNSP

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Motivation from Different Countries

TEXAS, USA - ERCOT

- According to the Generation Interconnection Status report in November 2020, approximately 100 GW of inverter-based resources was under study for future interconnection to the ERCOT grid.
- Adequacy of Inertial and Frequency Response is particularly important for single area interconnection like ERCOT because all of the Frequency Response has to come from within the Interconnection.
- A decline of inertia is expected due to increasing amount of inverter-based resources that replace the conventional synchronous units
- To identify and increase the understanding of system issues under high penetration of renewable generation, ERCOT conducted a dynamic stability assessment for such high penetration conditions and evaluated potential solutions.

AEMO – Australia

- In Australia, currently, AEMO does not dispatch inertia. Instead, AEMO uses constraint equations to limit the rate of change of power system frequency in vulnerable regions by controlling interconnector flows.
- Inertia is reducing in some regions of the Australia, particularly South Australia
- The Inertia Rule establishes a framework for the management of inertia. From 1 July 2018, TNSPs that are Inertia Service Providers will have an obligation to provide inertia network services. AEMO is now required to calculate the inertia requirements for each inertia sub-network in accordance with the inertia requirements methodology. The inertia requirements are specified as follows:
  - ✓ The minimum threshold level of inertia, being the minimum level of inertia required to operate an inertia sub-network in a satisfactory operating state when the inertia sub-network is islanded; and
  - ✓ The secure operating level of inertia, being the minimum level of inertia required to operate an inertia sub-network in a secure operating state when the inertia sub-network is islanded.

Role of Inertia and Quantification of Frequency Containment Reserve

Dr. Julia Matevosyan

Lead Planning Engineer, ERCOT

What is Inertia?

- Rotating generators and motors synchronously connected to a power system have stored kinetic energy.
- Immediately after a contingency event (e.g. generation trip), this stored kinetic energy is drawn from the remaining synchronous generators to maintain balance between production and consumption - inertial response.
- Mechanical power input into the generators however is still unchanged.
- Generators will start to slow down and system frequency declines as a result
- The rate of frequency decline depends on the total amount of inertial response available at the time of an event.
- **Inertial response currently provides an important contribution to reliability in the initial moments following a generation or load trip event determining the rate of change of frequency (RoCoF).**

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What is Inertia?

Synchronous inertia of a machine is based on the commissioned design capability of the plant. It can be determined through appropriate validation procedures based on the following relationship:

$$Stored\ kinetic\ energy\ = \frac{J\omega_o^2}{2} = H \cdot S_n$$, where

- *Stored kinetic energy* is in MVA-seconds;
- *J* is the combined moment of inertia of a synchronous machine and turbine prime mover in kg·m^2, based on its size and weight;
- ω_o is the nominal rotor speed in rad/s, and
- S_n is the machine's rated capacity in MVA.
- *H* is the figure of merit used to analyze the synchronous machine's inertial response inertia constant in seconds. $H=\frac{J\omega_o^2}{2}\cdot S_n$
- The inertia response that a synchronous machine can provide is independent of the machine's power output
- Total system response to an initiating event is determined by the summation of the contributions from each of the online synchronous machines

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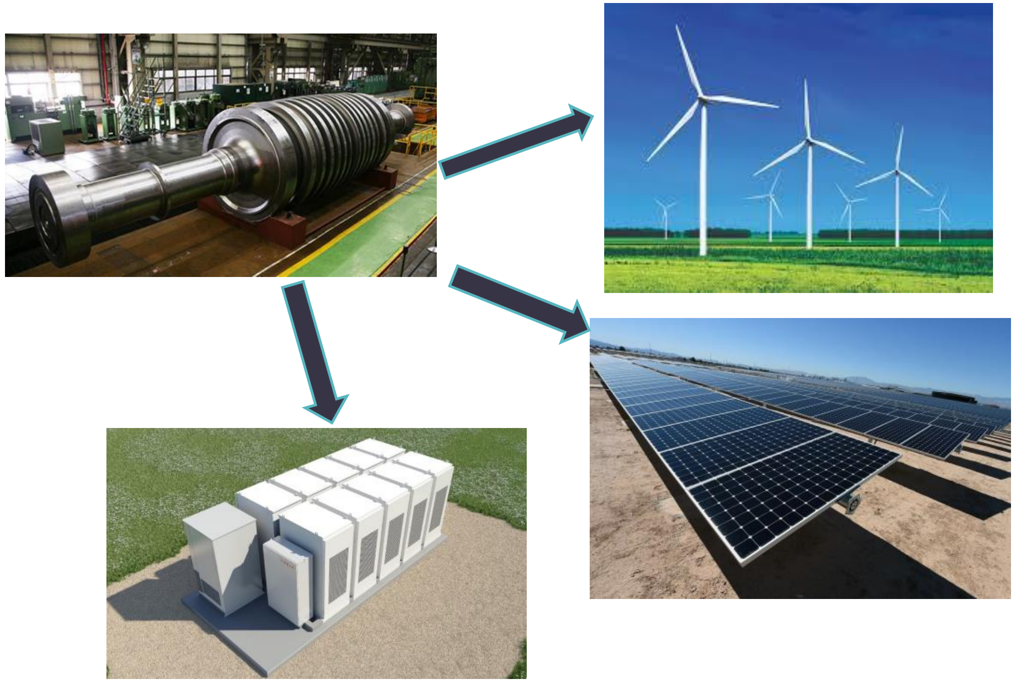
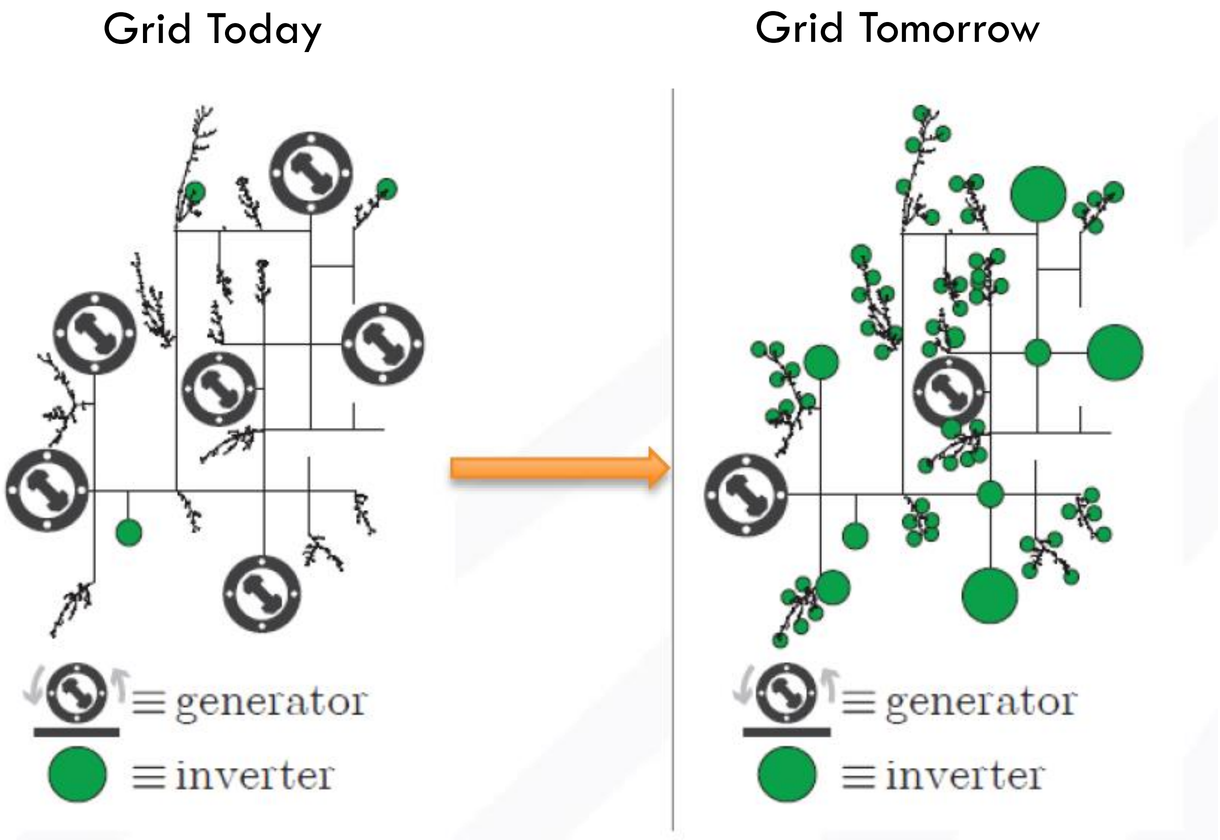
Changing Resource Mix





