Power System Balancing and Operation with Large Shares of Wind Power

Anca Hansen, Kaushik Das (Technical University of Denmark)
and Damian Flynn (University College Dublin)

The WinGrid Project

- EU H2020 Marie Curie Innovative Training Network (ITN)
- **The WinGrid consortium aims to train and launch the next generation of researchers on power system integration issues associated with the large-scale deployment of wind generation, focusing particularly on modelling and control aspects of wind turbine and grid interface design, system stability and robust implementation**
- Expert group of 7 leading universities and one large company
- 8 internationally renowned industrial partners

Presenters

Day 1 - Agenda

DAY 1 – Tuesday 15 June	
Session 1 – Chair, Damian Flynn, University College Dublin	
10-11 (CET)	**Introduction, power system operation, stability and markets** Damian Flynn, University College Dublin
11–12 (CET)	**Standards for modelling of wind in power system studies** Poul Sorensen, Technical University of Denmark
12–13 (CET)	**Recommendations for wind integration studies, looking towards 100% renewables systems** Hannele Holttinen, Recognis, IEA Wind Task 25
LUNCH	
Session 2 – Chair, Anca Daniela Hansen, Technical University of Denmark	
14–15 (CET)	**Opportunities and challenges with standards-based communication between DSOs and DER** Phillip Douglass, Dansk Energi
15–16 (CET)	**Hybrid power plants for future power systems** Kaushik Das, Technical University of Denmark
16-17 (CET)	**Offshore wind and grids** Nicolaos A Cutululis, Technical University of Denmark

Day 2 - Agenda

DAY 2 – Wednesday 16 June	
Session 3 – Chair, Anca Daniela Hansen, Technical University of Denmark	
9-10 (CET)	**Power system balancing with wind power** Bent Myllerup Jensen, Energinet
10-11 (CET)	**Developments in simulating VRE time series for power and energy system studies** Matti Koivisto, Technical University of Denmark
11-12 (CET)	**North sea energy hub & multiDC - large-scale offshore wind power integration** Tilman Weckesser, Dansk Energi
12-13 (CET)	**Offshore wind build-out in the North sea and the Baltic sea** Nina Dupont, Ea Energianalyse
LUNCH	
Session 4 – Chair, Kaushik Das, Technical University of Denmark	
14-15 (CET)	**Kermit: simulation tool to analyse the frequency containment and restoration response of power systems, especially useful in the case of large amounts of renewable generation** Wouter de Boer + Maurin Horler, DNV GL
15-16 (CET)	**Inverter-based resource integration in ERCOT** Julia Matevosyan, Electric Reliability Council of Texas
16-17 [CET]	**Wind power capabilities to provide ancillary services** Anca Daniela Hansen, Technical University of Denmark

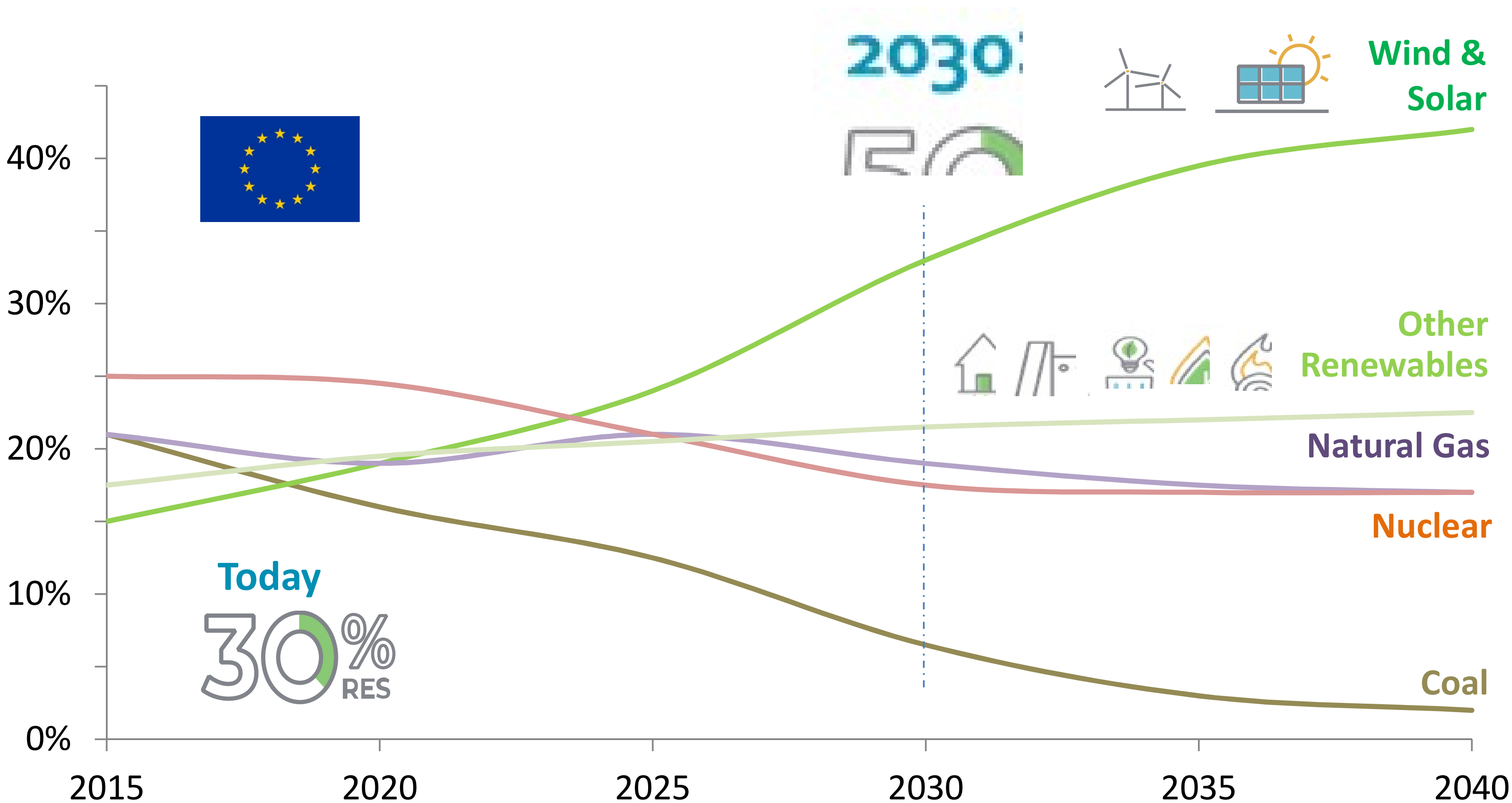
Day 3 - Agenda

DAY 3 – Friday 18 June	
Session 5 – Chair, Kaushik Das, Technical University of Denmark	
10-11 (CET)	**Challenges faced by the wind industry** Lukasz Kocewiak, Ørsted
11-12 (CET)	**Electricity market structures with high RES shares** Magnus Korpås, Norwegian University of Science and Technology
12-13 (CET)	**Operating Ireland's power system at high non-synchronous renewable generation levels** Simon Tweed, EirGrid
LUNCH	
Session 6 – Chair, Damian Flynn, University College Dublin	
14-15 (CET)	**Grid code requirements for wind and hybrid power plants – perspectives from wind turbine manufacturers** Pukhraj Singh, Suzlon
15-16 (CET)	**Inertia-based fast frequency response from wind turbines** Nick Miller, Hickory Ledge
16-17 (CET)	**Control and communication in a 100% inverter based system** Deepak Ramasubramanian, Electric Power Research Institute
17-17.05 (CET)	**Concluding remarks** Damian Flynn, University College Dublin

