System Operations Challenges the work of CIGRE SC C2

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EU context

Increasing shares of renewables

Development of European Internal Energy Market

Environmental drivers

Green Deal

Carbon neutrality by 2050

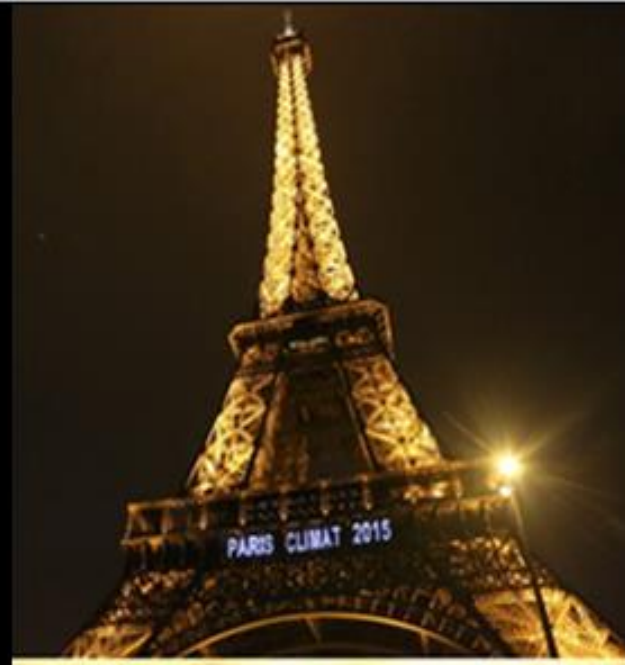
Affordable and cost efficient energy to end customer

by adequate **market design, technological and operational innovations,**

and sufficient **grid capacity** that play a role to balance cross-border supply and demand

Affordable
Competitive
Costumer-centred
Flexible
Non-discriminatory
Secured
Sustainable

Limiting the global average temperature rise well below 2 degrees Celsius above pre-industrial levels are goals of the COP21 Paris Agreement



World Context

Flexibility & Controllability	Observability & Integration	Sustainability & Energy Efficiency	What are the system Needs?
Usage of installed technology capabilities	Cooperation Coordination	Regulation Harmonization	How to achieve the targets?

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Transition to RES
Impact on System Operation

- Especially based on Wind and Solar Energy
- Increased volatility of renewables in the generation mix
- Increased operational uncertainty and risks
- Requires accurate forecast algorithms, predictability is important
- Often has priority and its curtailment is one of the last remedial actions
- Significant share embedded in the distribution network
- Long distance power transmission
- Security of supply under pressure: More volatile and increased power flows
- Volatile Markets and tending to become short-term oriented
- RES not yet structurally providing ancillary services

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Decommissioning of Conventional PP
Impact on System Operation

Synchronous machines have been provided all flexibility needed to operate the power system … And now?

- **Decrease of system inertia**
  - ✓ More frequent, faster and less damped dynamic phenomena are expected (e.g. larger fluctuations in frequency)
- **Reduction of short circuit power level:**
  - ✓ Impact on fault current support
  - ✓ Larger voltage dips and larger propagation of low voltages during disturbances
  - ✓ Impacts the operation of protection relays
- **Impacts the active and reactive power reserves availability**
  Decrease of redispatch possibilities, endangering network security
  Will conventional power plants keep on delivering system supporting services?
- **Prices expected to become more volatile: rise at times without wind or sun**

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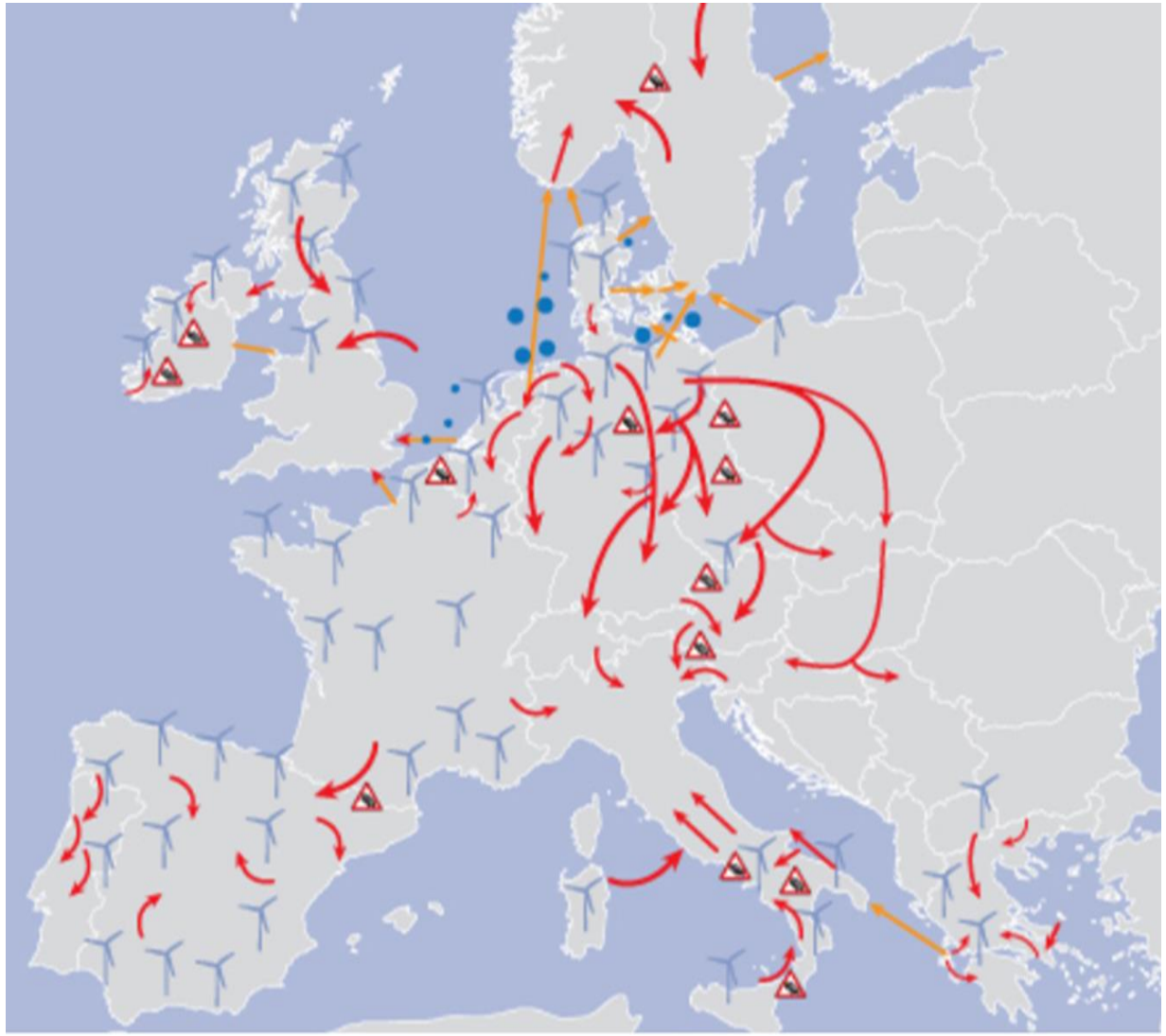
Operational Challenges

The grid is not a copper plate

- Increased **uncertainty due to RES** volatility and **more dynamic markets**
- **Volatile and increased power flows** and **long distance** power transmission
- **Operational complexity**, which requires more **decision support**, **integration and coordination**
- More **Observability and Controllability** is necessary in the power system
- **Optimal dispatch of flexibility options** is needed to guarantee security of supply and affordability.



Need for flexibility?

Strong need for flexibility

Flexible Power Reserves

DSR

Storage and EV

Flywheels

PEIG

Conventional Power Plants

Classical Remedial Actions

Flexible Flow Control

FACTS

DC Links

Automatic Control SPS, WACS

Synchronous Condensers

Integration of new technology

Cooperation and Coordination with DSOs

New requirements for PEID

- **Inertia and Fast Frequency** response
- Enhancement of **disturbance ride through capabilities for voltage and frequency contingencies**
- **Ancillary Services provision** from RES and ESS
- **Active and Reactive power control** using HVDC links or placing converters in end-to-end of corridors
- **Power Oscillation Damping**
- **System restoration support**
- **New Grid forming control concepts -** PE needs to behave as a voltage source, synchronize with others, behave properly in islanded mode, take care of overcurrent limitation, be compatible with conventional machines and other grid following PE.
- **Develop adaptive protection system** - capable of correctly operating in different operating conditions (e.g. with high PE penetration and low short circuit power levels)
- **Adequate network models**

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Need for Observability/Controllability?