Source: DOE Solar Energy and Technology Office

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Inertia Estimation Methods

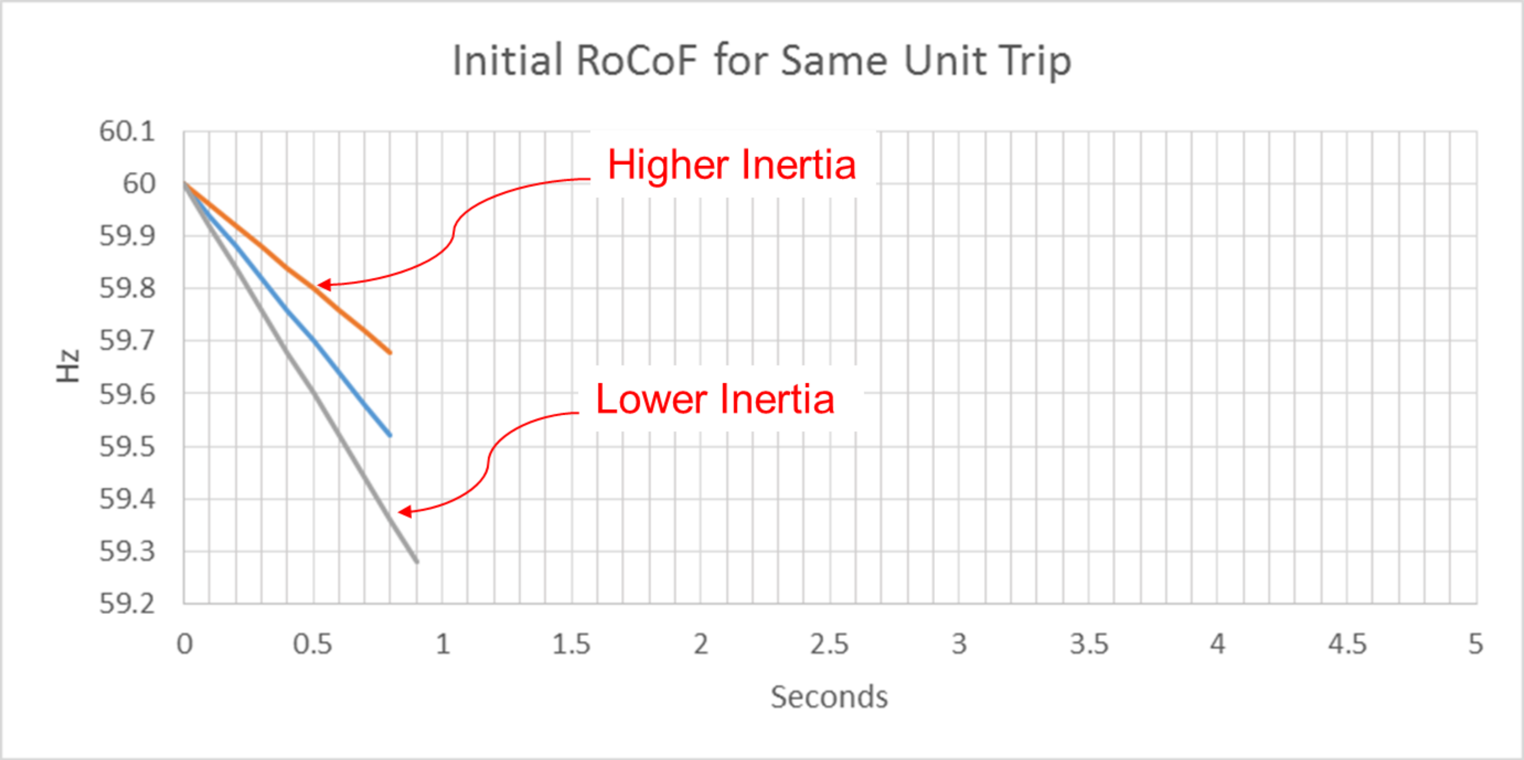
	Input Data										
	EMS^	Frequency	Active Power	Known Event(s)	When	Estimates Rotating Inertia?	In Use?	New Monitoring equipment*	Modulator	Basis for Forecasts^	Includes Load Inertia
Unit Commitment	✓	✗	✗	✗	Real Time	✓	✓	✗	✗	✓	~
Event Driven System	✗	✓	✗	✓	Post Mortem	✓	✓	✗	✗	~	✓
Event Driven Regional	✗	✓	✓	✗	Post Mortem	✗	✓	✓	✗	~	✓
Continuous Signal - Ambient	✗	✓	✓	✗	Real Time	✓	✗	✓	✗	✓	✓
Continuous Signal – Stimulated	✗	✓	✗	✓	Real Time	✓	✓	✓	✓	✓	✓

^EMS data required for forecasting or contingency estimates
*Assuming some PMUs in place

Source: EPRI White Paper
'Online Inertia Estimation & Monitoring: Industry Practices & Research Activities',
000000003002016195

Effect of Inertia on System Frequency

- With increasing integration of Inverter- Based Resources (such as wind, solar, battery storage), there could be periods when total inertia of the system is low, as less synchronous machines will be dispatched.
  - ✓ During such situations, it is essential to have adequate frequency response capabilities.

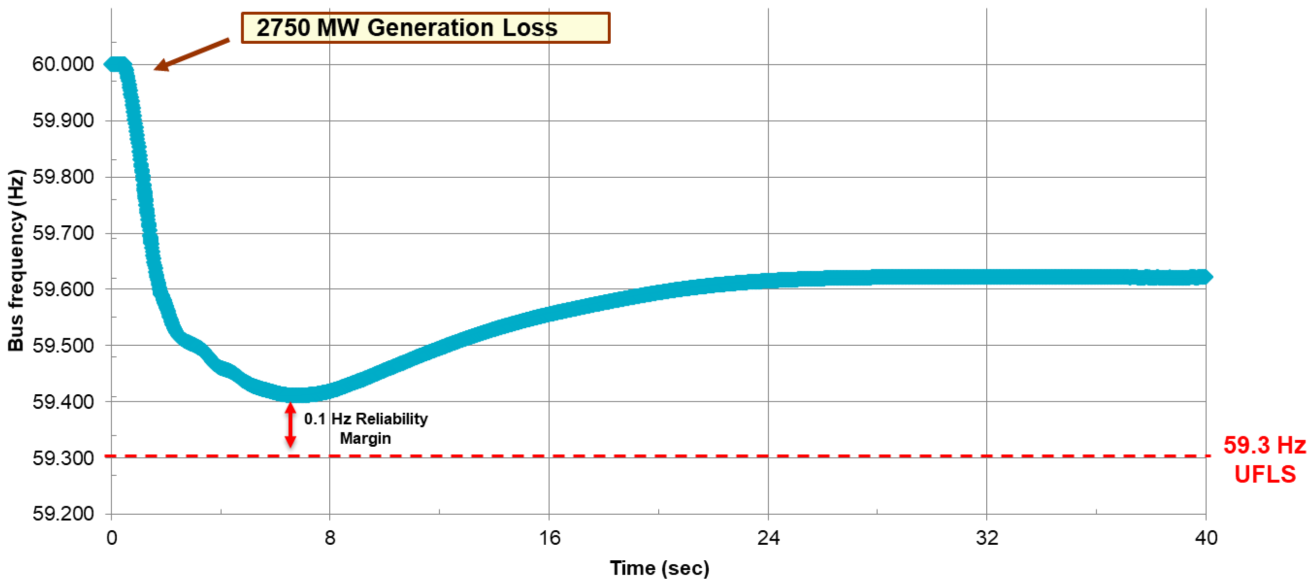


RoCoF – Rate of Change of Frequency

ERCOT

Quantifying Frequency Containment Reserve

- After a generator trip, to arrest system frequency above involuntary underfrequency load shedding trigger (UFLS), frequency containment reserves are used
- In ERCOT Responsive Reserve Service (RRS) is procured to provide frequency containment
- RRS can be provided by generators through governor response (also called PFR) or
- Load Resources with underfrequency relays, through 0.5 second step response at 59.7 Hz



- ERCOT used to procure 2800 MW of frequency containment reserve for all hours
- Studies shown that during lower inertia times, due to higher RoCoF after generation trip this amount is not sufficient

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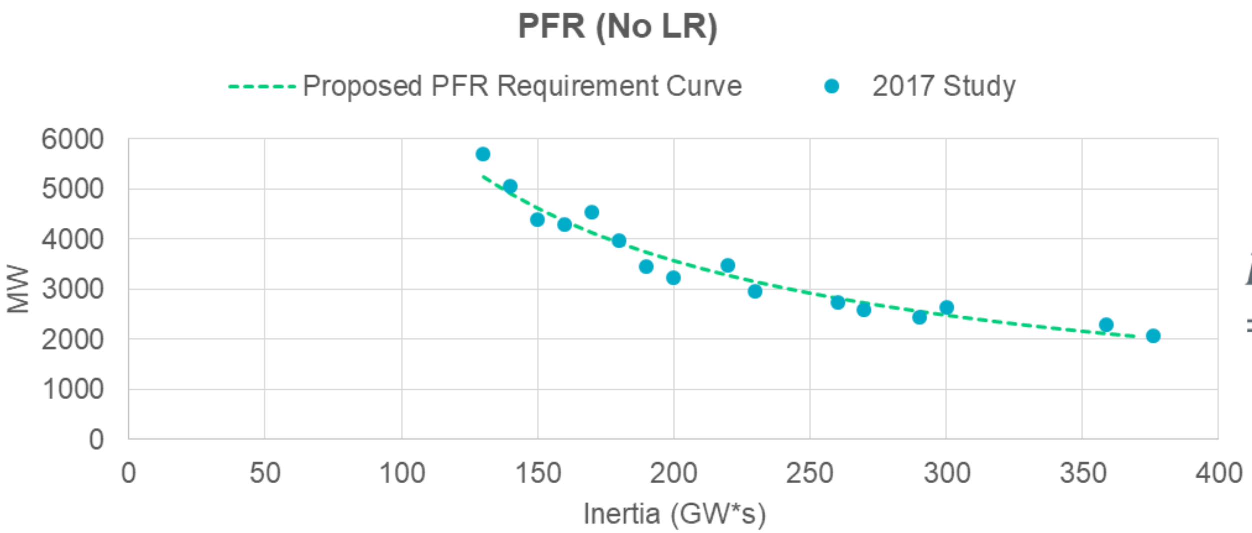
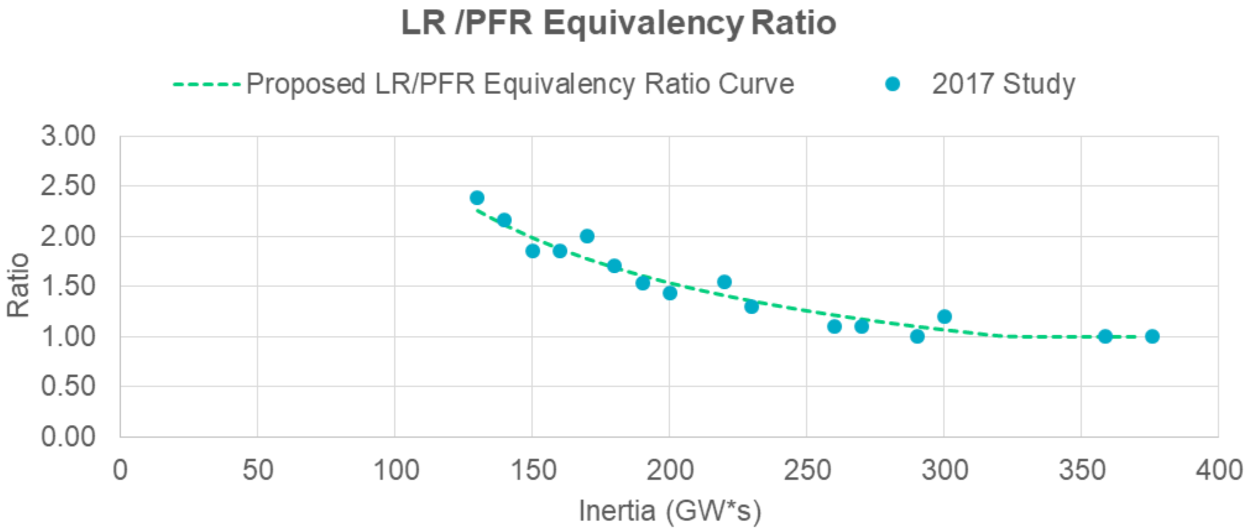
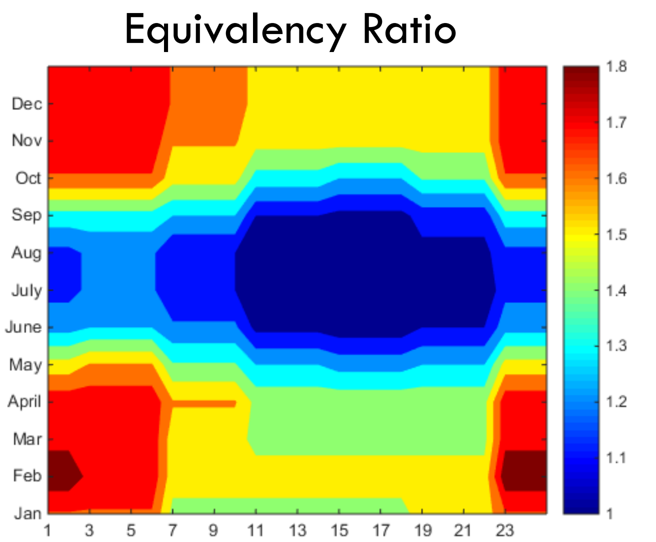
RRS Requirements in ERCOT