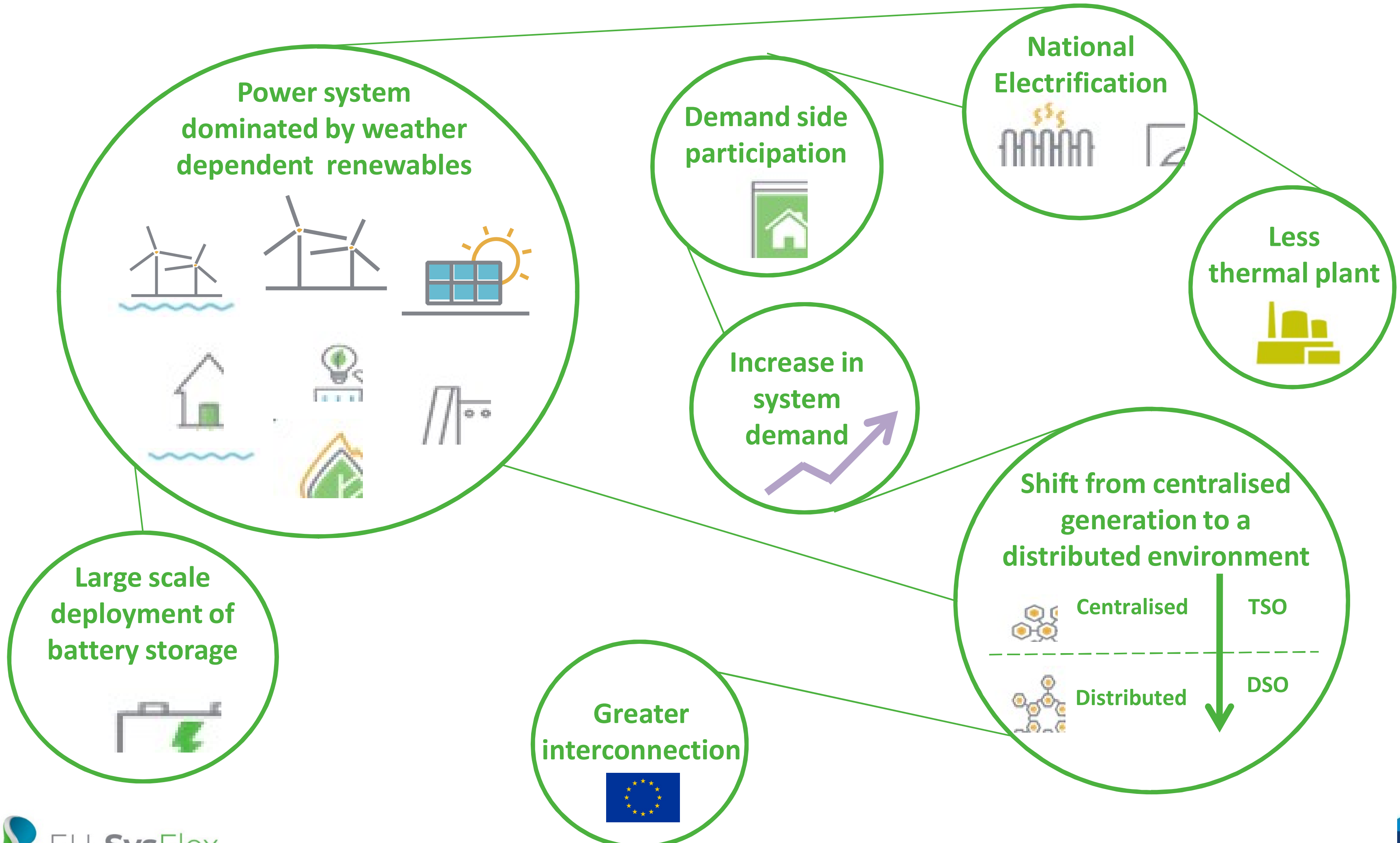
Power System Operation, Stability and Markets

Damian Flynn
University College Dublin, Ireland

European RES Transformation



System Challenges 2030



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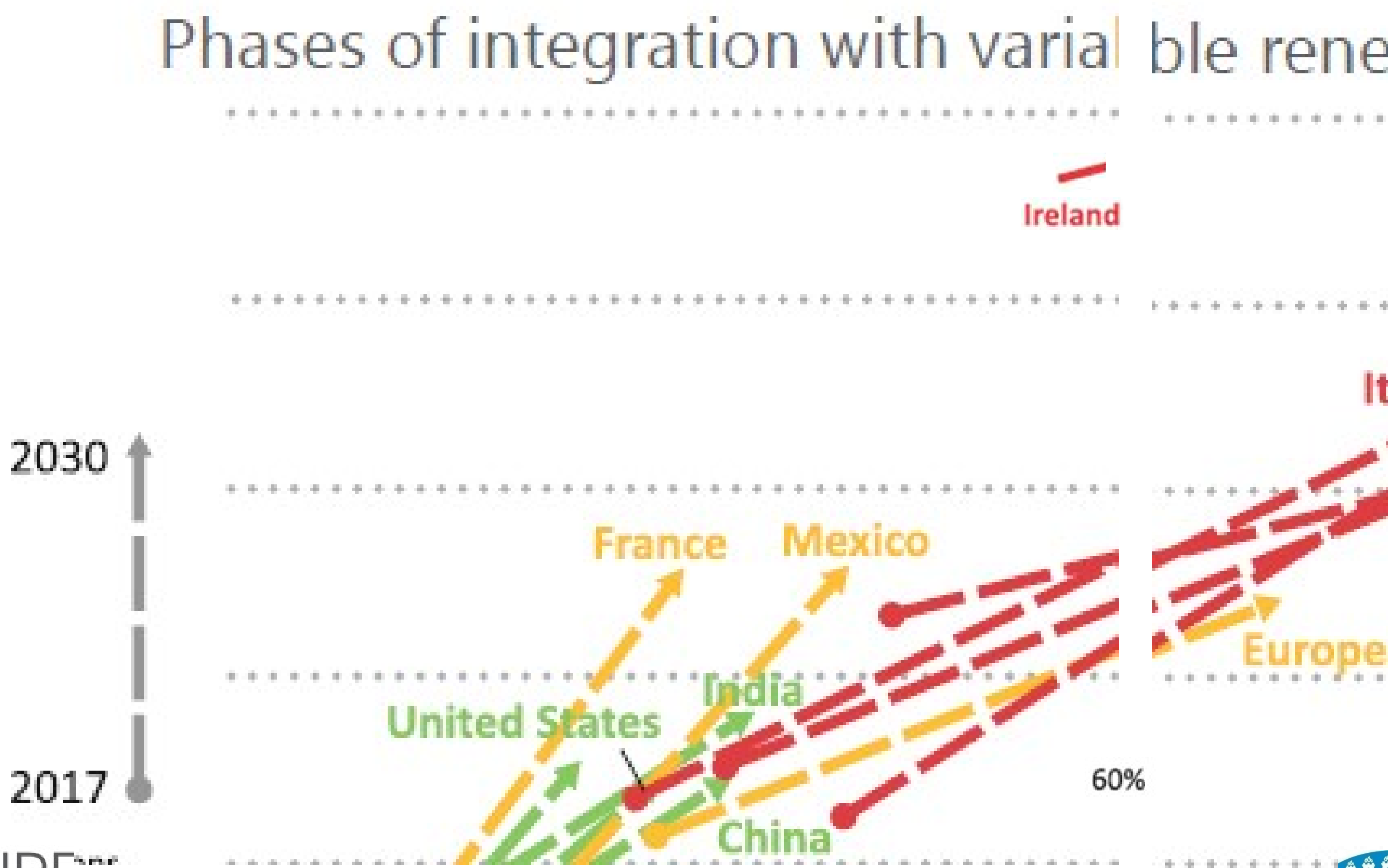
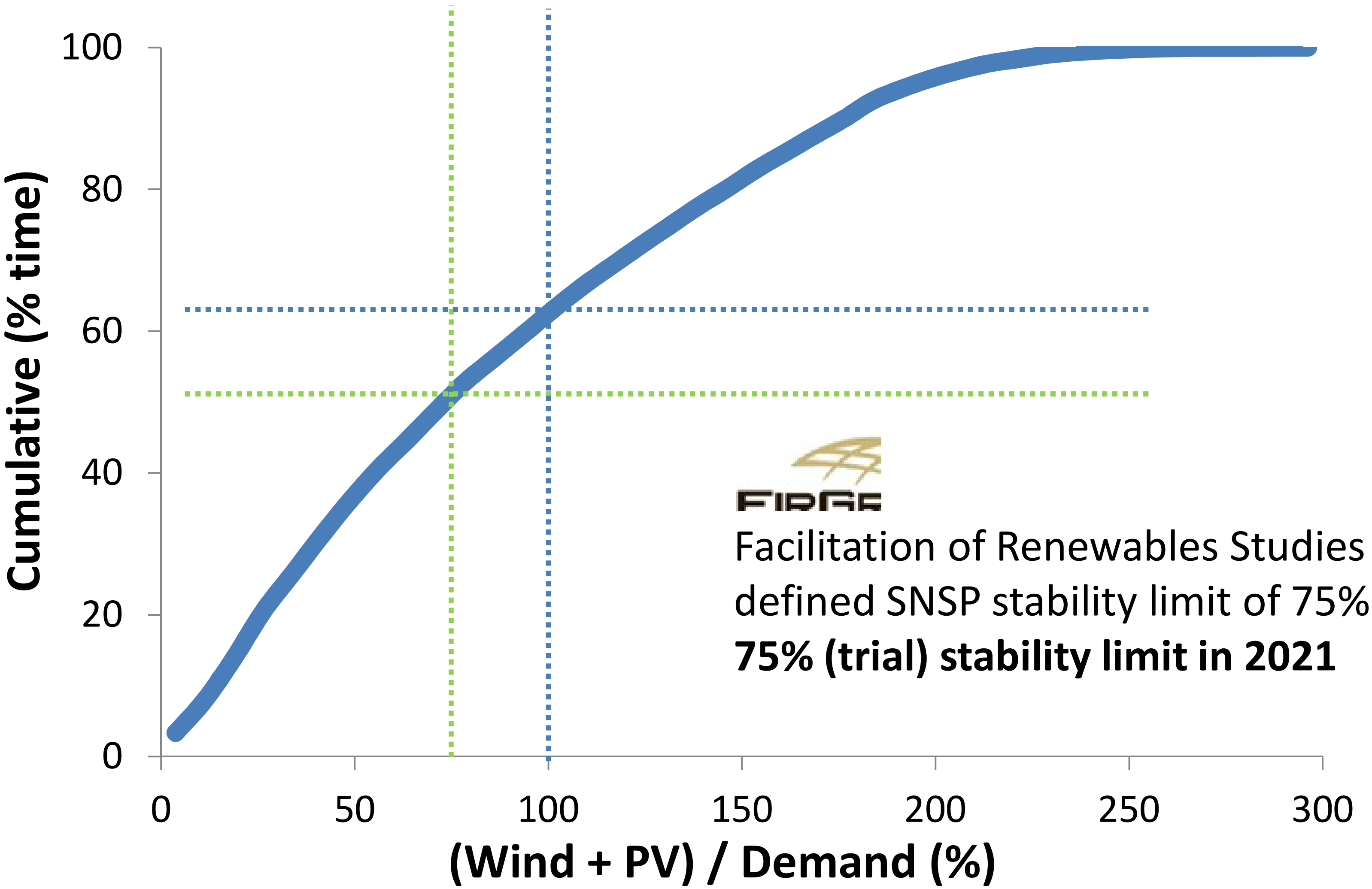
Power System of the Future