Access to "lots" of DATA
Data exchange Platforms

Accurate data FORECAST to reduce the operational uncertainty

EMERGING TOOLS
Big Data Analytics, Artificial Intelligence, Machine Learning for AWARENESS and DECISION SUPPORT
(e.g. Hybrid SE, DSA, WAMS, Optimisation)
New Generation of SCADA EMS systems

Automatic Power Flow Control, SIPS and WACS (PMUs) using fast available flexibility
to keep system Stability
Preparing for a cyber-physical system

More Extreme weather events already today!

An **adequacy situation**, e.g. as this month in California, is different from a **tornado or an earthquake** that will cause permanent damage to the infrastructure.

The consequences of a blackout are also strictly connected to **correct operation protection and control systems**. E.g. during emergency situations that cause UFLS is crucial to keep critical loads in service.

Critical situations e.g. caused by severe weather conditions, **that turned into success stories**, and the lights stayed on:

- **Cold weather operation at MISO** in January 2019 (MISO operated with extreme cold, with unplanned generation outages. The emergency operational procedures were activated and MISO reliably met all obligations)
- **Separation of SA January-February 2020**, the islanding event lasted for 17 days (crucial support also from available flexibility which includes BESS installed and VPP in SA). This occurred during an extremely hot summer in Australia full of many other operational challenges.

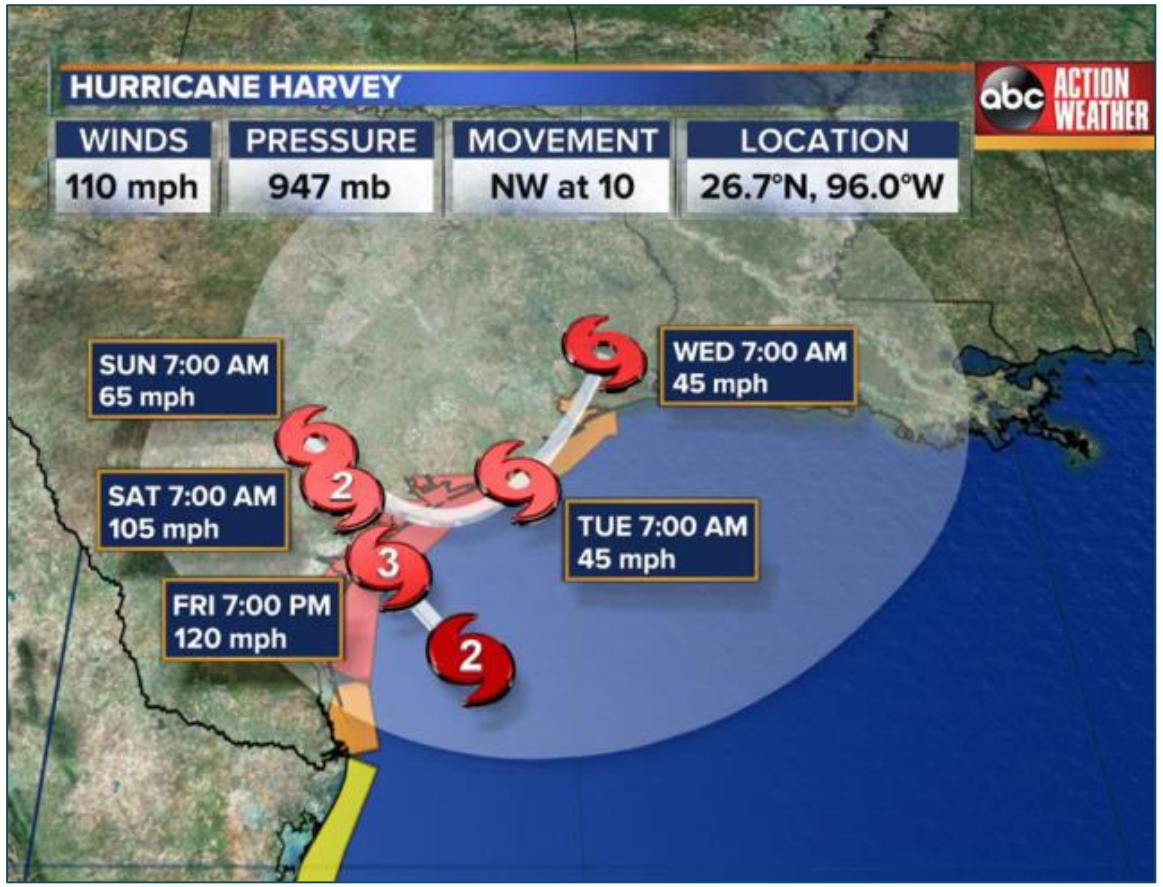
More Extreme weather events already today!

15/08/2020: California USA (source: Preliminary Root Cause Analysis Rotating Outages August 2020)

- **Rolling blackouts in CAISO (Flex Alert)**
  - **Extreme heat in across Western US , expected cloud cover that will reduce PV output, and wildfires threatening power lines**
  - **Electricity demand exceeding the existing electricity resource planning targets**, amplified by the extreme heat.
  - Need for **flexibility**

- **Lessons learned**
  - Update the resource and reliability planning targets
  - Ensure that the generation and storage projects are completed by their targeted dates
  - Increase flexibility: Expedite the regulatory and procurement processes to develop additional resources that can be online by 2021
  - Enhance market practices to ensure they accurately reflect the actual balance of supply and demand during stressed operating conditions

More Extreme weather events already today!



- 130 - 150 mph winds and 12.5 foot storm surge
- 51.88 inches of rainfall causing flooding in 50 counties
- Spawned tornadoes in Texas, Louisiana, Alabama, Mississippi, Tennessee and North Carolina
- 42,000 lightning strikes
- $125 billion in damages

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Welcome to the world of CIGRE

- A global community for the collaborative development and sharing of power system expertise
- Not for profit, established in Paris, France 1921
- A long history as a key player in the development of the power system
- Produces reference publications based on practical experience and analysed data
- An open, engaging, fact-based culture
- Connecting power systems professionals from all over the globe

(https://www.youtube.com/watch?v=HgZE2V-I1NE)

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CIGRE’s Strategic Directions

1. Future Power System
2. Environment and Sustainability
3. Best use of Existing Systems
4. Unbiased Information for all Stakeholders

CIGRE's Domain of Work

Group A – Equipment:

A1 Rotating electrical machines
A2 Power transformers and reactors
A3 Transmission and distribution equipment

Group B – Technologies:

B1 Insulated cables
B2 Overhead lines
B3 Substations and electrical installations
B4 DC systems and power electronics
B5 Protection and automation

Group C – Systems:

C1 Power system development and economics
C2 Power system operation and control
C3 Power system environmental performance
C4 Power system technical performance
C5 Electricity markets and regulation
C6 Active distribution systems and distributed energy resources

Group D – New materials & IT:

D1 Materials and emerging test techniques
D2 Information systems and telecommunication

Strategic Directions of SC C2

	Real-time System Operation and Control	System Operational Planning and Performance Analysis	Control Centre Infrastructure and Human Resources for System Operation
After 2019	+ Increased cooperation and coordination with more active players in the end to end system	+ Impact on system operations from new generation mix	+ Connection with cyber security and vulnerability aspects in control centres
	+ PMU based Wide Area Control	+ Impact assessment on integration of new technologies	
	+ Operation and control of new technologies	+ Restoration in evolving environment + Operational Resilience	+ WAMS system requirements and their integration within control centres
	+ Information and data exchange in real-time operation		
	+ observability, controllability and flexibility (new ancillary services and congestion management schemes)	+ Harmonisation and preparation of operational requirements in new grid codes	+ New tools for decision support and situational awareness
	+ Impact of Sector Coupling in the operational framework of the electrical system		+ new skills for operators incl. crisis management for a resilient power system

Overview of WG led by SC C2

- Real time System Operation and Control
- System Operational Planning and Performance Analysis
- Control Centre Infrastructure and Human Resources for System Operation
- Joint Working Groups

SC C2 Chair
Susana de Graaff (NL)