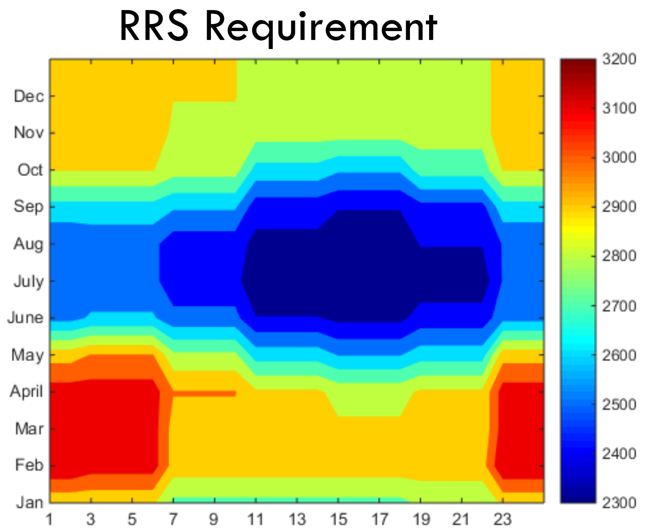


$$PFR(No\ LR) = 399275 \times Inertia^{-0.890}$$



$$LR/PFR = 173.28 \times Inertia^{-0.892}$$





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Source: Weifeng Li, ERCOT

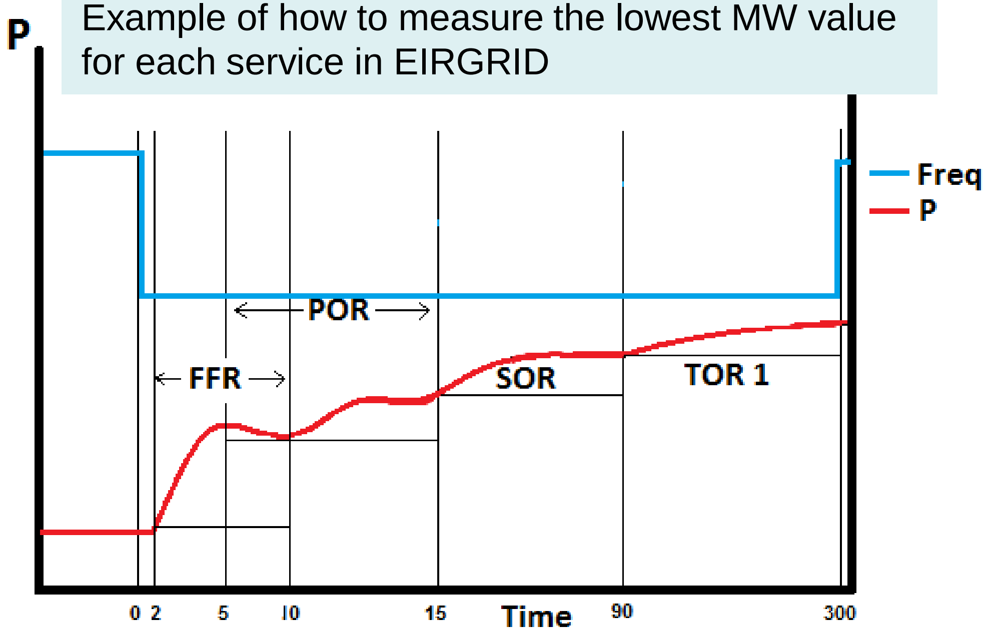
EIRGRID

Quantifying Primary Operating Reserve (POR)

(EIRGRID uses the term POR for PFR)

- EirGrid contract POR to contain frequency to above code requirement of 49.0Hz
  - ✓ **POR must reach contracted volume of response within 5 seconds**
- POR is scheduled to be at least 75% of the single largest infeed
  - ✓ **Single largest infeed varies in real time with dispatch and is at most 500MW**
- FFR is procured under DS3 System Services and is in use today
- Have deployed a specific, fixed scheme to contain over frequency after the loss of an exporting HVDC interconnector
  - ✓ **Wind generation is tripped in stages at 50.5Hz and above**

Example of how to measure the lowest MW value for each service in EIRGRID



http://www.eirgridgroup.com/site-files/library/EirGrid/Aggregators-OR-Test-Report-Template.docx

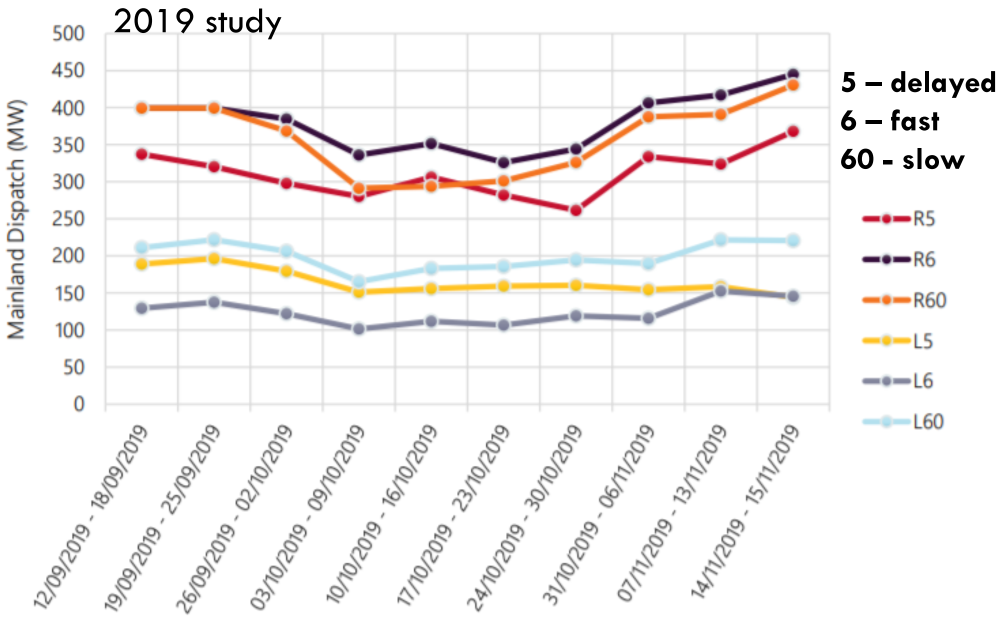
In 2020, 866MW of POR available in Ireland and 449MW in Northern Ireland Also, 638MW of FFR in IE and 154MW of FFR in NI, 500MW Largest Contingency in IE

https://www.eirgridgroup.com/site-files/library/EirGrid/DS3-System-Services-Regulated-Arrangements-Gate-2-Procurement-Summary.pdf

AEMO

Quantifying Frequency Containment Reserves

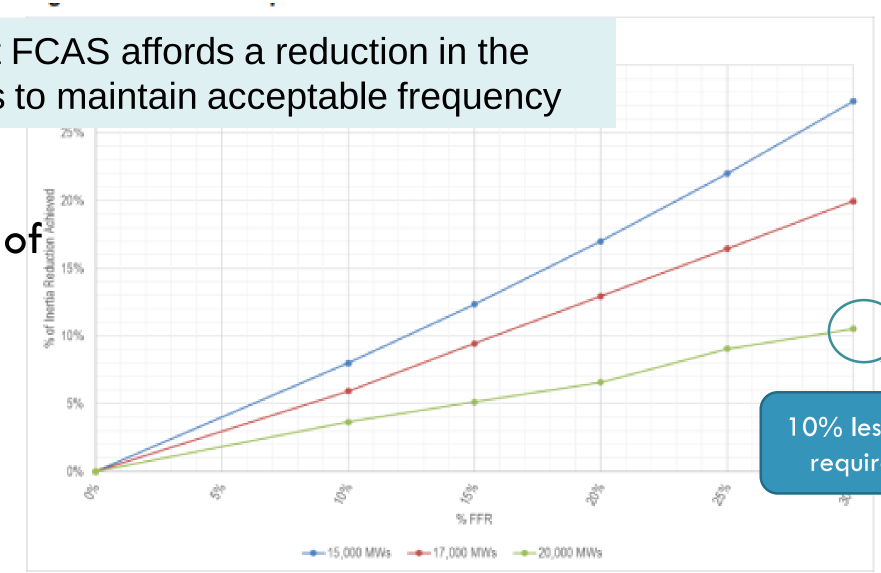
- Contingency FCAS for containment is procured as fast raise/lower (6s) and slow raise/lower (60s)
  - ✓ **Slow services do not need to act if frequency recovers above 49.9Hz (or below 50.1Hz) within 6 seconds**
  - ✓ **A delayed FCAS service acts as a frequency restoration service**
  - ✓ **Regulation services exist for a 15mHz range**
- Volume procured = Largest Loss – Load Relief
  - ✓ **Loss varies in real time**
  - ✓ **Load relief being reduced from 1.5% to 0.5% over time**