- Higher net load variability + uncertainty
- Changing system service requirements
  - New reserve + ramping products + voltage support
- Fewer conventional plant on-line
  - Increased (conventional) plant cycling
  - Reduction in synchronous inertia + synchronising torque
- Sustainable network development
  - (Short-term) renewables curtailment
  - Increased network utilisation + active network measures
- System restoration and blackstart
- …

Flexibility Needs by Region 2030

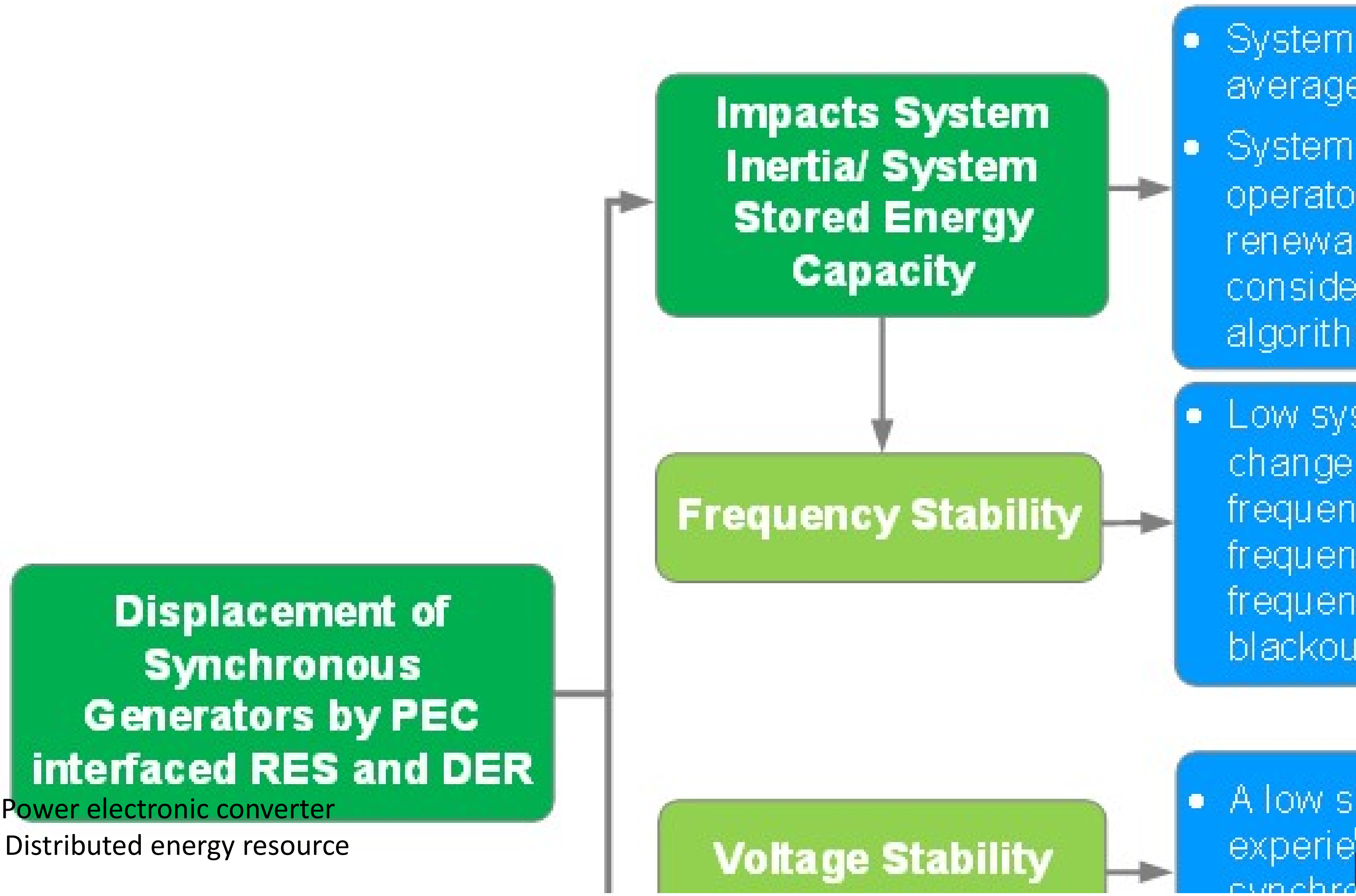


Ireland + N. Ireland 2030



SNSP – System non-synchronous penetration

Grid Stability Challenges



PEC – Power electronic converter
DER – Distributed energy resource

Technical Scarcities

System Service	Aim
Inertial Response	Minimise RoCoF
Fast Response	Slow time to reach nadir/zer
Frequency Containment Reserve	Contain the frequency
Frequency Restoration Reserve	Return frequency to nomin
Replacement Reserve	Replace reserves utilised to provide fa
Ramping	Oppose unforeseen sustained diverge unforecasted wind or solar producti