Strategic Advisory Group
Susana de Graaff (NL)

SC Secretary
Vinay Sewdien (NL)

Publication Advisor
Anjan Bose (US)

Tutorial Advisory Group
Jens Jacobs (DE)

WG C2.17
Wide area monitoring systems – Support for control room application

Walter Sattinger (CH)

WG C2.24
Mitigating the risk of fire starts and the consequences of fires near overhead lines for System Operations

Frank Crisci (AU)

WG C2.25
Operating Strategies and Preparedness for System Operational Resilience

Jens Jacobs (DE)

WG C2.26
Power system restoration accounting for a rapidly changing power system and generation mix

Babak Badrzadeh (AU)

WG C2.39
Operator Training in Electricity Grids at Different Control Levels and for Different Participants/Actors in the New Environment
Jayme Darriba Macedo (BR)

WG C2.40
TSO-DSO Cooperation – Control Centre Tools Requirements

Michael Power (IE)

JWG C2/B4.38
Capabilities and requirements definition for Power Electronics based technology for secure and efficient system operation and control
Jan van Putten (NL)

JWG C2/C4.41
Impact of high penetration of inverter-based generation on system inertia of networks

Mpeli Rampokanyo (SA)

More information on SC C2 activities: www.c2.cigre.org

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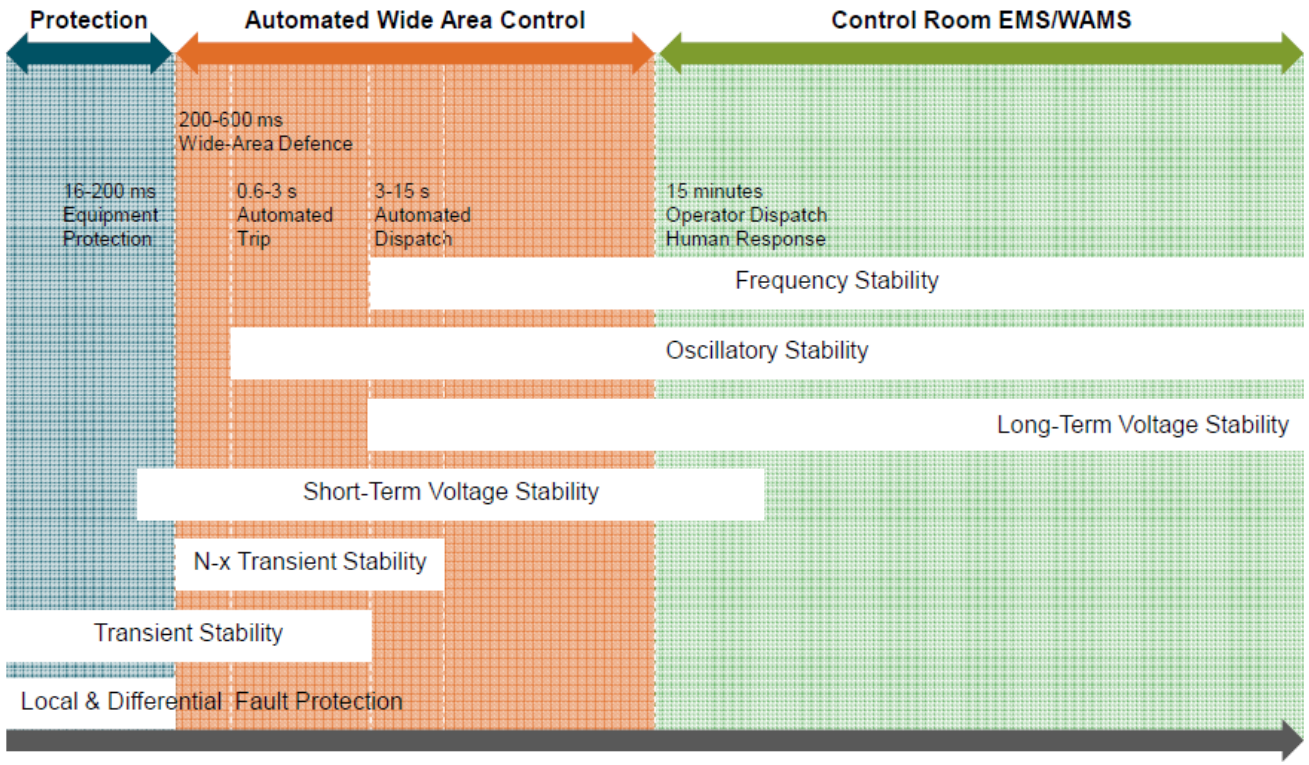
C2.17 – Wide Area Monitoring Systems – Support for Control Room Applications

- WAMS systems = knowledge of system dynamic performance which is currently not available in the SCADA/EMS
- Control room operators need simple and intuitive system dynamic awareness



C2.17

WAM Systems Specific Properties
Difference between SCADA and Phasor Approach

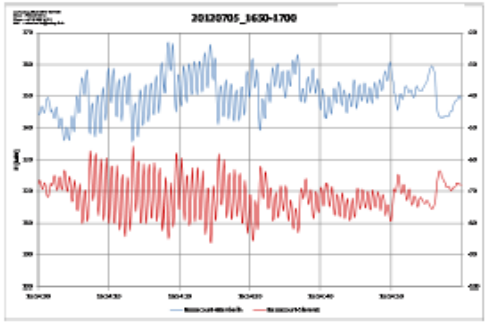
RTU

- Remote Terminal Unit (RTU)
- Cyclical data collection 1-10 s
- First Wide Area application -> AGC (Load-Frequency Control)
- Measurements are used for centralised monitoring and control

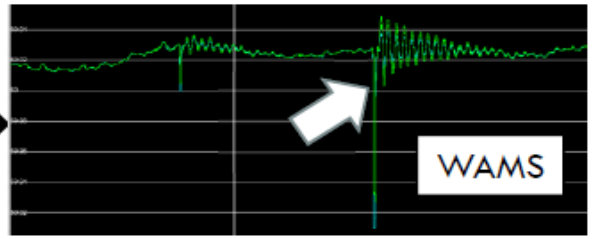
PMU

- Phase Measurement Unit (PMU)
- Each period (20 ms) one phasor acquisition with exact GPS time stamp
- **System dynamic** can be **on-line** asset due to timely high resolution data acquisition
- **Voltage phase angle difference** between two substation is one of the **key** performances of this technology

- Same data acquisition principle
- Due to precise "overlapping" wide area view possible