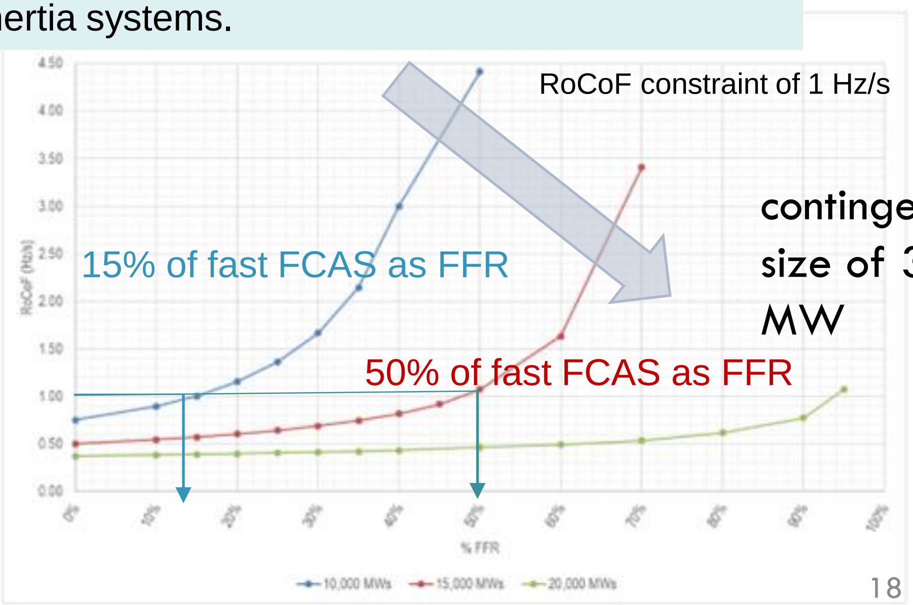
https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/2019/update-on-contingency-fcas-nov-2019.pdf

Mix of FFR and fast FCAS affords a reduction in the inertia requirements to maintain acceptable frequency

contingency size of 300 MW



FFR is more effective for low inertia systems compared to high inertia systems.



contingency size of 300 MW

https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Inertia_Requirements_Methodology_PUBLISHED.pdf

International experience and Challenges associated with high IBR

Dr. Nilesh Modi

Principal Engineer, Australian Energy Market Operator (Australia)

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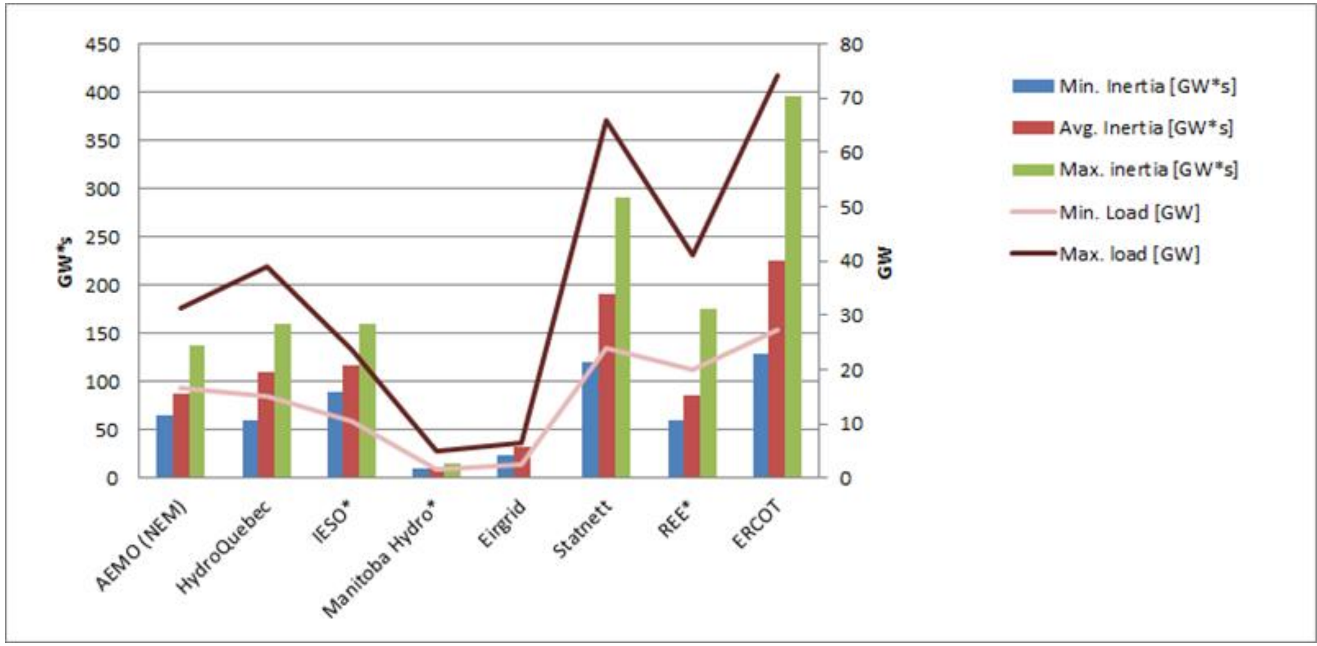
International experience

Frequency control, fast frequency response and minimum inertia levels

- Survey of International organisations through CIGRE network
- System Characteristics
  - ✓ Size of the system, nominal frequency range, inertia
- Frequency Control Requirements
  - ✓ Determination of quantity
    - Assumptions applied
    - Load inertia/relief, response time
  - ✓ Procurement of the service
    - Technology neutral
    - Market based or contracted
- Fast Frequency Response
  - ✓ Definition, requirements and procurement
- Minimum inertia levels
  - ✓ Definition and determination
  - ✓ Management of inertia levels



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International experience

Calculation of frequency control reserve

- Amount of frequency control requirements
  - ✓ Size of the contingency
  - ✓ Inertia
  - ✓ Load damping/relief
- Load relief
  - ✓ AEMO (Australia), Amprion (Germany), Coordinador Eléctrico Nacional (Chile), Japanese TSP (Japan), ERCOT (Texas), Hydro-Quebec (Canada), Statnett – Nordic (Denmark), Swissgrid (Switzerland), TenneT TSP B.V. (Netherlands)
    - 0.6 % to 1.5%
  - ✓ EirGrid (Ireland), IESO (Canada), Manitoba Hydro (Canada), ONS (Brazil), PJM (USA)
    - No load inertia/relief

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International experience

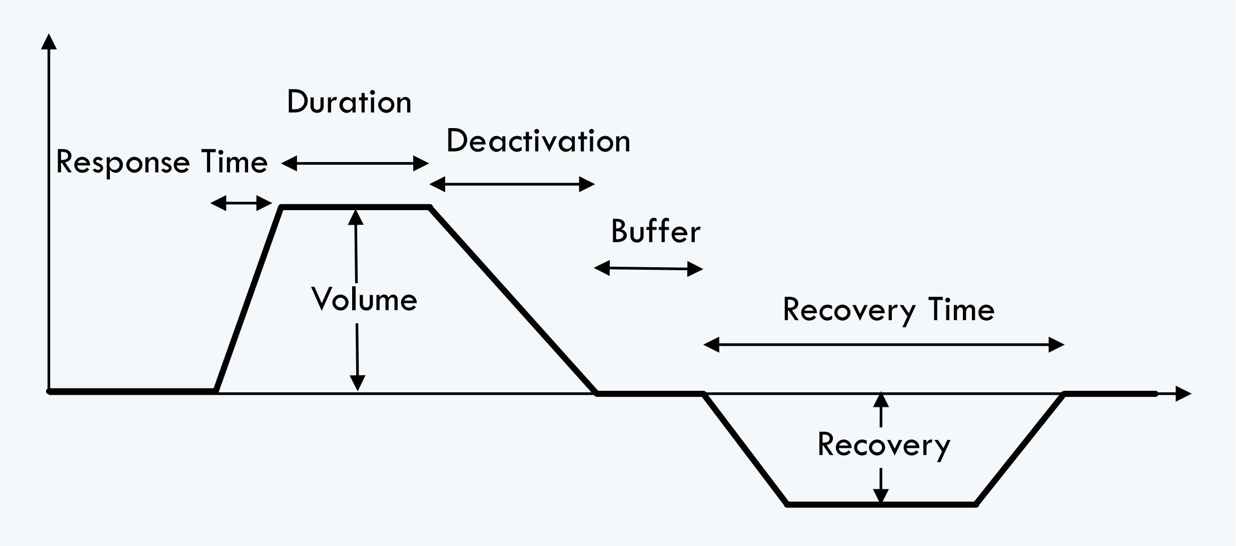
Procurement of frequency control reserve

- Market based
  - ✓ AEMO (Australia), Amprion (Germany), Statnett – Nordic (Denmark), ERCOT (USA)
- Reliability criteria
  - ✓ ONS (Brazil), Hydro-Quebec (Canada), Manitoba Hydro (Canada), TenneT TSO B.V. (Netherlands), Swissgrid (Switzerland), EirGrid (Ireland)
- Mandatory for all generators
  - ✓ Red Eléctrica de España (REE)

Fast Frequency Response

Definition and Characteristics

- **Fast Frequency Response**: power injected to (or absorbed from) the grid in response to changes in measured or observed frequency during the arresting phase of a frequency excursion event to improve the frequency nadir or initial rate-of-change of frequency
- Characteristics
  - ✓ Type of control (Static or Dynamic)
  - ✓ Trigger
  - ✓ Speed of Response/Full Activation Time
  - ✓ Sustaining time
  - ✓ Magnitude/volume of response
    - Penalty for overprovision
  - ✓ Recovery time
  - ✓ Repeatability
  - ✓ Symmetry
  - ✓ Procurement

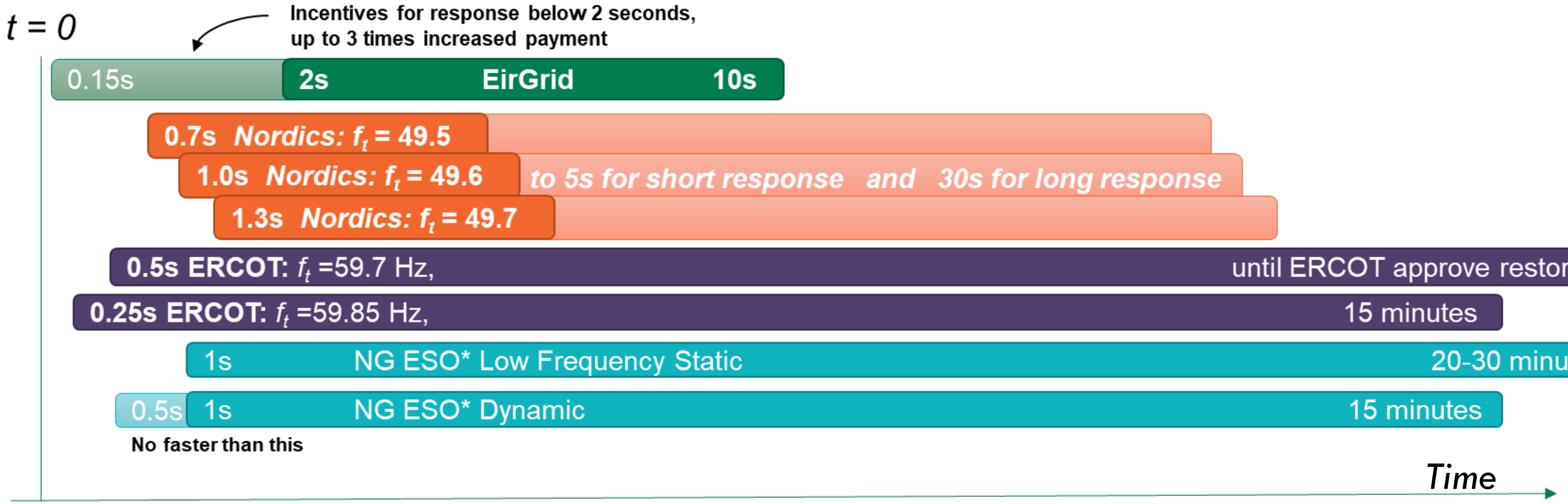


Fast Frequency Response

Characteristics

- Response time
  - ✓ ONS (Brazil) and CEN (Chile): < 1 sec and up to 5 sec
  - ✓ EirGrid (Ireland): < 2 sec
  - ✓ ERCOT (Texas): 0.25 sec and 0.5 sec
  - ✓ AEMO (Australia): < 1 sec