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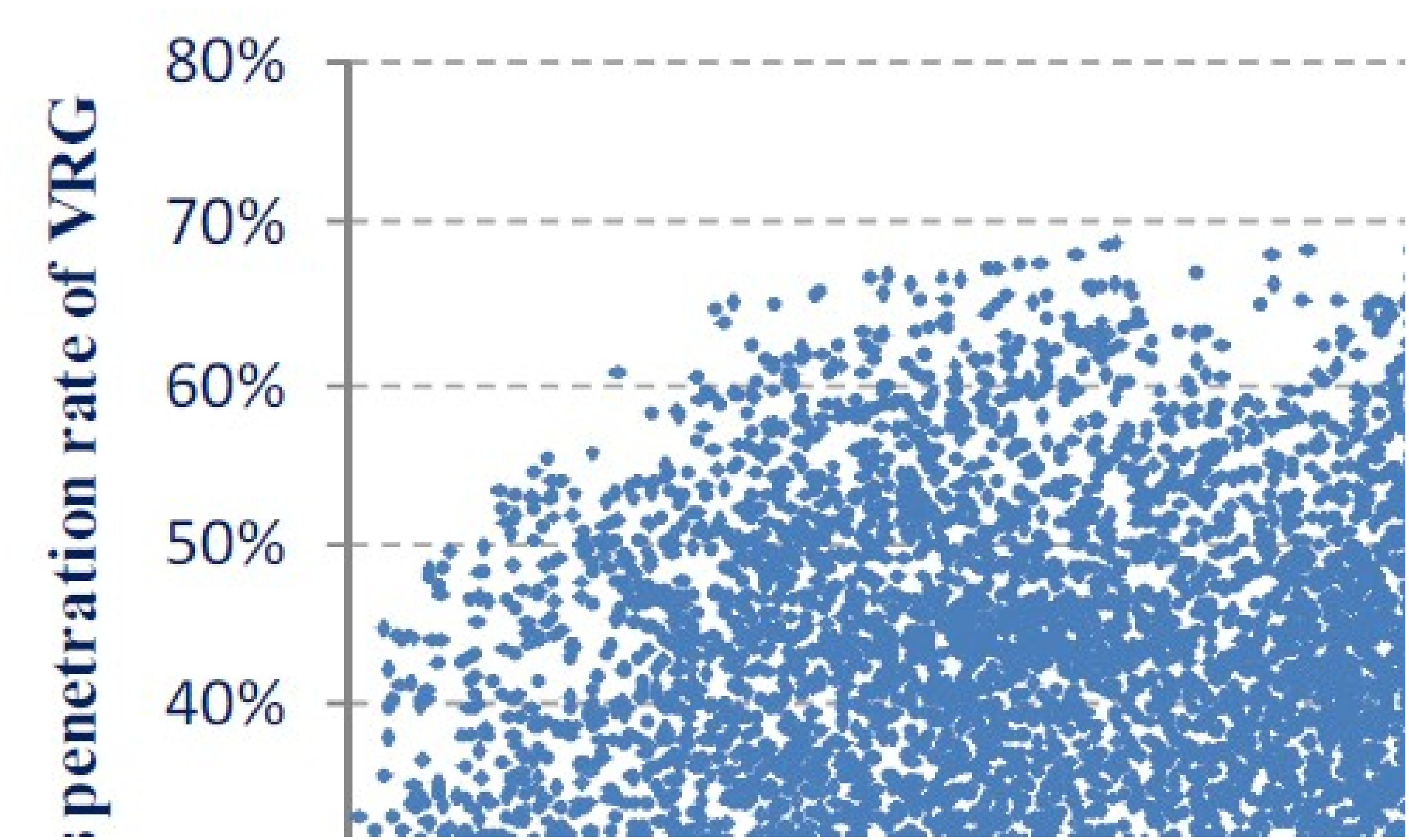
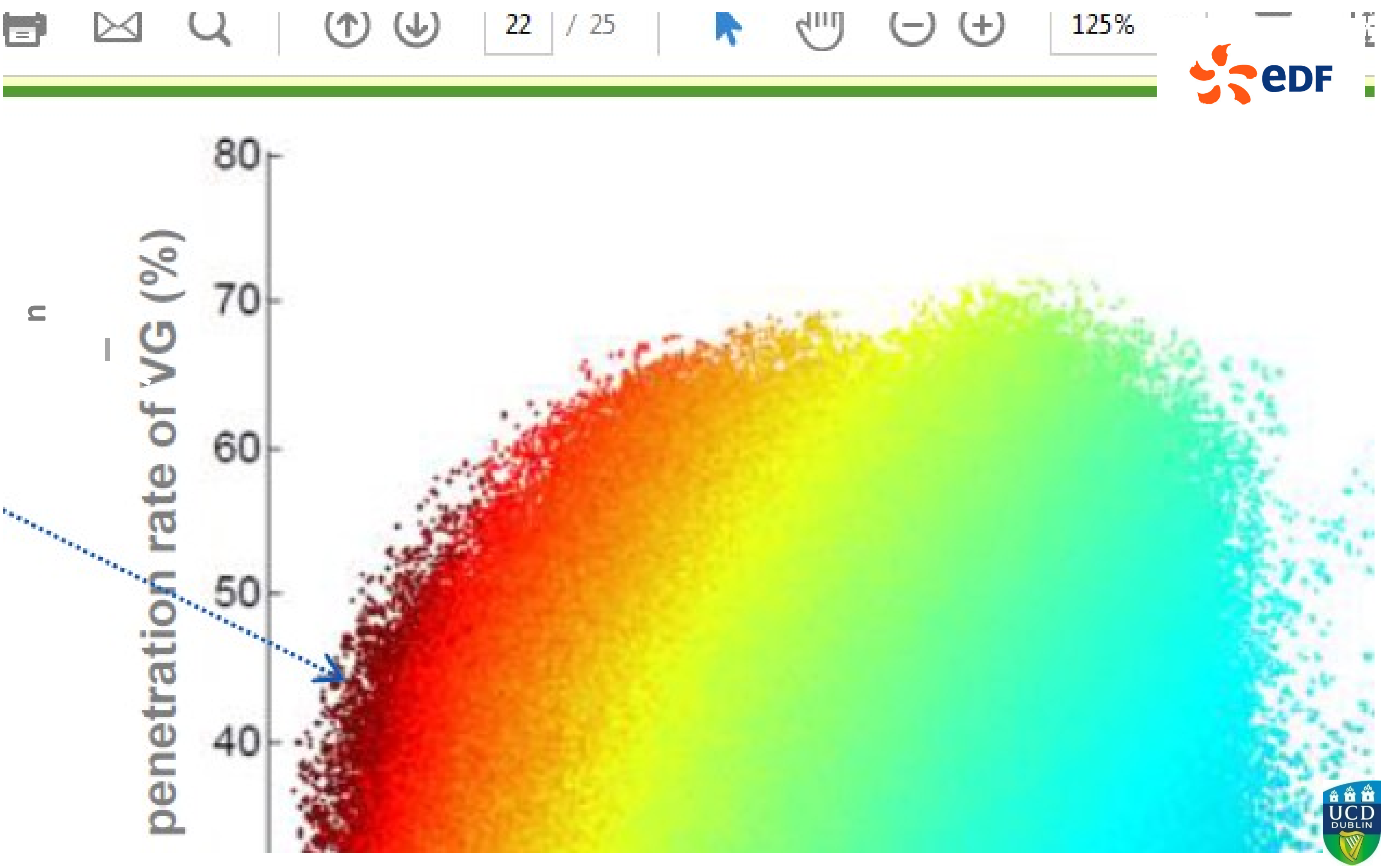
European Continental Area