Same event



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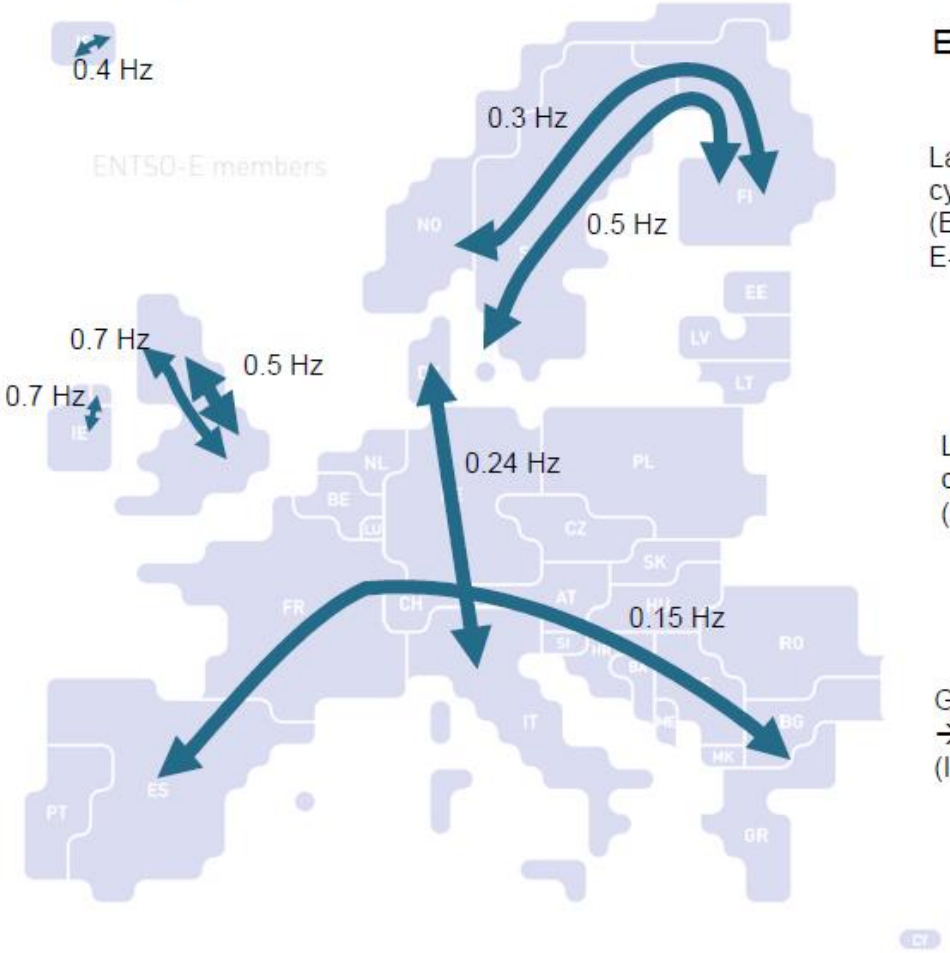
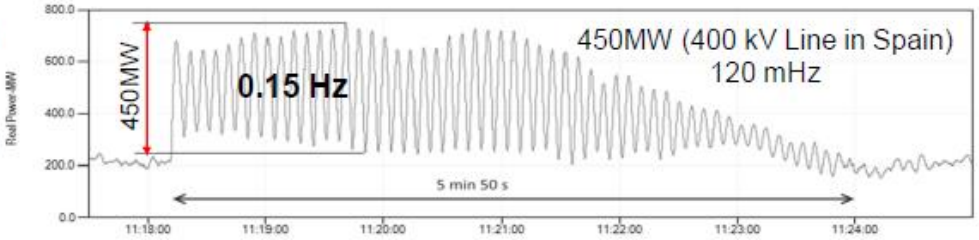
European Oscillation Examples

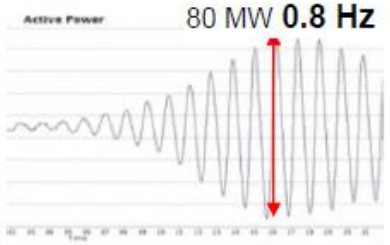


Examples of unstable oscillations recorded by WAMS.

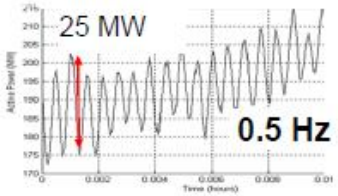
Large limit cycles (Europe E-W 2016)



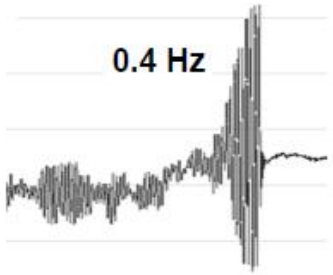
Large limit cycles (GB 2011)



Small limit cycles (Nordic 2006)



Growing → split (Iceland 2010)



Many more oscillation patterns present in Europe

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Conclusions

Benefits in real-time:

- ✓ alarm on occurrence of large/poorly damped oscillations
- ✓ Participating regions
- ✓ Regions contributing to problems where measures help
- ✓ Monitoring inertia (frequency stability)
- ✓ Wide area control for fast frequency response
- ✓ Monitoring of phase angle (transient/voltage stability)
- ✓ Support for black start and power system restoration

https://e-cigre.org/publication/750-wide-area-monitoring-systems--support-for-control-room-applications

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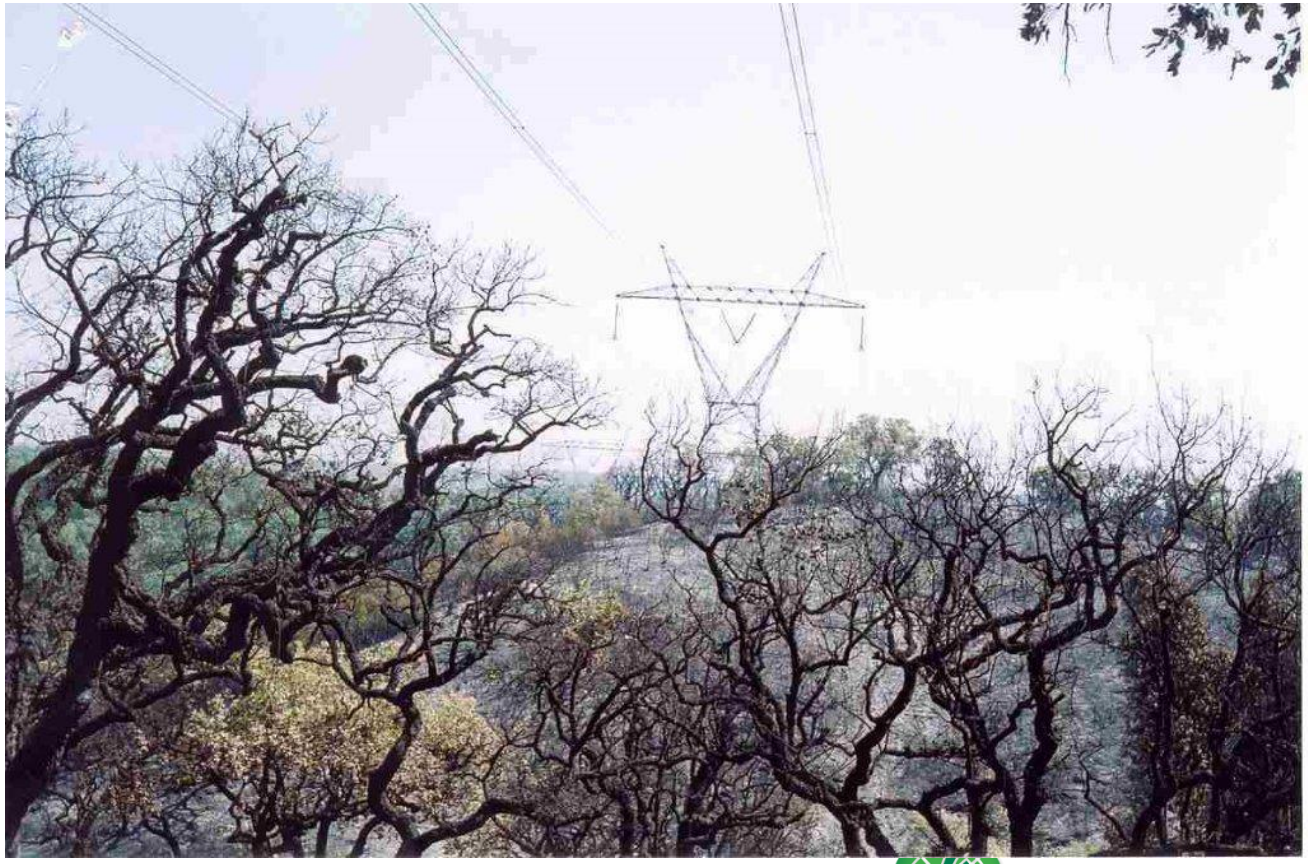
C2.24 - Mitigating the risk of fire starts and the consequences of fires near overhead lines for System Operations



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C2.24

- **Challenges tackled:**
  - ✓ Risk of powerlines starting fires increases significantly on extreme fire danger days
  - ✓ Powerline-caused fire meaning extreme fire danger
  - ✓ Risk of powerline equipment damage increases when wildfires burn out of control
  - ✓ Climate change means:
    - More heatwaves
    - More days of extreme fire danger
    - More days when powerlines could start a fire
    - More days when wildfires may occur and damage powerlines
  - ✓ Challenges:
    - What can utilities do to stop fires
    - What can utilities do to mitigate the consequences of wildfires
- **Expected outcome: survey on fire start and strategies to avoid the risk of fire and its consequences**

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C2.25 - Operating Strategies and Preparedness for System Operational Resilience

- In power system operations, resilience generally means the ability to respond quickly to and recover from a disruption. To enhance system resilience, various strategies from the provision of sophisticated operation and control capabilities to preparing for the effective and prudent operations can be considered.

- The increased awareness of the potential adverse impact on power system operations from physical and cyber invasions, high impact low frequency (HILF) events and increased frequency of system disturbances caused by natural phenomena (hurricanes, earthquakes, etc.), results in a shift in the focus of the energy industry from purely developing preventive measures towards providing and enhancing resilience following these major disturbances (interruptions).