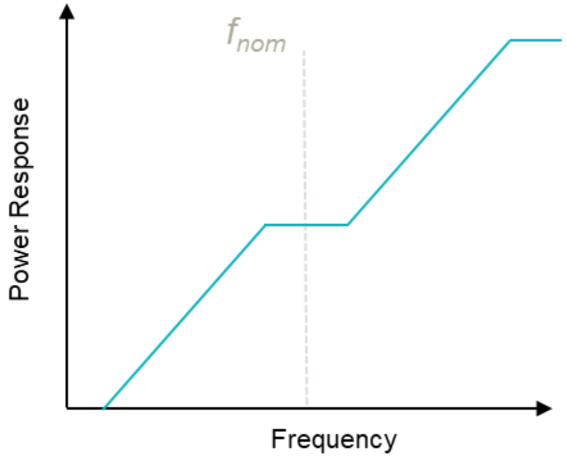
- Duration
  - ✓ ONS (Brazil): up to 5 sec
  - ✓ CEN (Chile) : at least 5 min
  - ✓ EirGrid (Ireland): at least 8 sec
  - ✓ ERCOT (Texas): 15 min or 1 hour

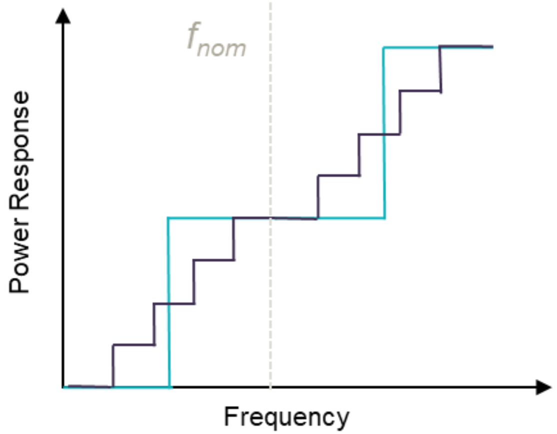


Fast Frequency Response

Types of response

- Eirgrid (Ireland)
  - ✓ **Dynamic response (~proportional response)**
  - ✓ **Stepped static response**
  - ✓ **Static response**
- ERCOT (Texas)
  - ✓ **< 5% droop with ±17 mHz**
- AEMO (Australia)
  - ✓ **Continuous response (~proportional response)**
  - ✓ **Switched response**





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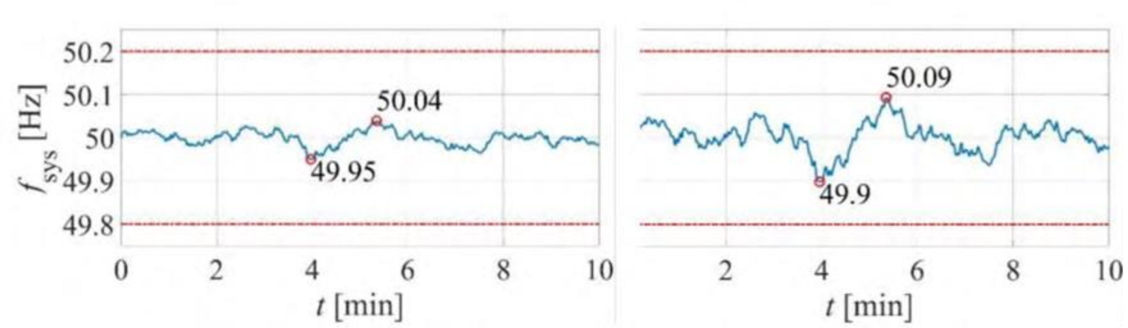
Challenges associated with increasing non-synchronous RES penetration levels

- Contingency size
  - ✓ Large off shore/ on shore connections with single transmission circuit to main grid
  - ✓ Energy deficit
- Reduction in inertia
  - ✓ Frequency nadir and RoCoF
- Frequency control services
  - ✓ More intermittency need more regulation
- Emergency frequency control scheme



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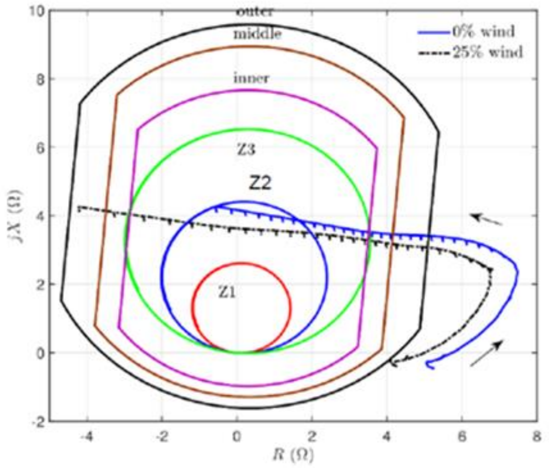
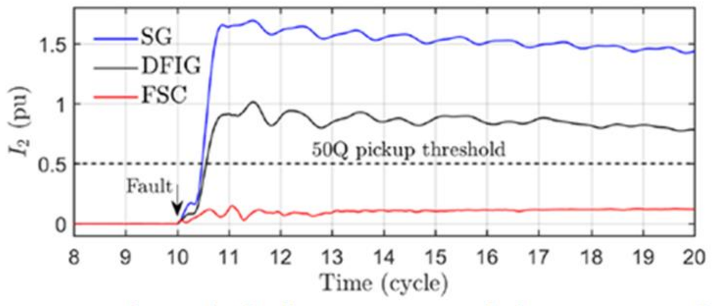
Challenges associated with increasing non-synchronous RES penetration levels

System protection

- Over current protection
  - ✓ Lower fault current
- Distance protection
- Power swing blocking and out of step tripping
  - ✓ Much faster power swings
- Negative sequence based protection schemes
- Anti-islanding protection
  - ✓ Vector shift relay
  - ✓ RoCoF based relay





Management of Minimum Inertia – International Experience

Dr Diptargha Chakravorty

Senior Consultant, TNEI Services, UK

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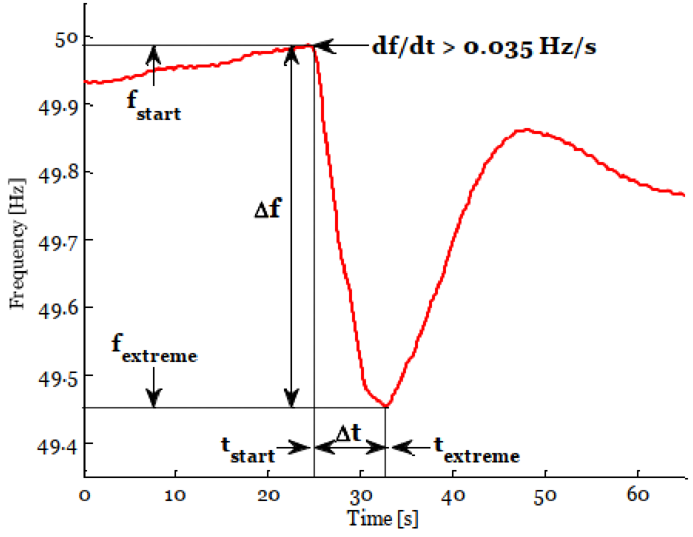
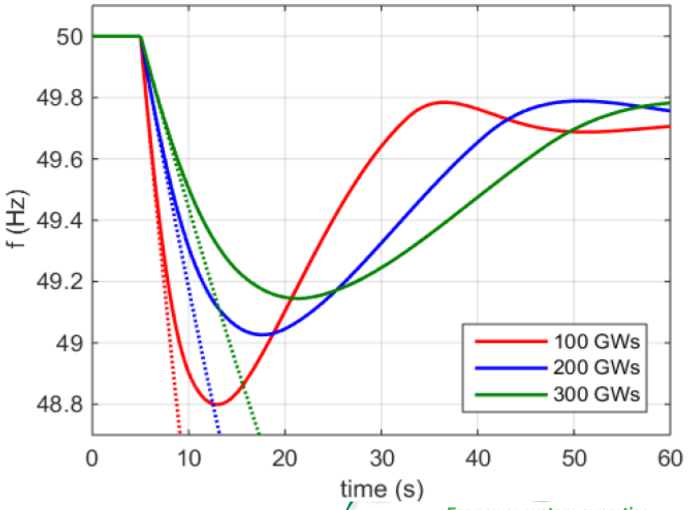
Frequency response indicators

Low inertia issues

- Several indicators to assess the impact of a disturbance
- The maximum frequency deviation can be expressed as a function of the power imbalance and the effective kinetic energy in the system
- To maintain the security of a system under low inertia scenarios, measures currently adopted in the operational timescale are based on following three approaches
  - Calculating critical inertia floors e.g. AEMO, ERCOT, EIRGRID
  - Maximum RoCoF constraint as defined by the grid code e.g. AEMO, EIRGRID, NGESO UK
  - Real-time inertia monitoring and forecasting e.g. ERCOT, EIRGRID, Nordic TSOs





[source]: https://eepublicdownloads.entsoe.eu/clean-documents/Publications/SOC/Nordic/Nordic_report_Future_System_Inertia.pdf

AEMO – Australia

Secure operating level of inertia

Step 1
- Identification of relevant contingencies while islanded
- Loss of largest generating unit/system or load

Step 2
- Assess frequency trajectory following contingencies identified in step 1
- Establish relationship between inertia levels and required FCR

Step 3
- A linear relationship assumed between FCR availability and inertia
- This characteristic can be determined for an islanded system/ sub-network

Step 4
- Identify the secure operating level of inertia, given by the amount consistent with both the availability of FCR and the FCR required for acceptable freq