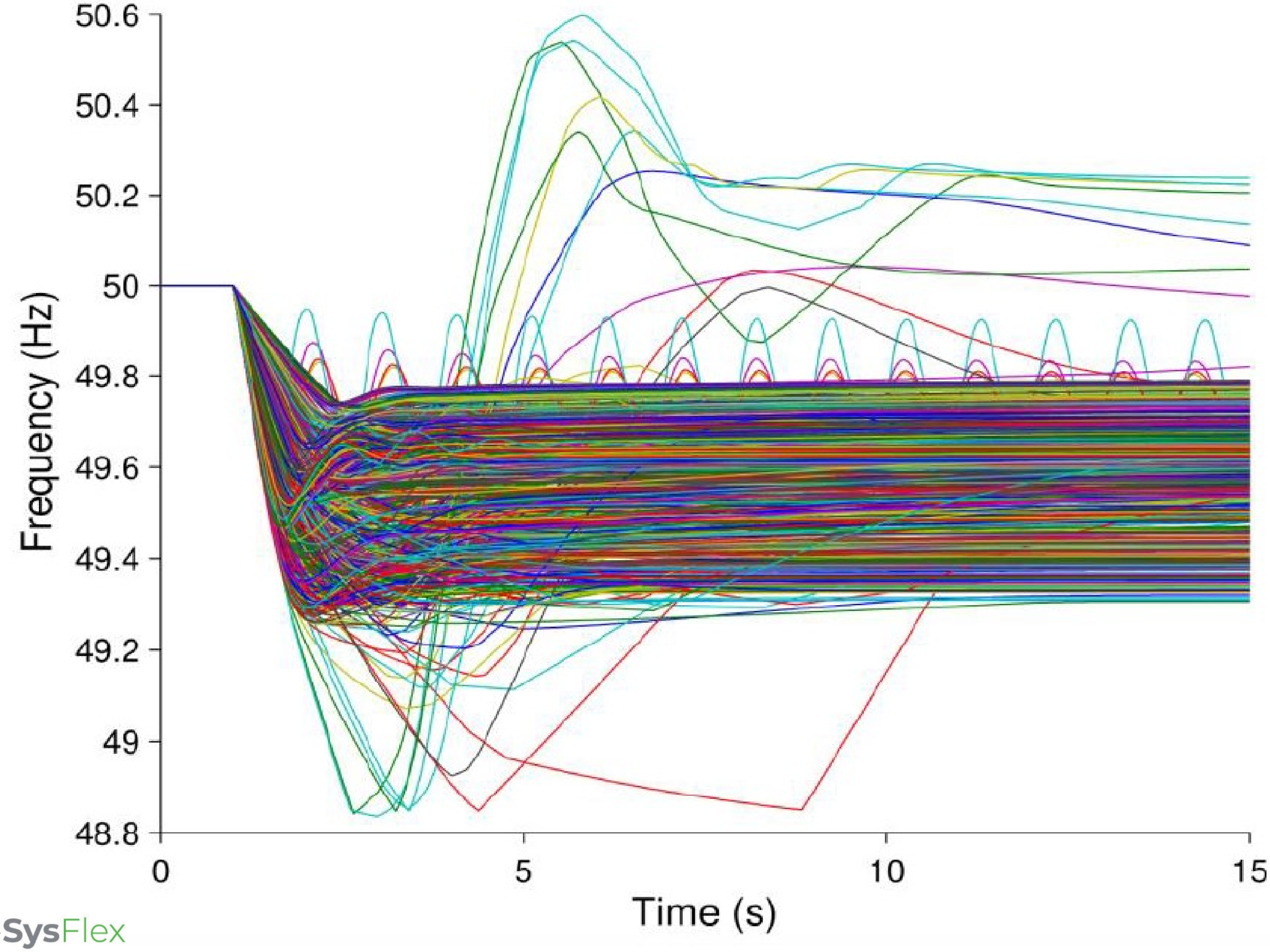
varies between 10% and 71% of



System Frequency Response



Loss of Largest Infeed



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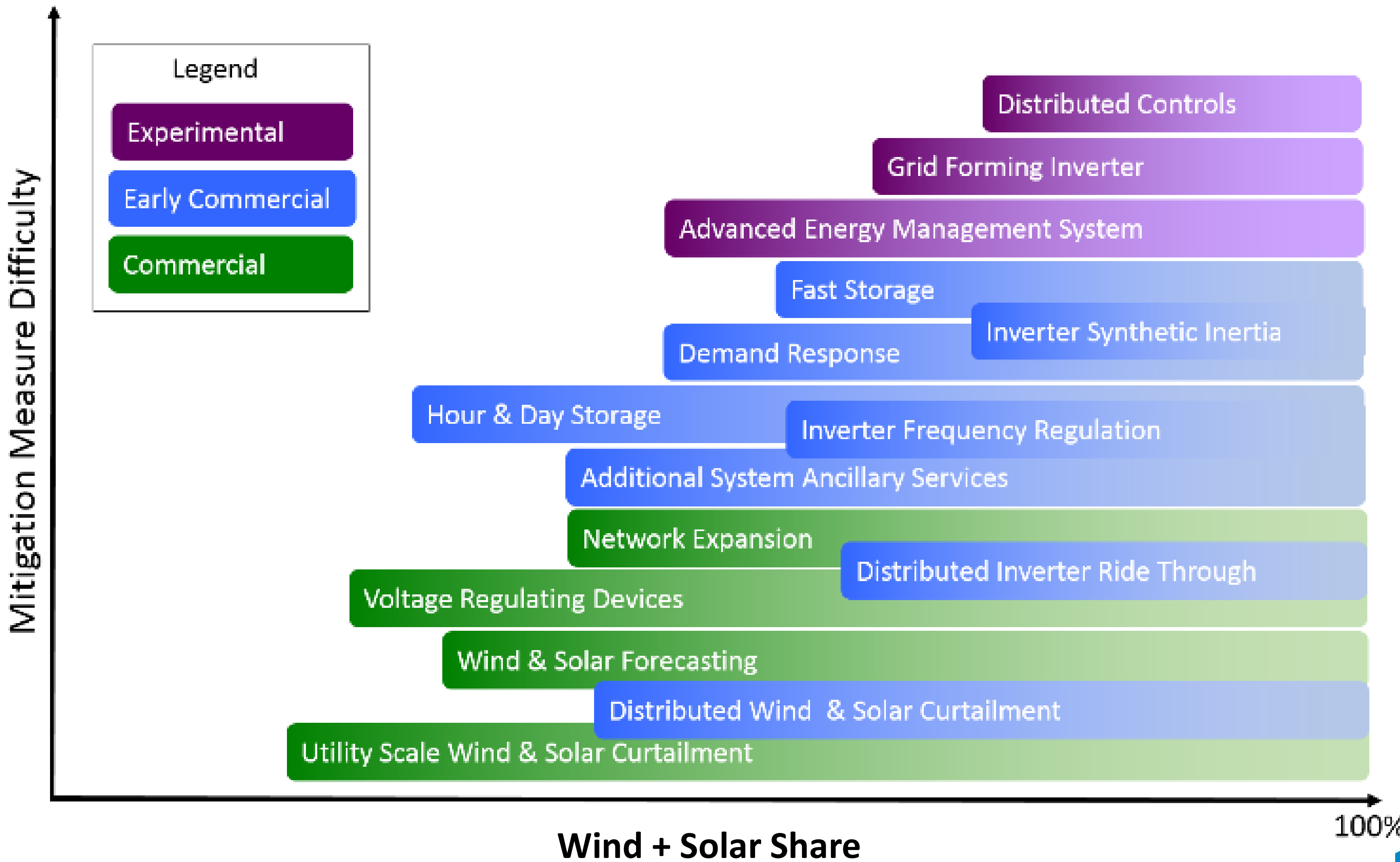
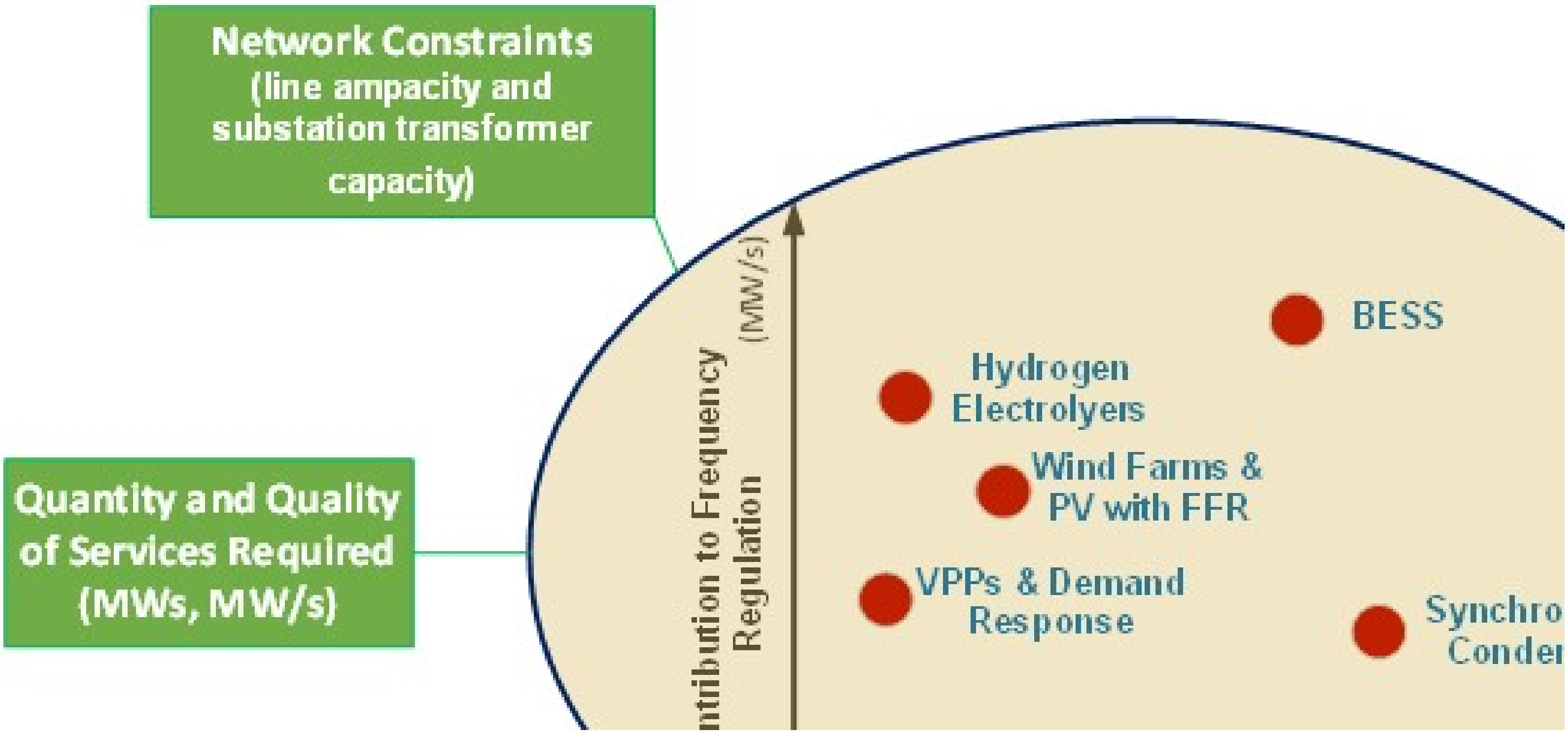
Potential Solutions