- WG C2.25 focuses on operational resilience, i.e. the operating and control strategies and risk mitigation preparedness that can support system operators to more effectively manage system disturbances, restore the disrupted power grid to a secure state and eventually to its pre-disturbance state.

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C2.25 - Lessons Learned USA

Identify areas of enhancement or improvement to strengthen operational resilience

Distribution Automation Devices

Mobile Substations

Drones

Staging Sites

Pole Hardening and Inspections

Vegetation Management

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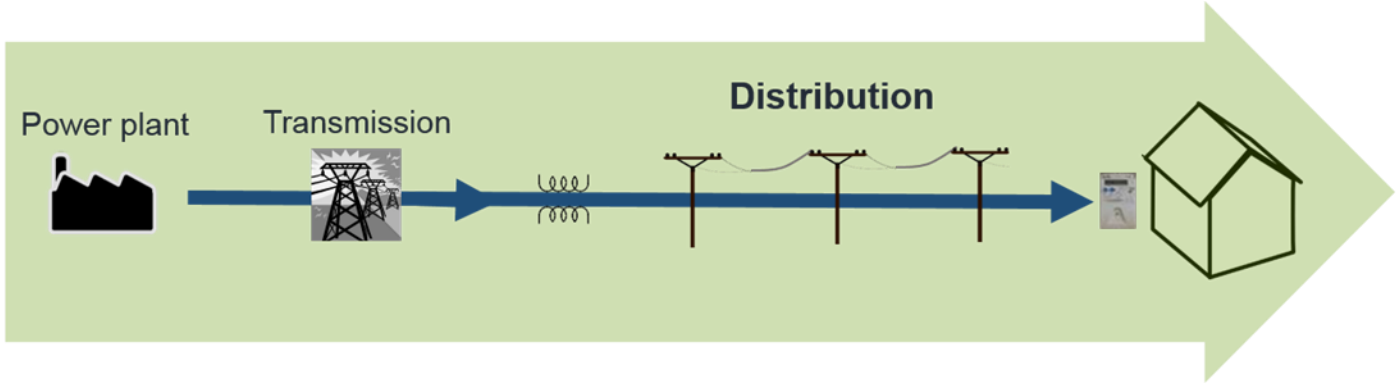
C2.26 - Power system restoration accounting for a rapidly changing power system and generation mix

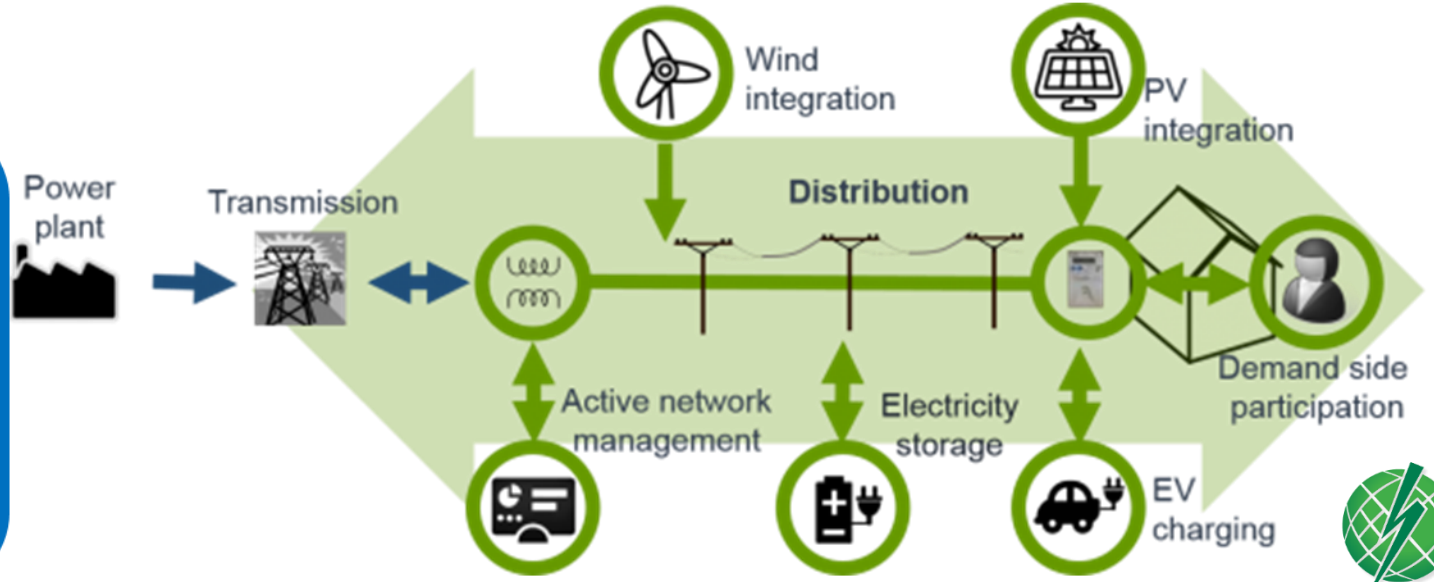
Traditional:

- Several SRAS capable synchronous generators
- Centralised
- Firm availability
- Sufficient controllable load is available for pick-up



Emerging:

- Decline of SRAS capable synchronous generators
- Less centralised
- Less firm availability
- Increased penetration of DER results in a decline in controllable loads for pick-up



Source: AEMO

C2.26 Value proposition

- Challenges posed due to increased uptake of inverter connected generation, both large-scale and distributed energy resources
- The use of inverter connected generation for black starting/system restart support
- The use of distribution network for black starting/system restart support
- The use of HVDC links for “black” starting/system restart support
- System restart testing involving wider transmission and distribution networks
- Interactions with cybersecurity
- Applications and types of offline power system modelling and simulation tools
- Tools and techniques for control rooms

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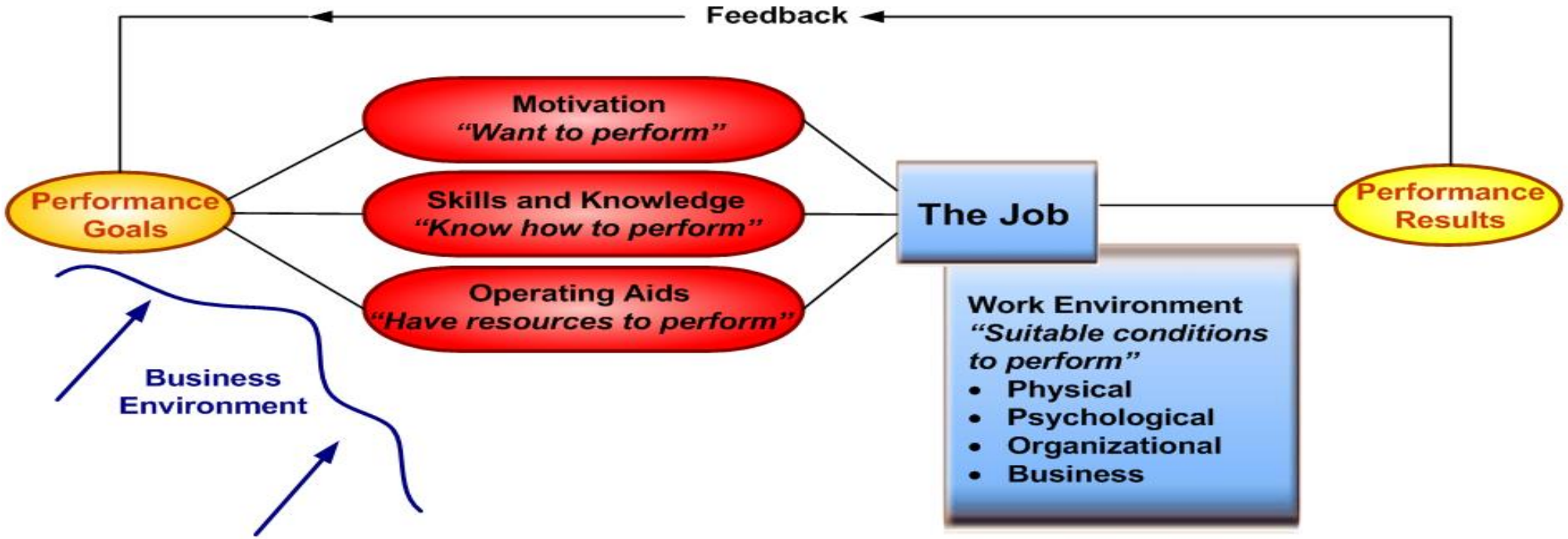
C2.39 - Operator training in electricity grids at different control levels and for different participants/actors in the new environment