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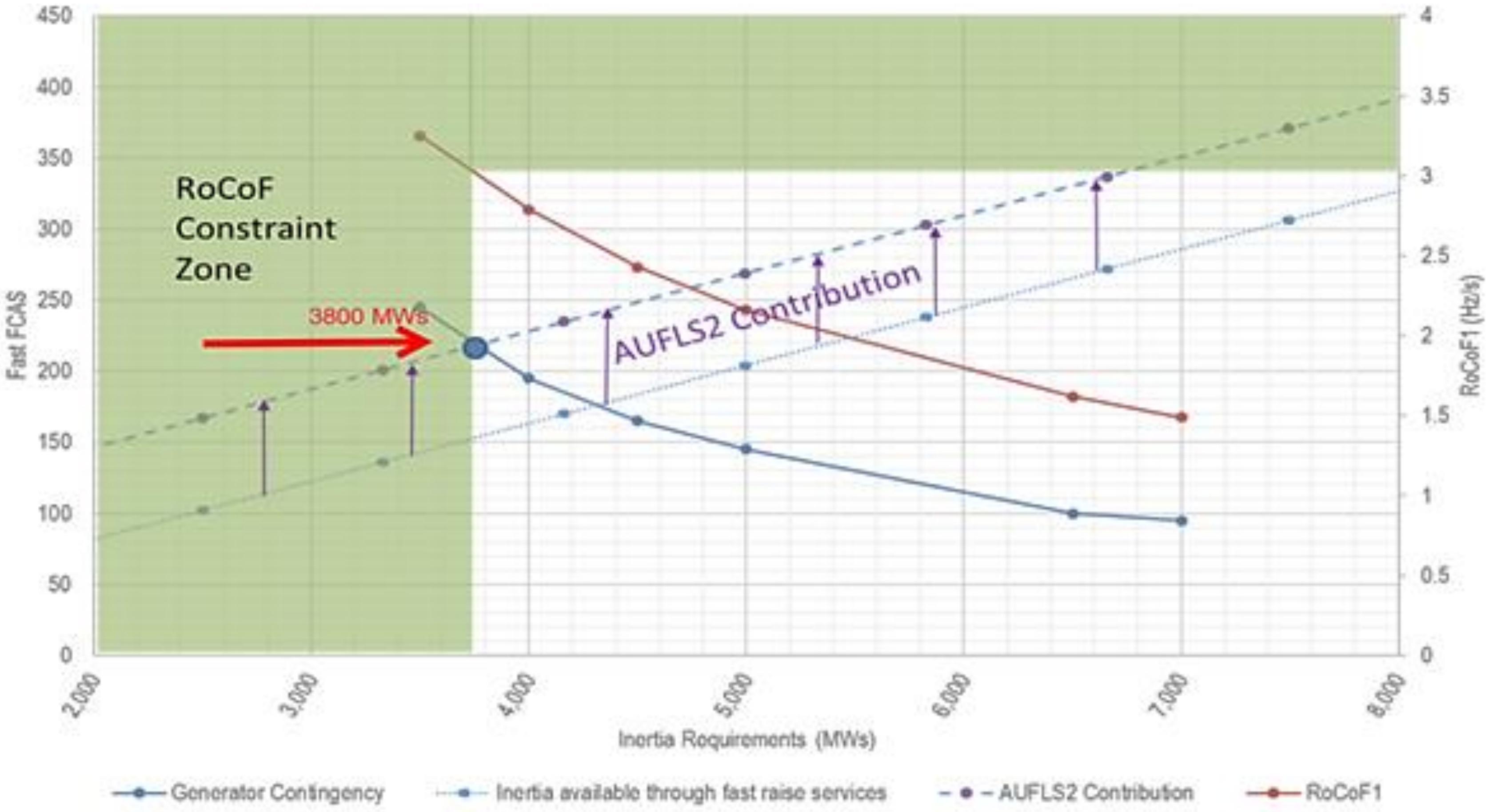
Min inertia calculation

Tasmania Example



- Max RoCoF limited to ±3Hz/s, measured using a 100ms averaging window
- AUFLS2 provides additional fast FCR ≈ 65MW
- AUFLS2 uses calculated RoCoF to trip variable number of load blocks when the trigger frequency is reached
- Secure operating level of inertia in this example is 3,800MWs

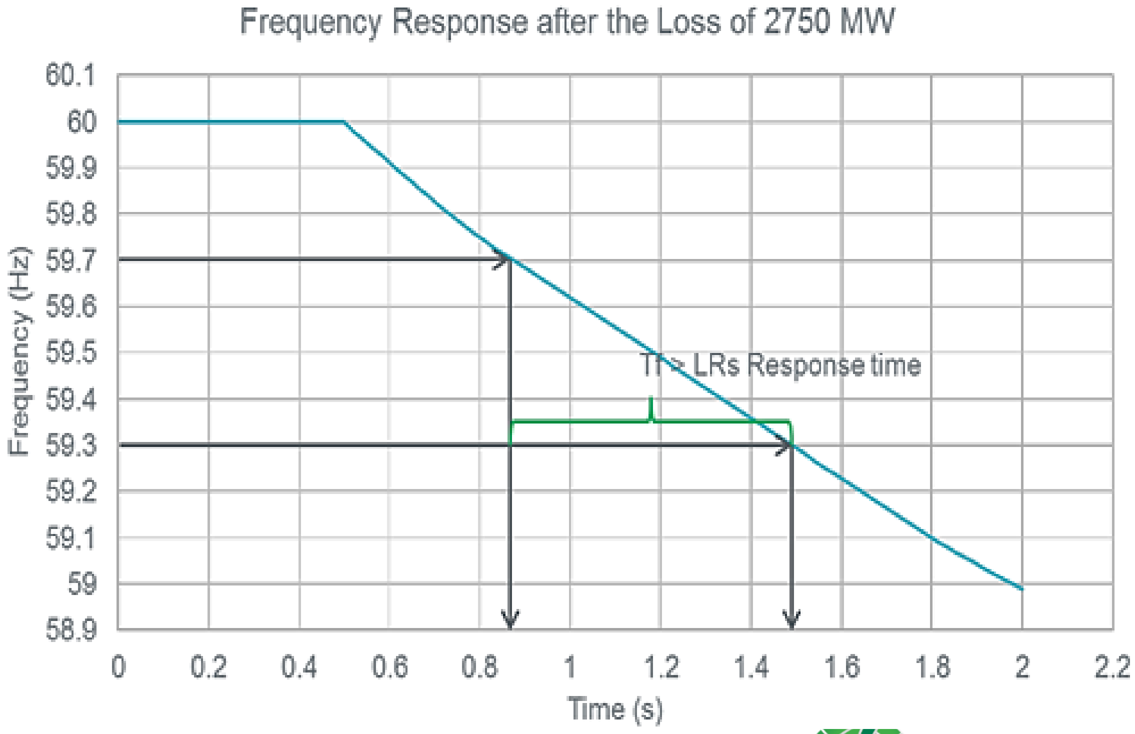
- AUFLS2 – Adaptive under-frequency load shedding scheme
- FCR – Frequency containment reserve

ERCOT – USA (Texas)

Critical inertia

Defined as the minimum system inertia that is necessary to ensure ERCOT's FFR resources can be effectively deployed before frequency drops below 59.3Hz following the simultaneous loss of 2750MW.

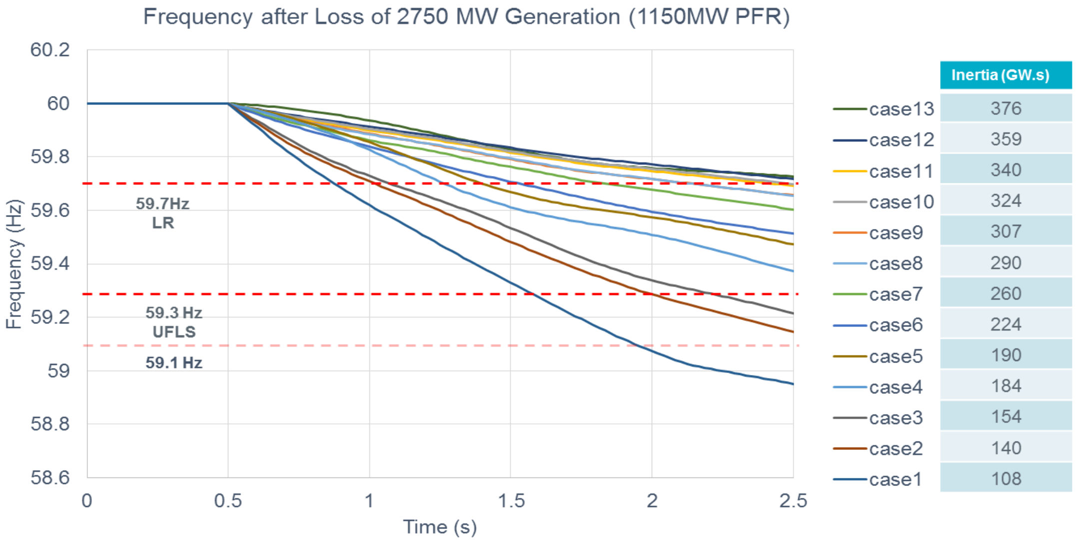
- Load Resources provide Responsive Reserve Service (RRS) in about 25 cycles after the frequency drops below 59.7Hz
- First stage under-frequency load shedding (UFLS) trigger level is set at 59.3Hz in ERCOT
- If the system inertia is below the critical level then the Load Resources may not have sufficient time to provide RRS to arrest the frequency before it reaches UFLS trigger level