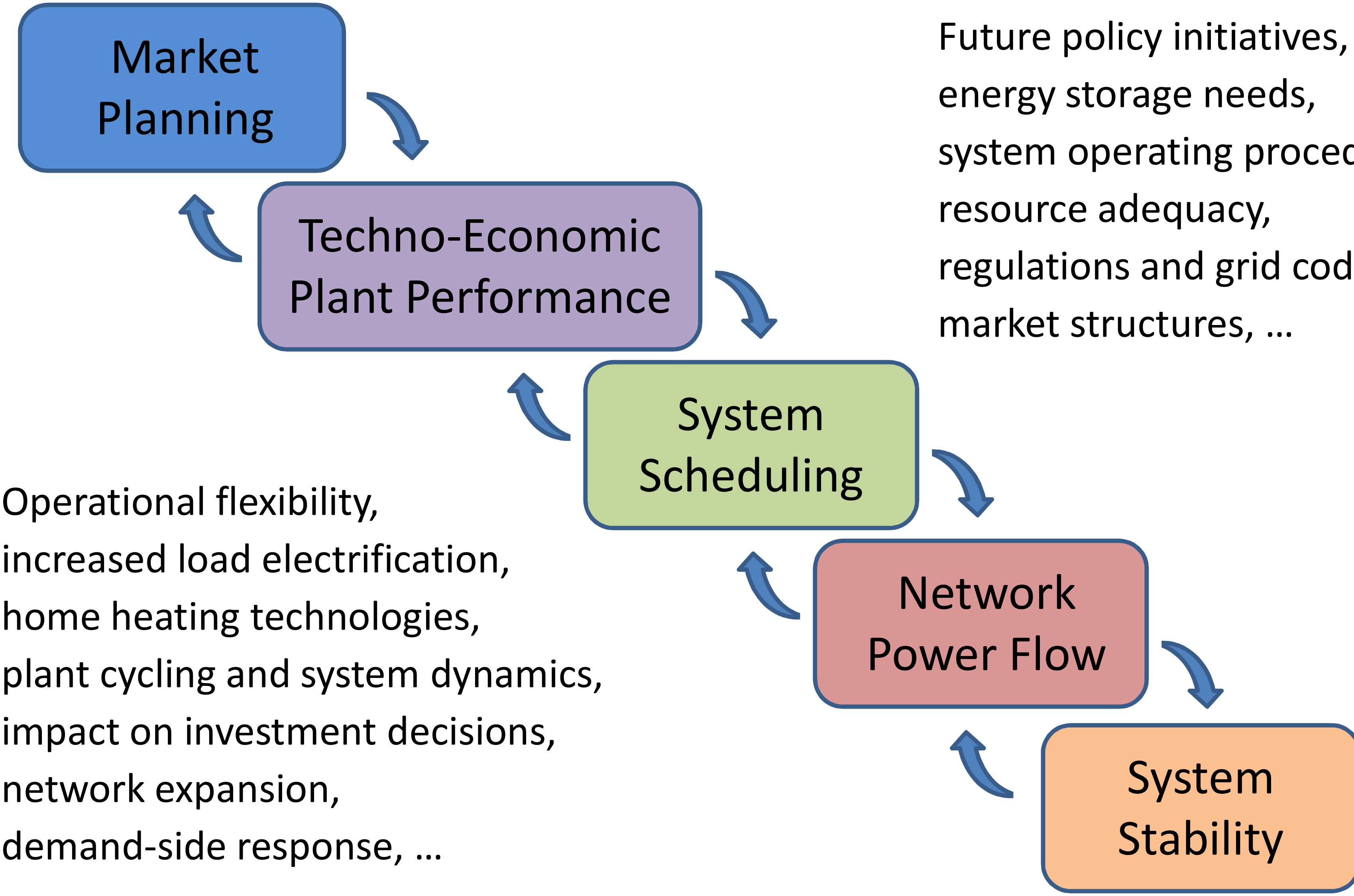
Technology Capability Chart



FFR – Fast frequency response
BESS – Battery energy storage system

VPP – Virtual power plant
SVC – Static var compensator

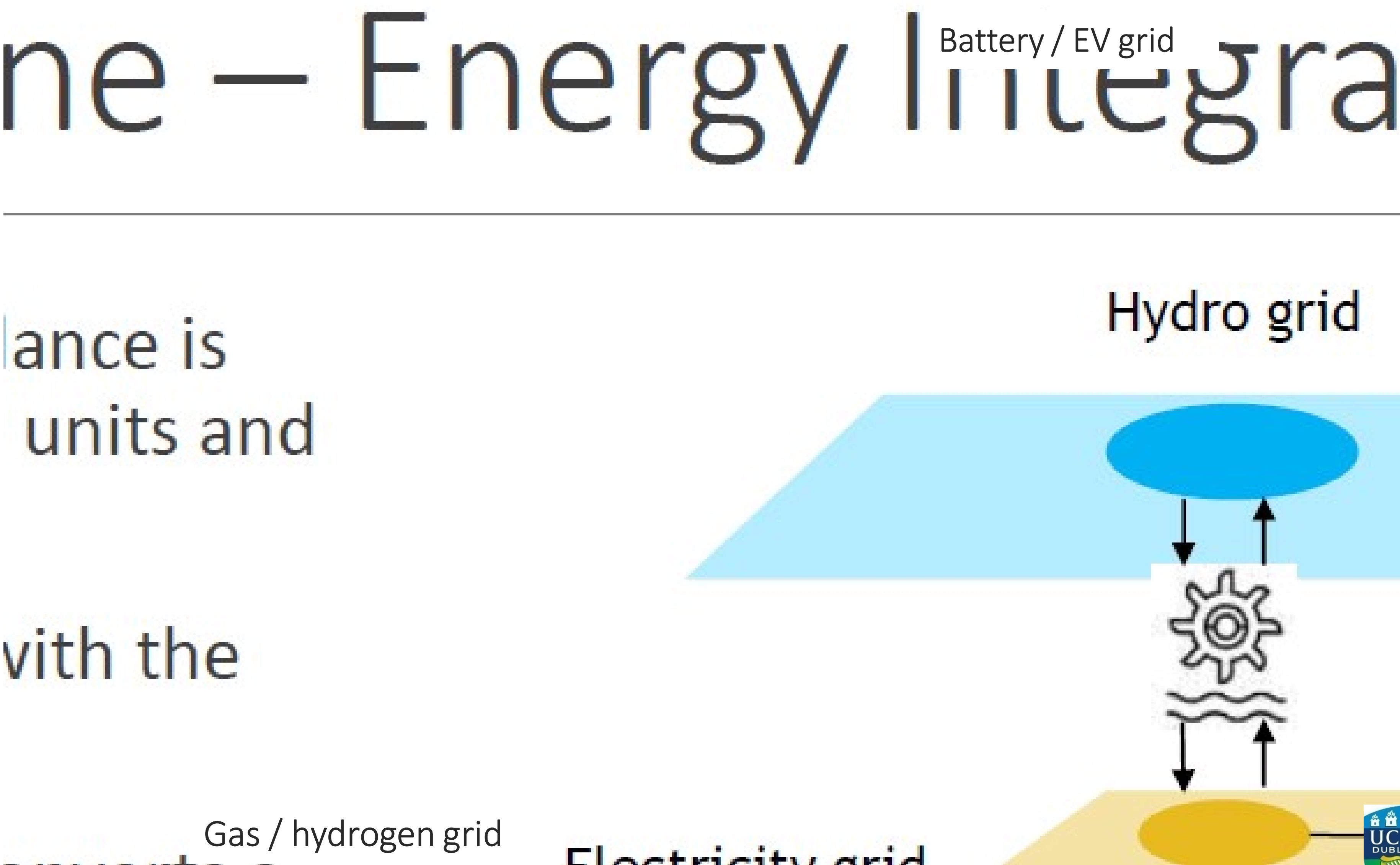
Integrated System Planning



Future policy initiatives,
energy storage needs,
system operating procedures,
resource adequacy,
regulations and grid codes,
market structures, …

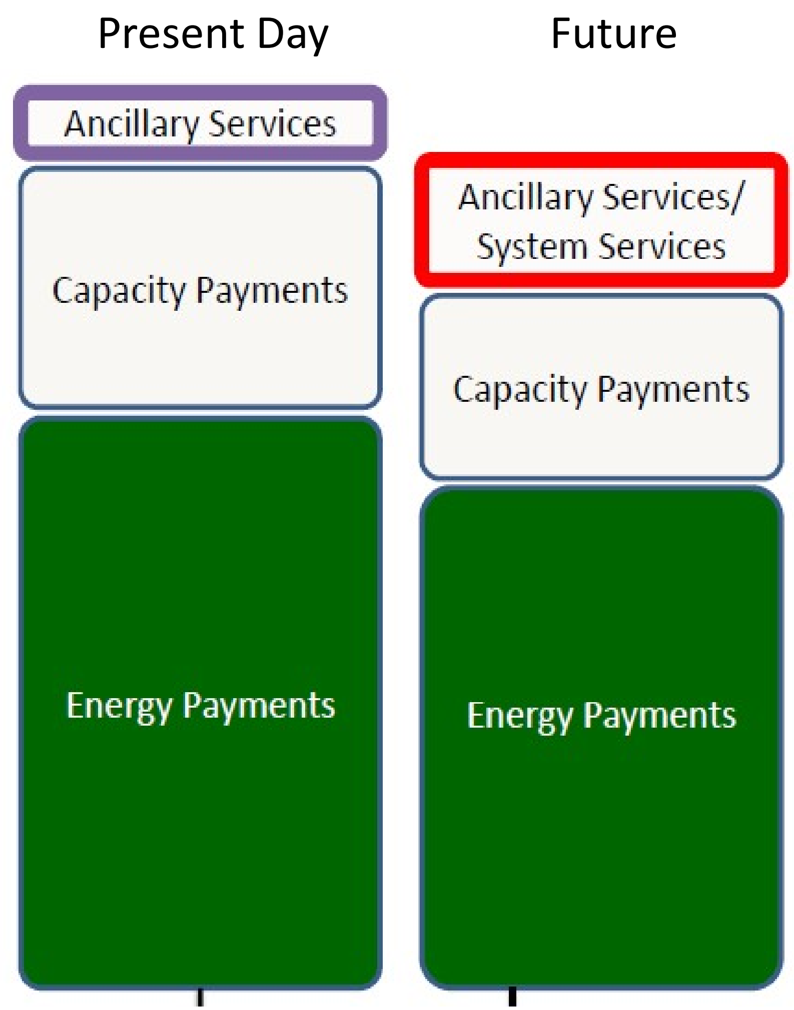
Operational flexibility,
increased load electrification,
home heating technologies,
plant cycling and system dynamics,
impact on investment decisions,
network expansion,
demand-side response, …

Energy Systems Framework



Rebalancing Revenue Streams

- Reward flexibility
- Reward service reliability
- Availability vs. performance reward mechanisms
- Higher renewables utilisation
- Lower energy prices