Operators Training & Knowledge Management

- Understanding of a more complex environment
- Knowledge regarding dynamic phenomena
- Need for more analysis closer to real-time
- New technologies



Source: CIGRE TB 524

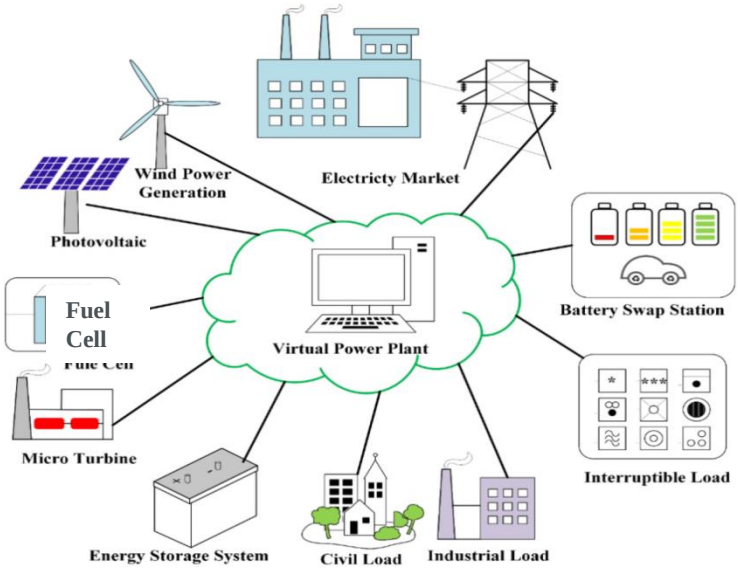
C2.40 - TSO-DSO Co-operation – Control centre tools requirements

The role of this CIGRE WG is to specify a set of control centre tools for both the TSO and DSO to manage and operate this newly evolved power system. The critical aspect that is addressed is that the tools must enable a very high level of co-operation between the TSO and DSO so that they can efficiently address system issues at the different levels.

Vertical Coordination

Coordination TSO-DSO

Access to flexibility (frequency reserves), voltage control and congestion management with DSO-TSO interaction



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C2/B4.38 - Capabilities and requirements definition for Power Electronics based technology for secure and efficient system operation and control

System Operation Challenges

New Operation of the Power System

Identifies areas where how we operate the power system needs to change. It includes the people, processes and tools in system operation that observe the bulk electric system and take necessary actions to maintain operational reliability. The new operation of the power system will require to increase the level of automatic control actions to cope with the expected faster and more frequent dynamic power system behavior. Some phenomena are expected to be too fast for a manual operational response.

New Behaviour of the Power System

With increasing power electronics interfaced devices, the system behaviour and response are bound to change. It identifies issues on new power system behaviour (e.g. lower resonance frequencies due to increasing HVAC underground cables).

Lack of Voltage and Frequency Support

System stability will remain crucial. This category deals with issues that result from lack of support for a stable voltage and frequency (e.g. increasing RoCoF resulting from decreasing synchronous generation).

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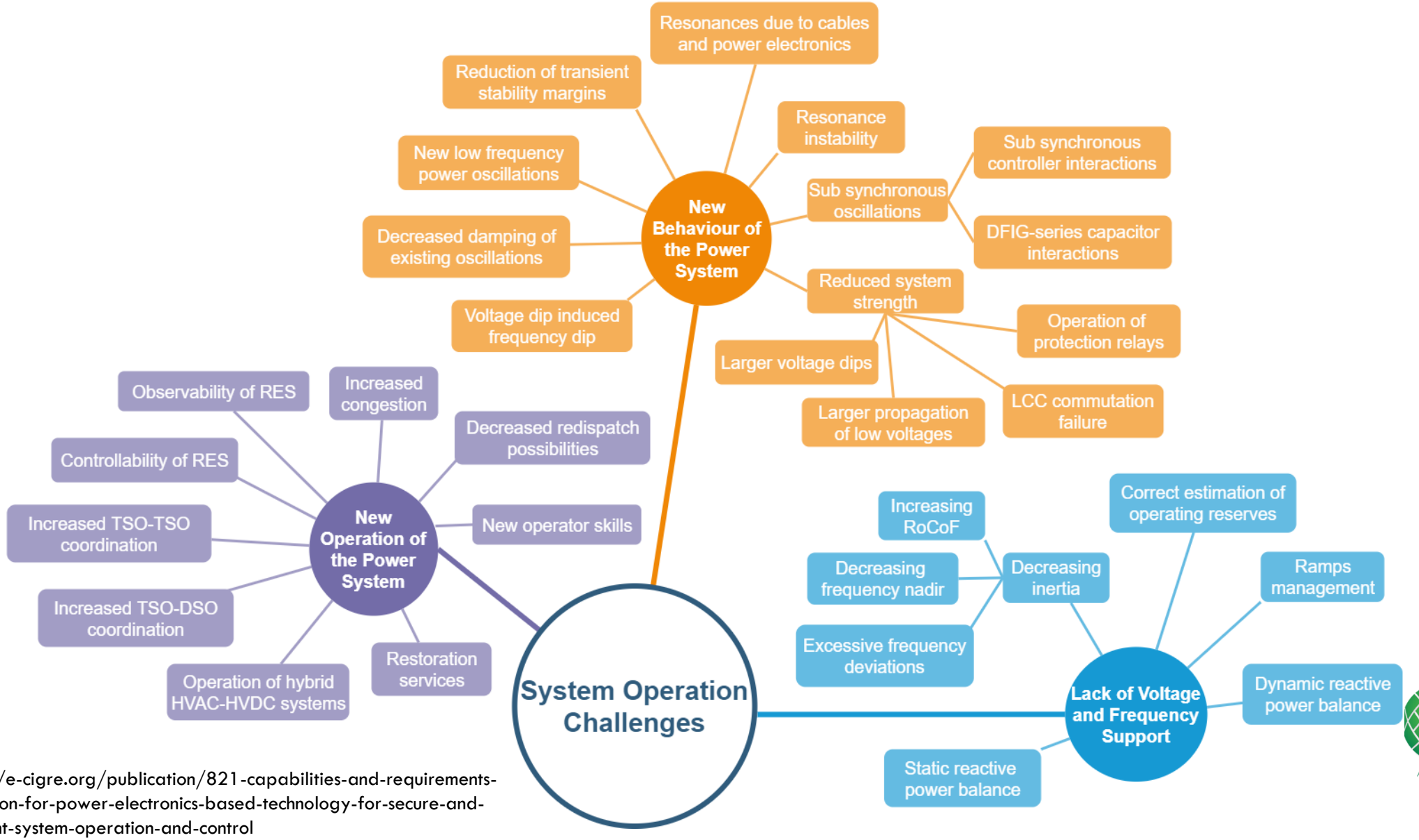
C2/B4.38 - Capabilities and requirements definition for Power Electronics based technology for secure and efficient system operation and control



https://e-cigre.org/publication/821-capabilities-and-requirements-definition-for-power-electronics-based-technology-for-secure-and-efficient-system-operation-and-control

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C2/B4.38 Mapping Table

		Power Electronics Interfaced Devices											
		HVDC		PE based FACTS						PE based generation			
Operational Challenges		VSC HVDC	LCC HVDC	STATCOM	SVC	TCSC	SSSC	UPFC	IPFC	PV	WTG Type III	WTG Type IV	BESS
Lack of voltage & frequency support	Increasing RoCoF	✓								✓	✓	✓	✓
	Decreasing frequency nadir	✓								✓	✓	✓	✓
	Excessive frequency deviations		✓									✓	✓
	Static reactive power balance			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Dynamic reactive power balance	✓		✓	✓			✓	✓		✓		
	Ramps management	✓	✓										
	Estimation of operating reserves												
New operation of the power system	Increased congestion												
	Observability of RES												
	Controllability of RES												
	Vertical coordination												
	Horizontal coordination												
	Operation of hybrid systems												
	Control of bi-directional flows	✓	✓										
	New operator skills												
	Power system restoration	✓								✓		✓	✓
New behaviour of the power system	Resonances due to cables and PE	✓		✓			✓	✓	✓	✓		✓	✓
	Reduction of transient stability												
	Resonance instability	✓		✓			✓	✓	✓	✓		✓	✓
	Sub-synchronous controller interaction	✓		✓	✓	✓		✓			✓	✓	✓
	New low frequency oscillations	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Decreased damping	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Voltage dip induced frequency dip										✓	✓	
	Larger voltage dips			✓	✓								
	PLL instability											✓	
	LCC commutation failure												
	Asymmetry withstand capability of PE	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
	Supply of single-phase traction load												

C2/C4.41 - Impact of high penetration of inverter-based generation on system inertia of networks

In this JWG primary frequency response studies will be carried out 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.