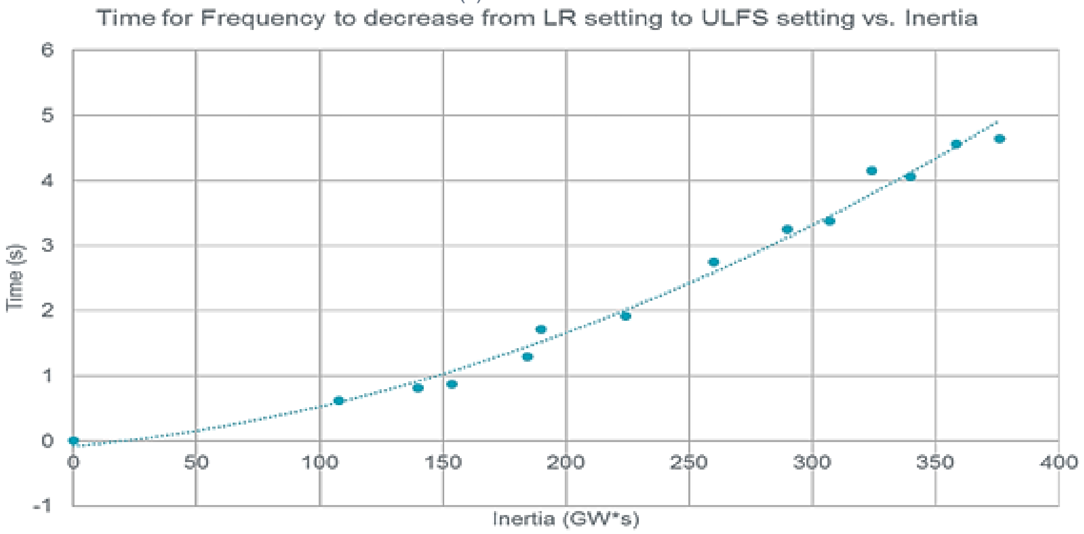


Source: Weifeng Li, ERCOT

Critical inertia calculation

Inertia regression





- A range of dynamic simulations are carried out to identify the time taken by the frequency to decrease from 59.7Hz to 59.3Hz
- 1,150MW of primary frequency response from generation is considered, no support from Load Resources
- Inertia corresponding to FFR within 25 cycles (0.416s) is 94GWs
- Considering safety margins and current operating practices, ERCOT’s critical inertia is set as 100GWs
- 130GWs is the lowest inertia experienced so far

Source: Weifeng Li, ERCOT

EIRGRID – Ireland

Inertia management guideline

- Several studies are carried out to assess the effect of largest infeed loss on the system when there is very high wind and low system inertia
- If the MW's from the largest infeed are too high (e.g. interconnector), loosing the infeed could mean that the rate of decline of the system frequency is high enough to trip off DERs by RoCoF protection, causing the frequency to decrease even further
- For a given system inertia, the largest infeed loss that can be safely accommodated is calculated as

$$\Delta P = RoCoF \times \frac{2H}{f}$$

- The RoCoF limit as per the grid code is 0.5Hz/s and the minimum operating inertia level has been presently set at 23GWs

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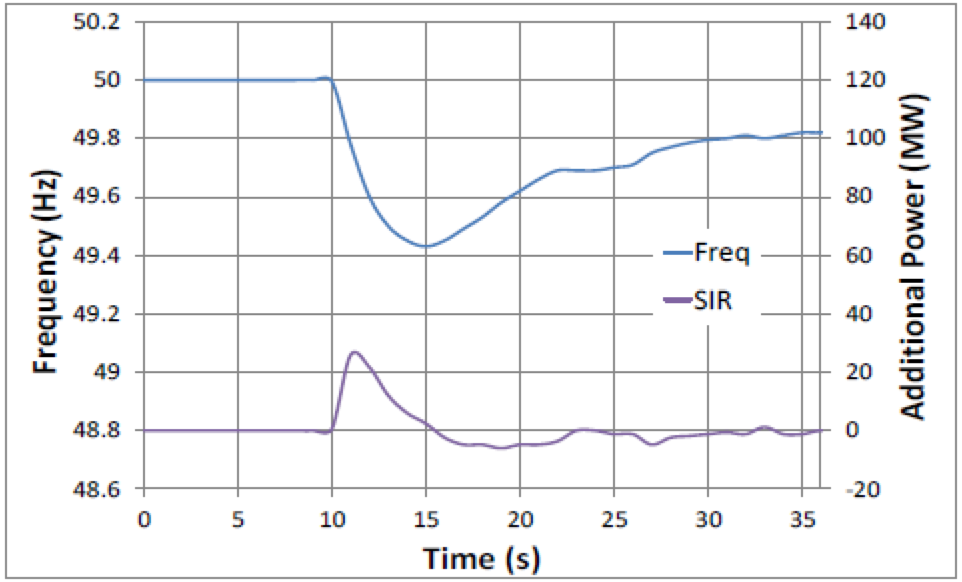
Synchronous Inertial Response (SIR)

DS3 system services

SIR = stored kinetic energy (at 50Hz) of a dispatchable synchronous providing unit × SIR Factor (SIRF)

$$SIRF = \frac{stored\ kinetic\ energy}{Minimum\ stable\ generation}\ [s]$$

- stored kinetic energy = $H \times S_n$ [MWs]
- H = inertia constant [MWs/MVA]
- S_n= rated apparent power [MVA]
- Synchronous providing unit = synchronous generator, synchronous condenser or synchronous motor



Sources:
http://www.eirgridgroup.com/site-files/library/EirGrid/DS3-SS-Protocol-v3.0.pdf
http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-DS3-System-Services-_Regulated-Arrangements_draft.pdf

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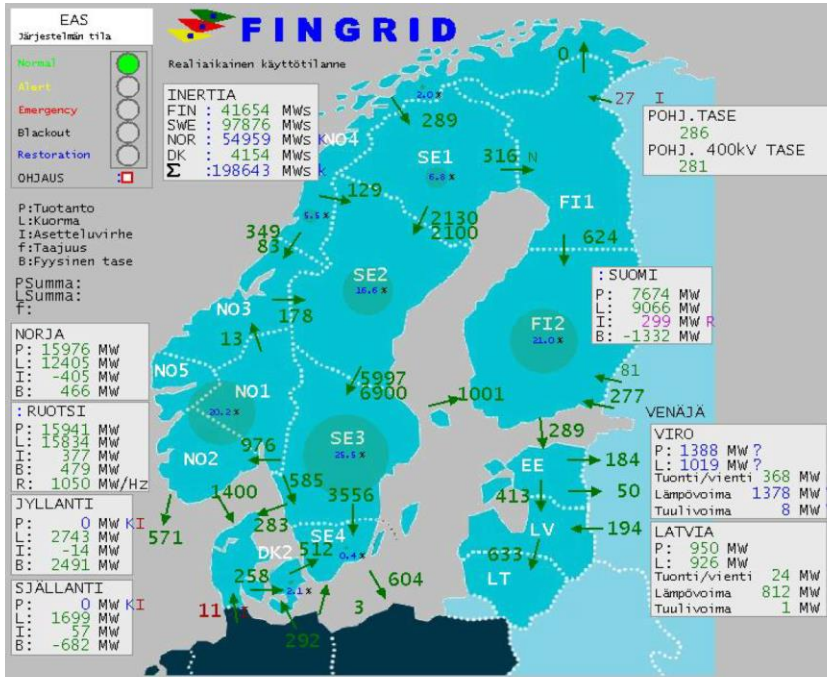
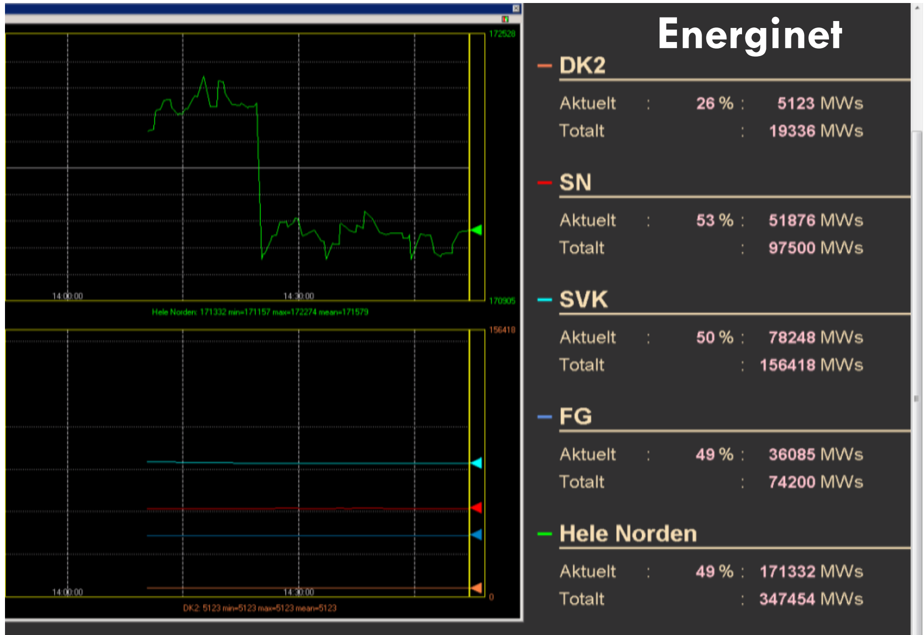
Nordic TSOs – Sweden, Norway, Finland, Denmark

Inertia monitoring and forecasting

- Circuit breaker (CB) positions and power measurements are used
- If CB position is closed, or MW>10% of nominal value then generator assumed to be synchronously connected
- Each TSO made real-time estimation of kinetic energy of its own area
- Kinetic energy of the whole Nordic system is around 390GWs



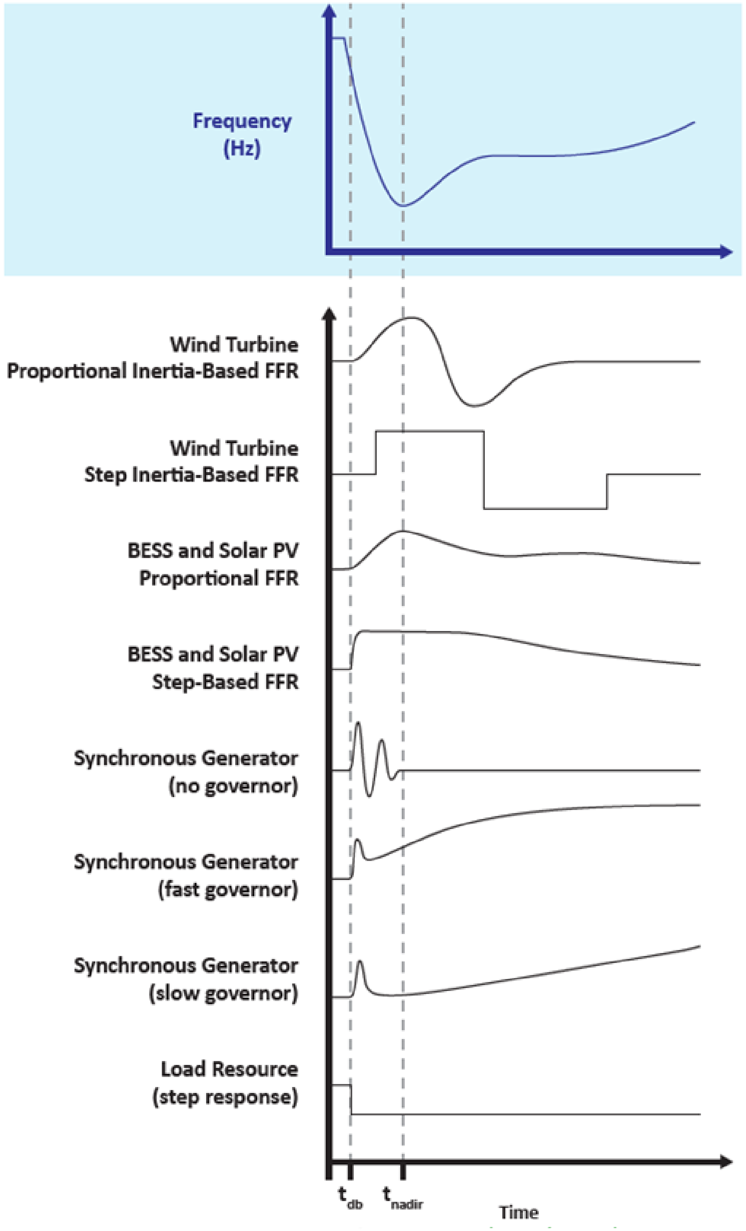


[source]: https://eepublicdownloads.entsoe.eu/clean-documents/Publications/SOC/Nordic/Nordic_report_Future_System_Inertia.pdf