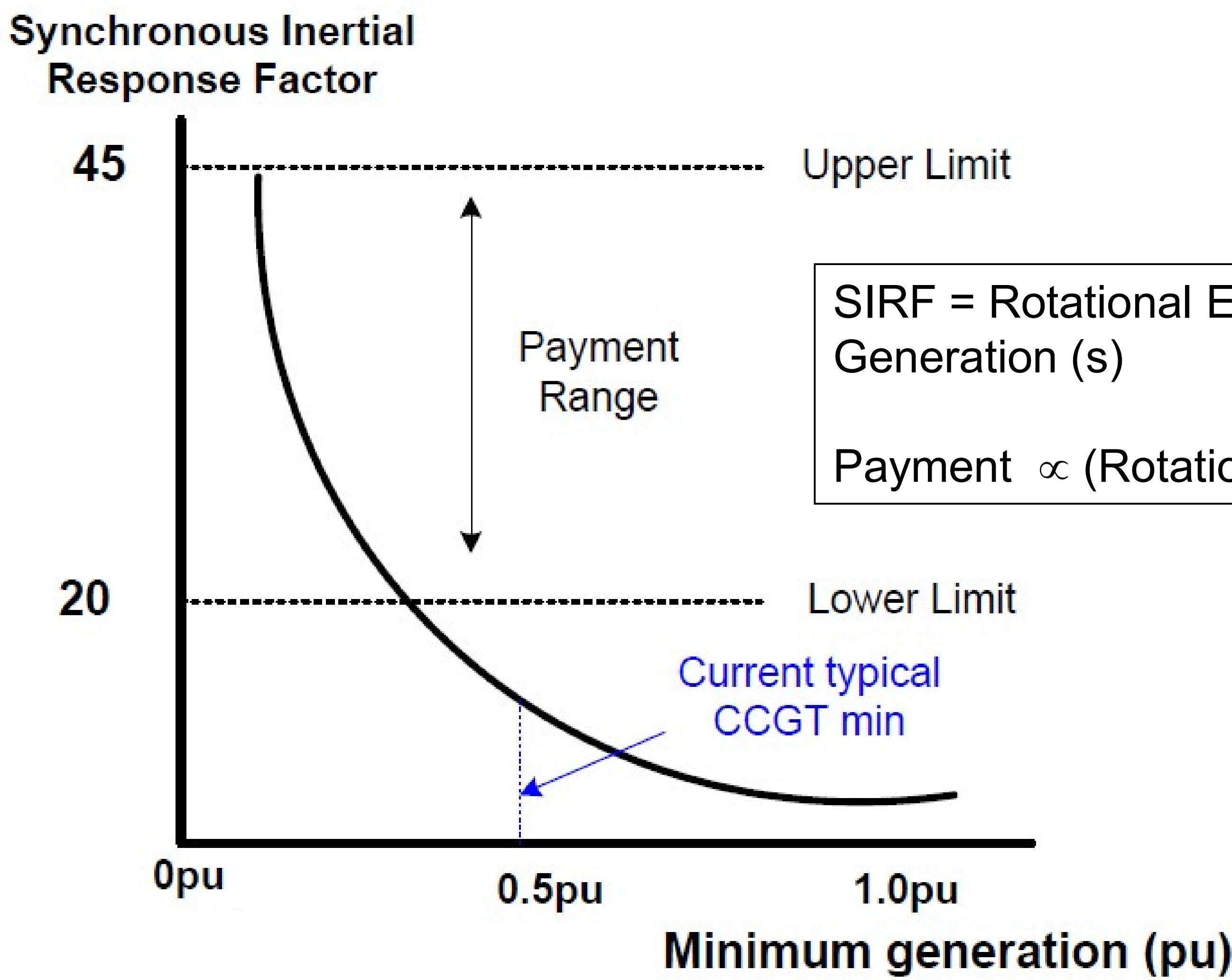


System Service Definitions

- Standard product concept
  - Minimum criteria must be met
  - Exceeding minimum criteria not rewarded
  - ‘Good’ fit for conventional generation
- Superproduct concept
  - Combination of several sub-products
  - Single provider or aggregator

- Supermarket concept
  - Technology neutrality promoted
  - Time varying availability vs. time varying needs
  - Complex (opaque?) decision making process

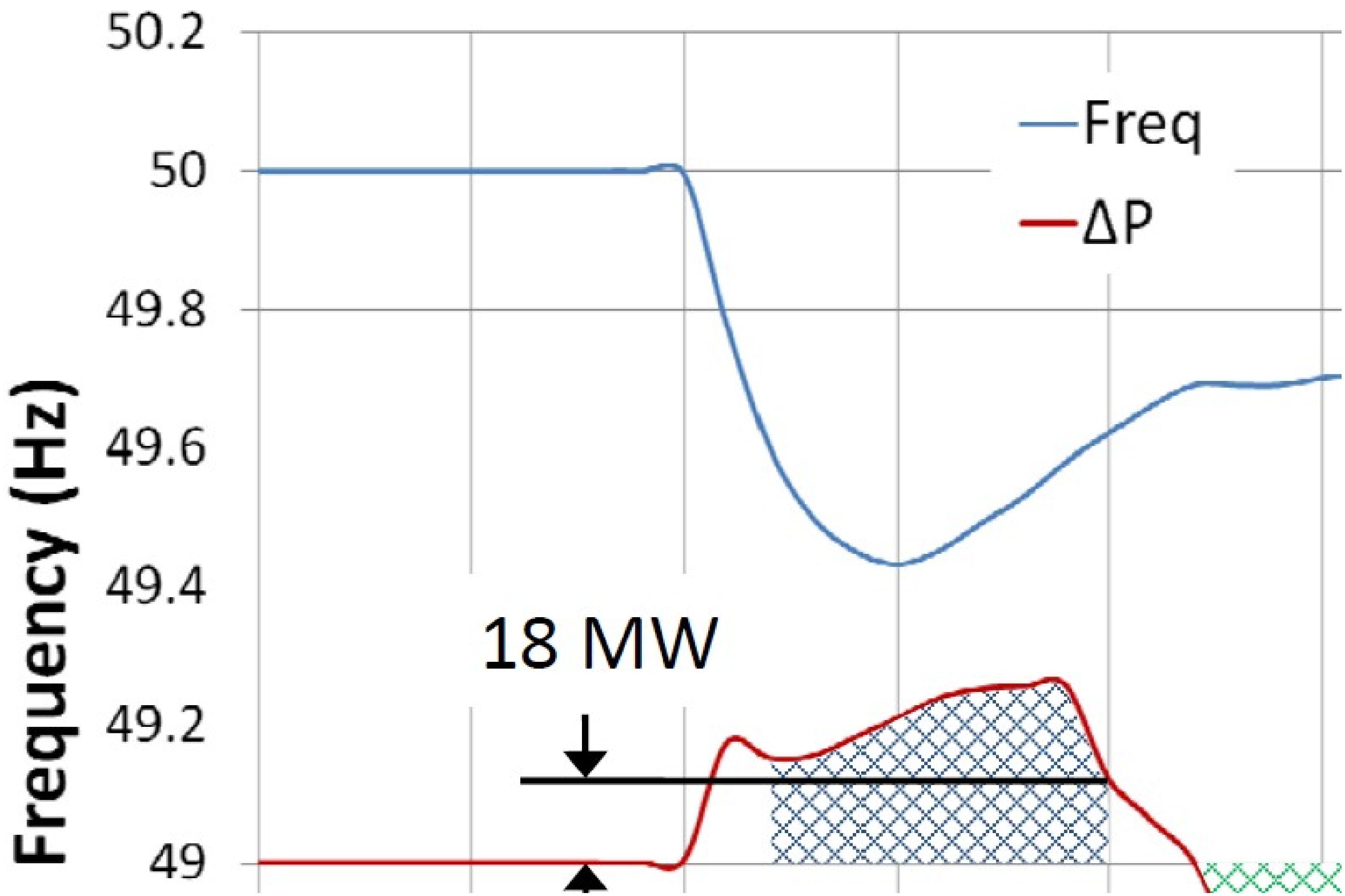
Synchronous Inertial Response



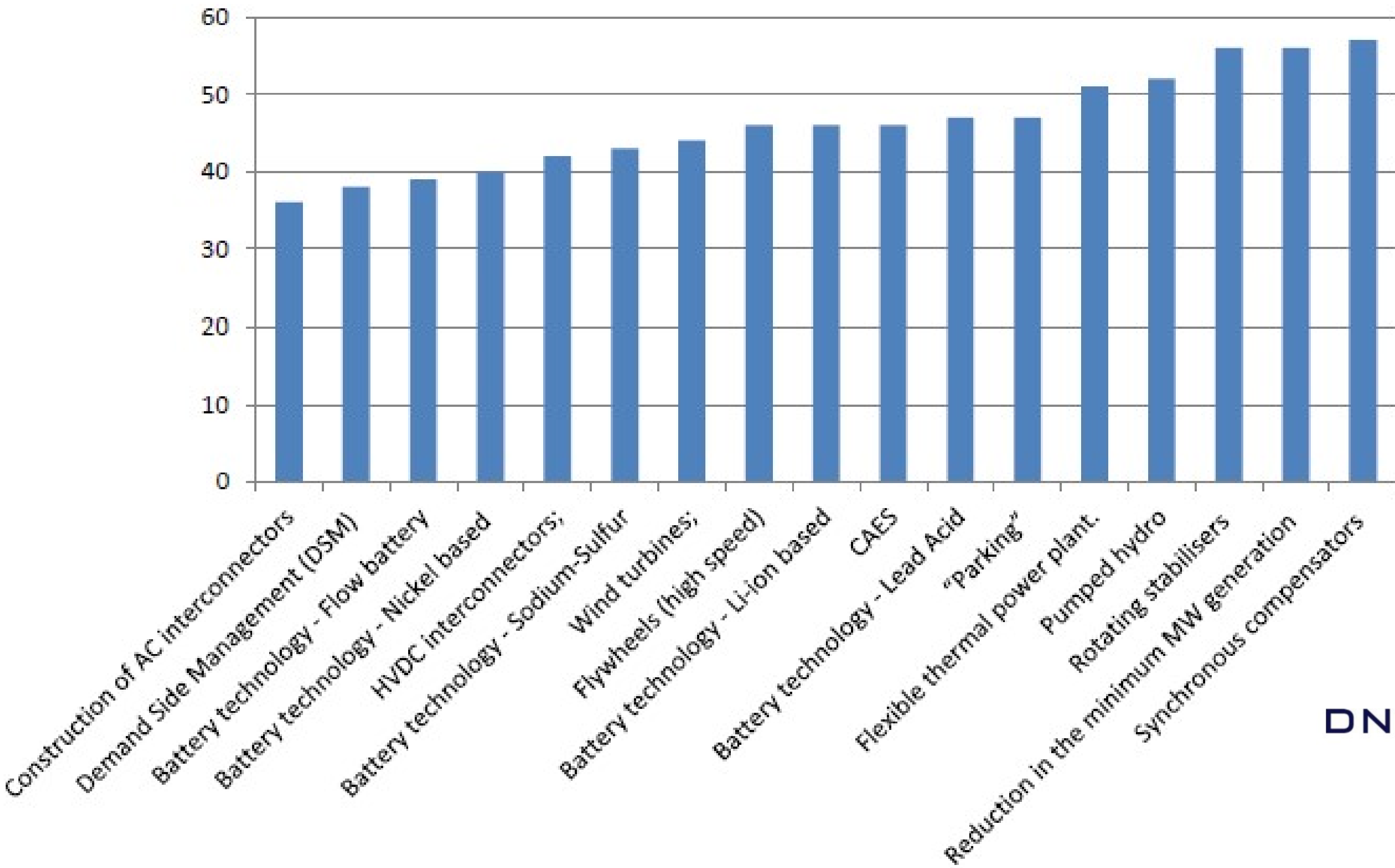
SIRF = Rotational Energy / Min Stable Generation (s)