The JWG addresses amongst others the following issues:

- Define operational measures to manage the dispatch of inertia and reduce the risk when operating with low inertia on the system.
  - ✓ Quantify Primary Frequency Requirements with increasing RES penetration
  - ✓ Demand Response requirements
  - ✓ Primary Reserves requirements
  - ✓ Fast Frequency Response techniques and requirements
- Methodology to establish rate of change of frequency limits with increasing non-synchronous RES penetration levels, and the integration of the methodology into the operational environment.
- 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.

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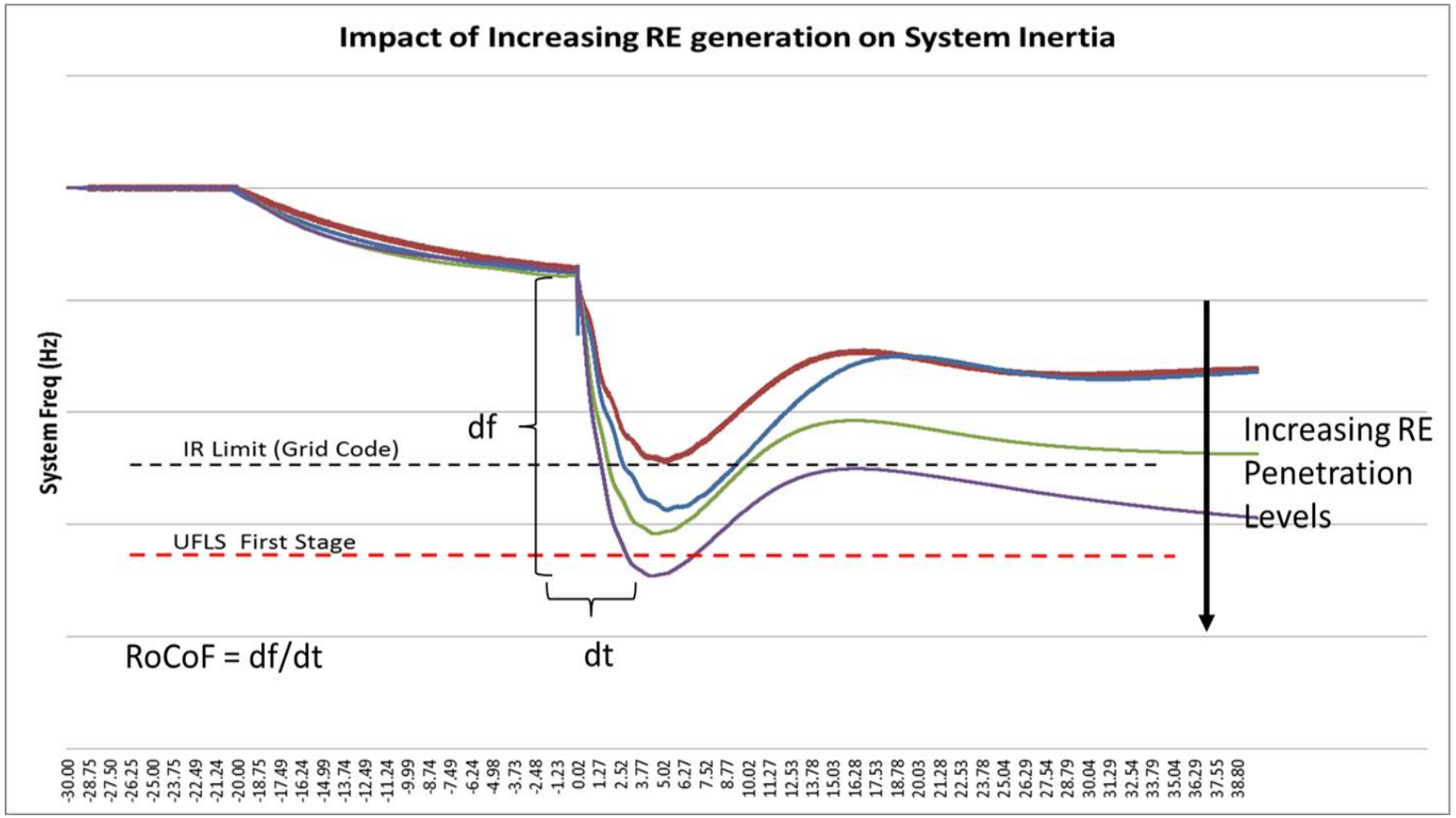


Impact of increasing RE generation on system inertia

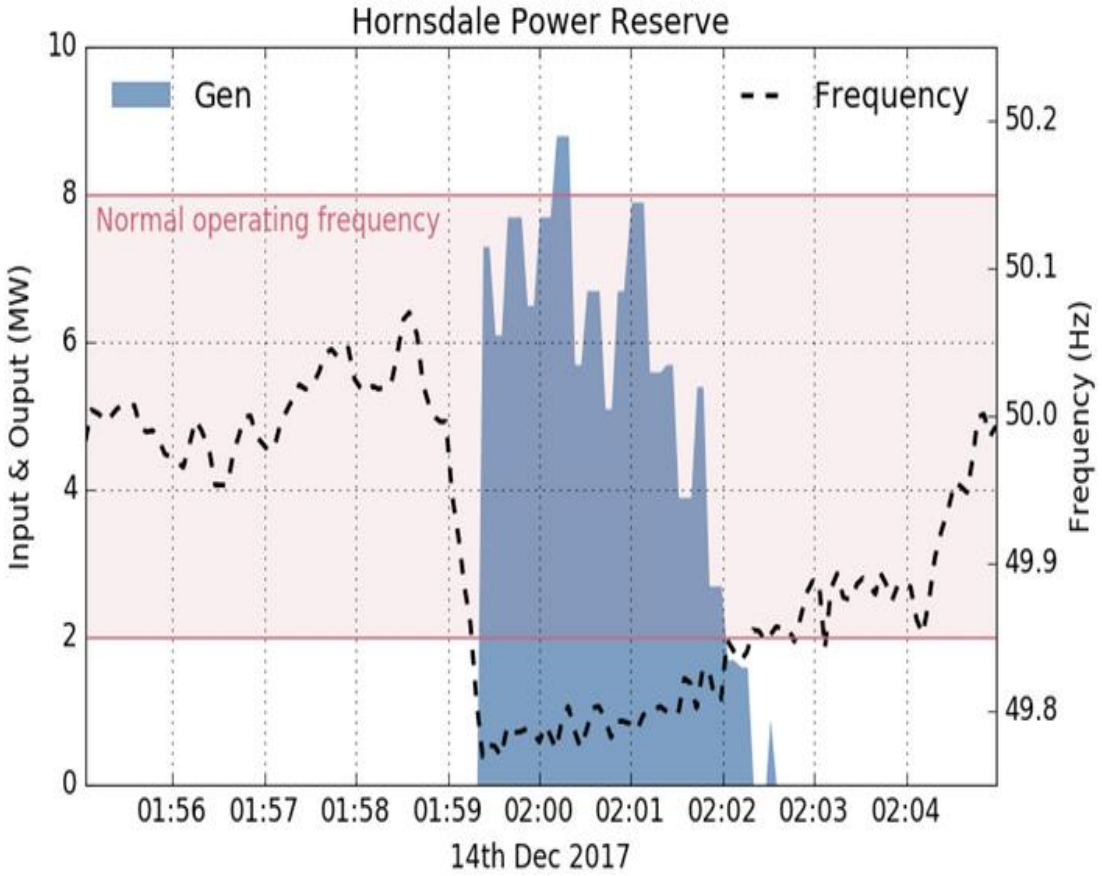
C2/C4.41: Example Frequency Support – Australia

Battery Energy Storage System

In South Australia, there is a 100 MW (129 MWh) BESS installation at Hornsdale, and a 30 MW (8 MWh) BESS installation at Dalrymple.