Frequency Response

Different technology types

Technology	Synch inertia	FFR type	FFR response time [s]	Sustained Response
Synchronous generator (incl. synch pumped hydro and compressed air storage) and synchronous condenser	Yes	-	-	-
Flywheel (synch connected)	Yes	Proportional response (IBFR) to freq or RoCoF	<0.01	<15min
Loads	Yes (only for motor loads)	Step response	0.25-0.5	Yes
Wind turbines	no	Step or proportional response (IBFR) to freq or RoCoF	0.5-1	Only for a few seconds, may have a recovery phase
Solar PV	no	Step or proportional response to freq or RoCoF	0.5-1	Yes (depends on solar condition)
Battery storage	no	Step or proportional response to freq or RoCoF	0.2-1	Yes (depends on battery SoC)
Smart load	no	Proportional response to freq or RoCoF	0.5-1	Yes



- IBFR – inertia-based frequency response

Inertia as an Ancillary Service & Existing Grid Code / Policies

Adham Atallah

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Inertia as an Ancillary Service

Introduction

- A number of power systems around the world is experiencing decline in synchronous inertia due to high penetration of inverter-based resources
- For a smaller subset of these power systems synchronous generating units, committed for energy production and provision of reserves, do not bring about sufficient levels of synchronous inertia
- These power systems started procuring inertia
  - ✓ as Ancillary Service product
  - ✓ or via tenders

Inertia as an Ancillary Service

Synchronous Inertia Response (SIR) Service in Ireland

- SIR service is implemented in Ireland as a part of DS3 System Services program
- $SIR = \ Stored\ Kinetic\ Energy\ x\ SIRF,$

where $Stored\ Kinetic\ Energy\ [MWs] = H \cdot S_n$ and $SIRF[s] = \frac{Stored\ Kinetic\ Energy}{Minimum\ Generation}$

- SIRF is set to 45 s if minimum generation is 0 or less
- $$SIR\ Trading\ Period\ Payment = SIR\ Available\ Volume \cdot\ SIR\ Payment\ Rate \cdot\ SIR\ Scaling\ Factor \cdot\ Trading\ Period\ Duration'$$

a) **SIR Available Volume** expressed in [MWs^2]) is the Available Volume of the Providing Unit

b) **SIR Payment Rate** is expressed in [€/MWs^{2}h] applicable to SIR

c) **SIR Scaling Factor** = SIR Locational Scalar x SIR Temporal Scarcity Scalar; and

d) the **Trading Period Duration** expressed in [h]

- The Scaling Factors are implemented to ensure that the required inertia is available where needed and, additionally, incentivized during times when it is needed the most

Inertia as an Ancillary Service

Great Britain Tender - Phase 1

- NGESO highlighted in the potential risks associated with the decline in transmission connected large fossil fuel generations. By stability, NGESO mean the stability of voltage and frequency and to ensure a safe, secure and economic operation of the transmission network.
- A detailed assessment was done for Scotland and a high level assessment was carried out for other areas. Based on the assessment criteria in January 2020 NGESO awarded 12 tenders to 5 providers across 7 sites, securing a total of 12.5GVAs of inertia until 31st March 2026.
- Among other aspects the assessment criteria includes:
  - ✓ Short circuit current contribution of >=1.5p.u. of plant’s MVA rating, operation across a range of minimum short circuit levels (expected to be within a range of 3-13kA)
  - ✓ Inertia (MVA.s) contribution of >=1.5p.u of plant’s MVA rating, the contribution should not degrade faster than the degradation of a 12s inertia constant
  - ✓ Ride through faults lasting for 140ms with a voltage depression of 0-0.3p.u.
  - ✓ Solution is expected to provide reactive current injection into a retained voltage depression at the point of connection within 5ms of the event

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Existing Grid Code / Policies

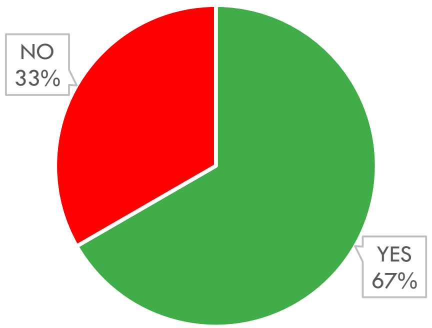
Overview

Entity	Country	Definition of Minimum Inertia Levels	Minimum Inertia Levels Calculation Methodology	Frequency Containment Reserves	Fast Frequency Response	Other Mitigating Measures
AEMO	Australia	YES	YES	YES	YES[1]	YES
ONS	Brazil	NO	NO	YES	YES	YES
Hydro Quebec	Canada	YES	YES	NO	NO	YES
IESO	Canada	YES	YES	YES	YES	NO
Manitoba Hydro	Canada	YES	NO	NO	YES	YES
Coordinador Electrico Nacional	Chile	YES	NO	YES	NO	NO
Amprion	Germany	YES	YES	YES	YES	YES
Eirgrid	Ireland	YES	YES	YES	YES	YES
CRIEPI	Japan	NO	NO	NO	NO	NO
TenneT	Netherlands	NO	NO	YES	NO	NO
Statnett	Nordic	YES	YES	YES	NO	YES
REE	Spain	NO	NO	YES	YES	NO
Swissgrid	Switzerland	YES	YES	YES	YES	NO
ERCOT	USA	YES	YES	YES	YES	YES
PJM	USA	NO	NO	NO	NO	NO

Existing Grid Code / Policies

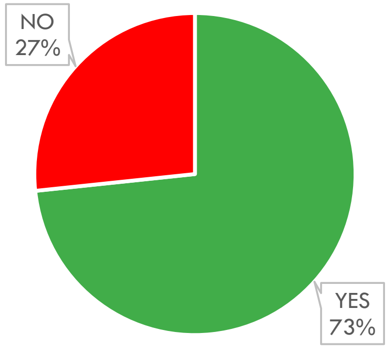
Overview

Definition of Minimum Inertia Levels

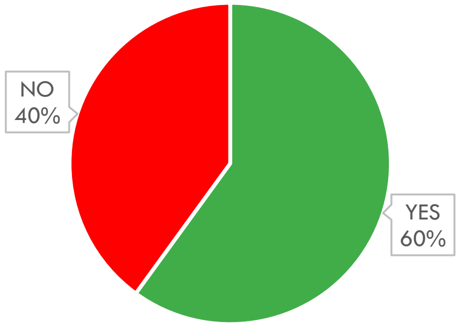


Min. Inertia Levels Calculation Methodology

Frequency Containment Reserves



Fast Frequency Response



Other Mitigating Measures

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Existing Grid Code / Policies

Conclusion

- Transmission system operators define in their grid code and policies the minimum requirements to operate their system securely and with a high reliability. Classically these requirements are steady-state voltage and frequency ranges, voltage and frequency dynamic stability and power quality.
- Inertia is becoming a challenging issue in parts of some transmission systems or transmission systems with specific characteristics leading the TSO to state specific related requirements in their respective grid codes.

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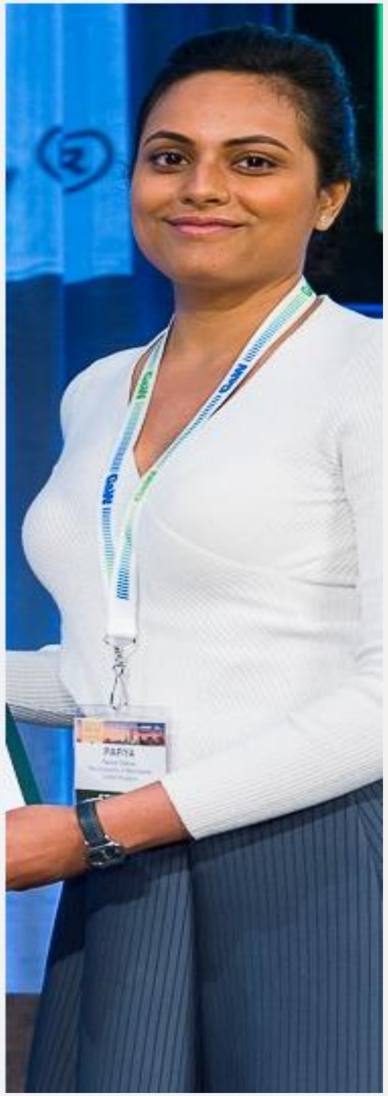
Concluding Remarks



Dr. Papiya Dattaray, JWG Secretary

Scientist / Engineer III, EPRI

Key Takeaways

Inertia is a growing concern for many utilities

- RoCoF and/or nadir
- System islanding, unwanted blackouts, cascade loss of generation, protection misoperation on large power swings, large RoCoF

Studies are common to determine Inertia shortfall in future studies and guard against security issues by

- Identifying an Inertia floor
- RoCoF Constraints
- Frequency response service procurements – FFR/ FCR services, definitions vary across TSO's to determine best solution
- Market based, contracted or mandatory

Utilities are looking and voltage and frequency together for inverter-based generation – Stability product as opposed to separate frequency/voltage products (Stability pathfinder)

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Further Important topics

Refer to the TB

Modelling

Modelling of Renewable energy generation both utility scale and residential, DER and its aggregate representation for transmission planning, composite load models, protection models and parameterization

Control

Inverter based generation is all about the control – **control philosophies** will hugely impact power system performance (Current source vs Voltage source, PLL instability in weak grid, grid parallel/forming, RMS vs. Full 3ph unbalanced).

Weak Dynamic Coupling

Dispersed centers of Inertia connected to each other with weak transmission links making inertia **both a system level and a regional issue.**

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Q & A

Pamela Kamera, JWG Secretary

Senior Engineer, ESP, South Africa

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Thank You