One of the aims of these batteries is to provide frequency control ancillary services.

On 14 December 2017 successful operation was demonstrated. The battery in Hornsdale discharged with millisecond response to immediately arrest the frequency excursion following a trip of a 560 MW coal fired power plant.



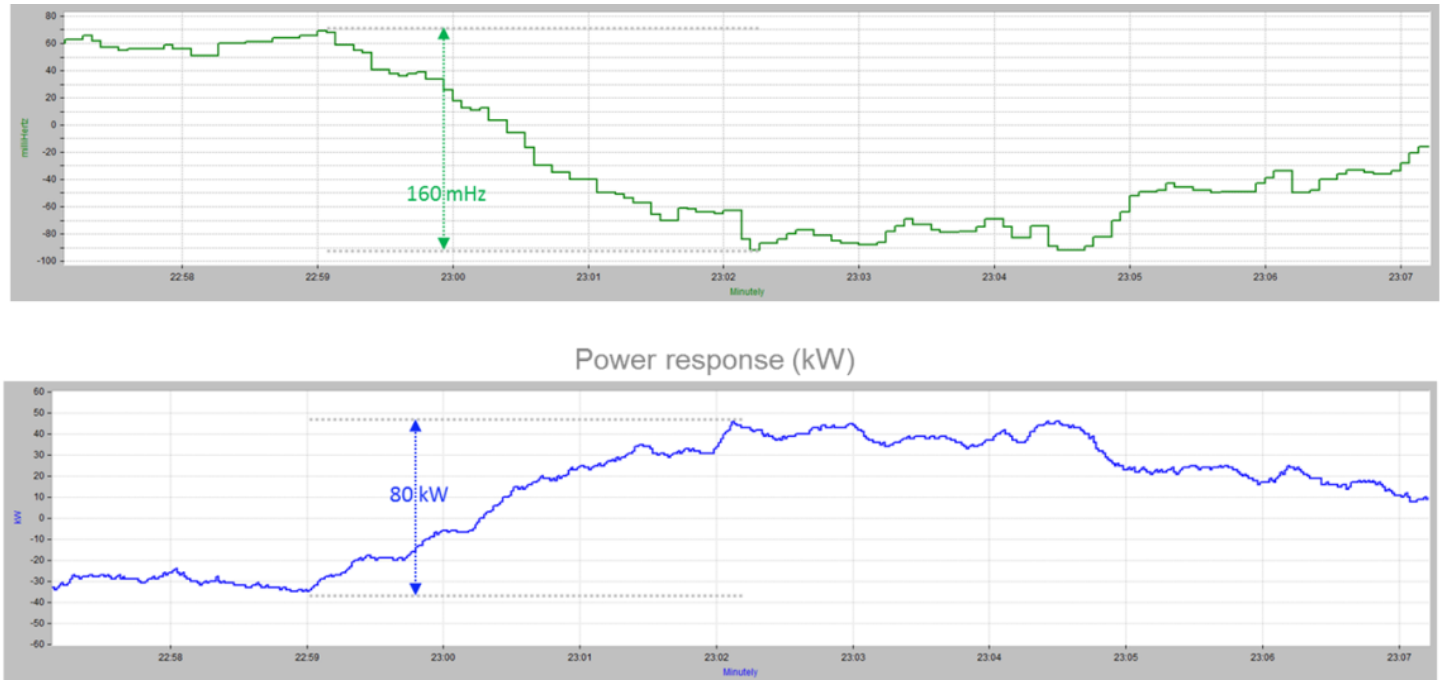
Hornsdale power reserve response to disturbance of 14 December 2017

Reference:
F. Crisci *et al.*, “Power System Restoration – World Practices & Future Trends,” *CIGRE Sci. Eng. J.*, vol. 14, pp. 6–22, 2019.

C2/C4.41: Example Frequency Support - Netherlands

Pool of assets

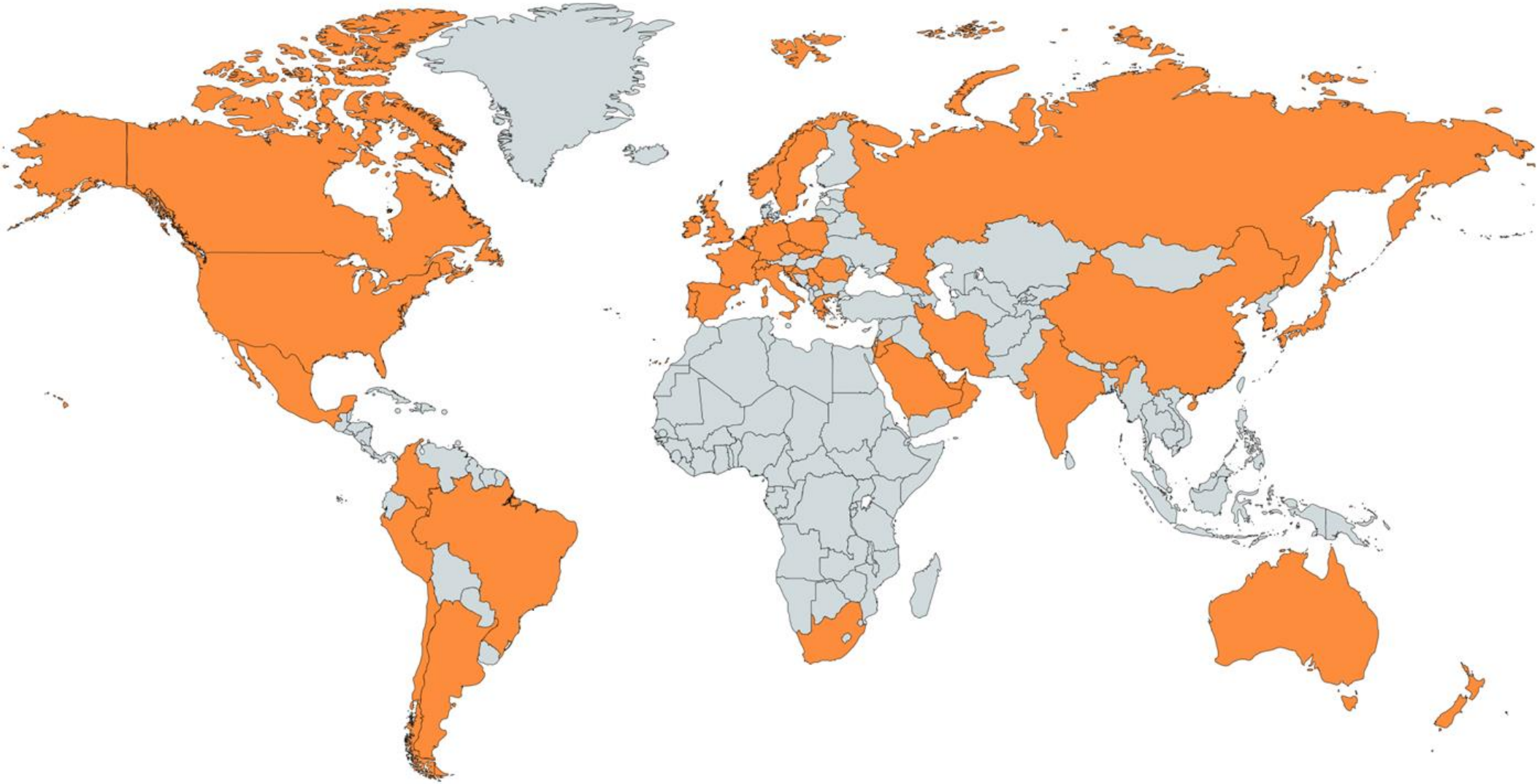
In 2016, a pilot project was initiated in the Netherlands with the aim to provide frequency containment reserves by aggregating responses from a pool of assets: electrical vehicles, heat-pumps, Bio-CHPs, battery installations, residential energy storage and wind turbines



Response of FCR pilot assets to frequency deviation

Reference:
D. Klaar, “Pilot projects for ancillary services,” in *Proceedings of the 2018 CIGRE Session*, 2018

Geographical distribution of SC C2 members



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