Payment $\propto$ (Rotational Energy x SIRF)

Fast Frequency Response



Fast Frequency Response Options?



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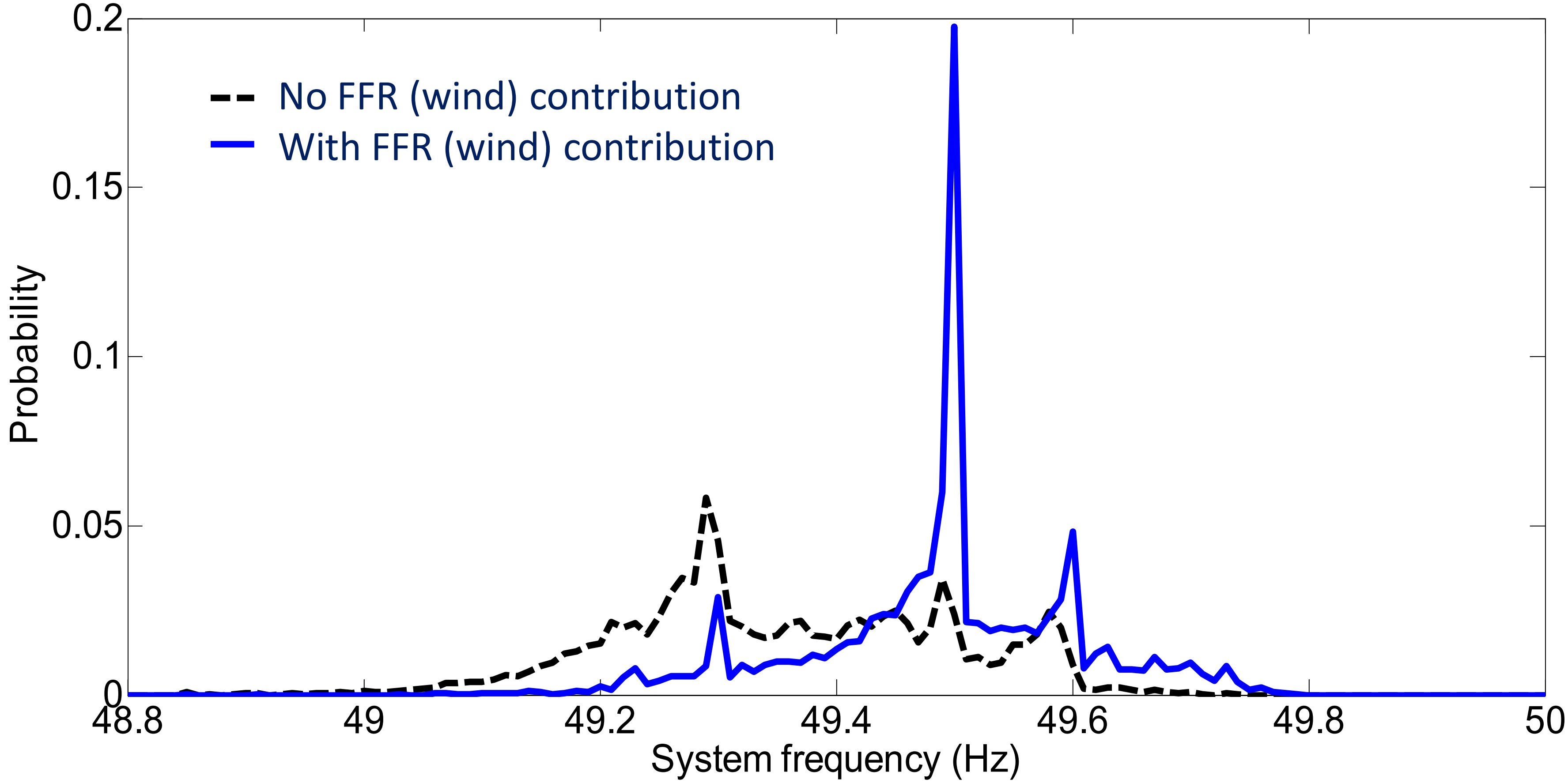
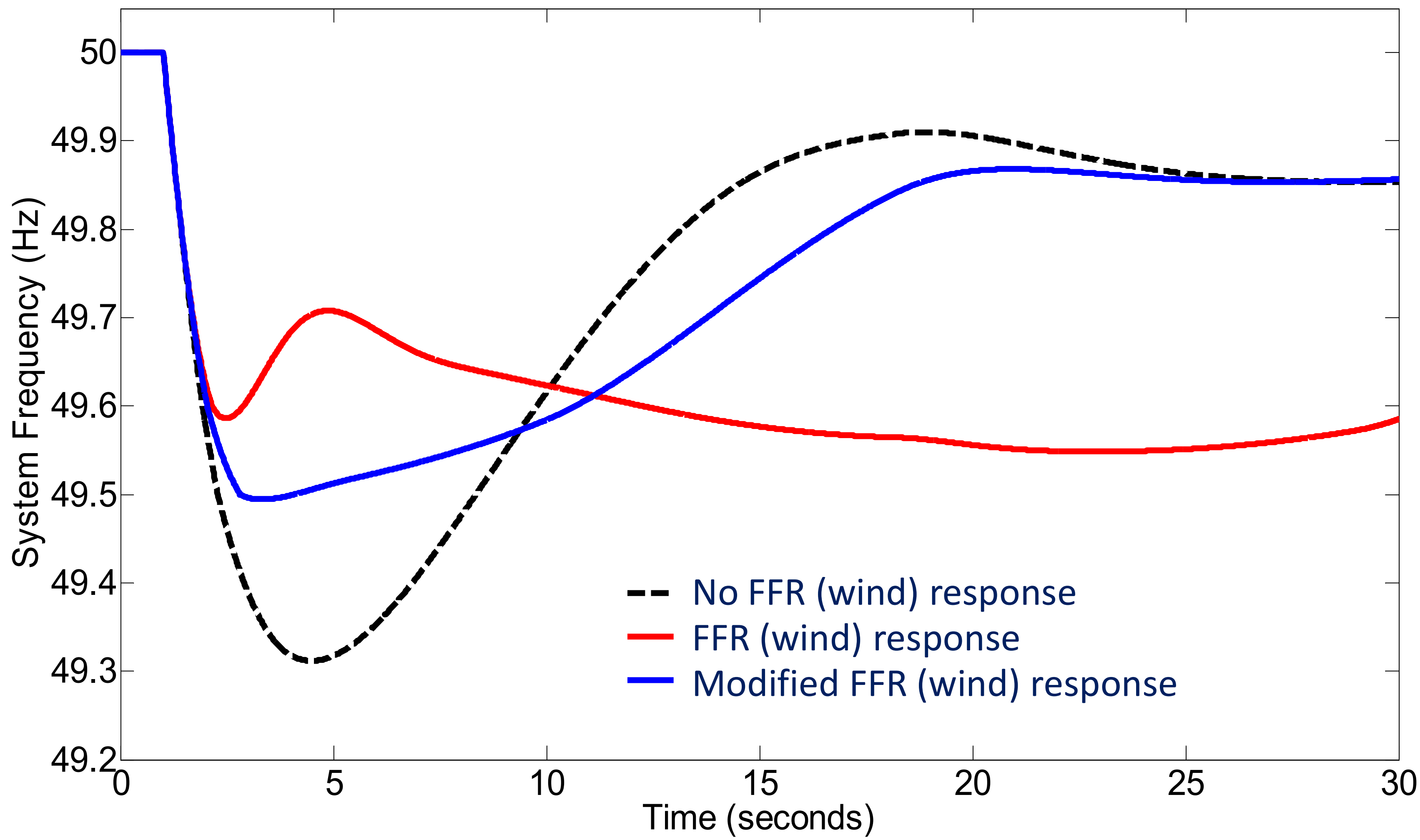
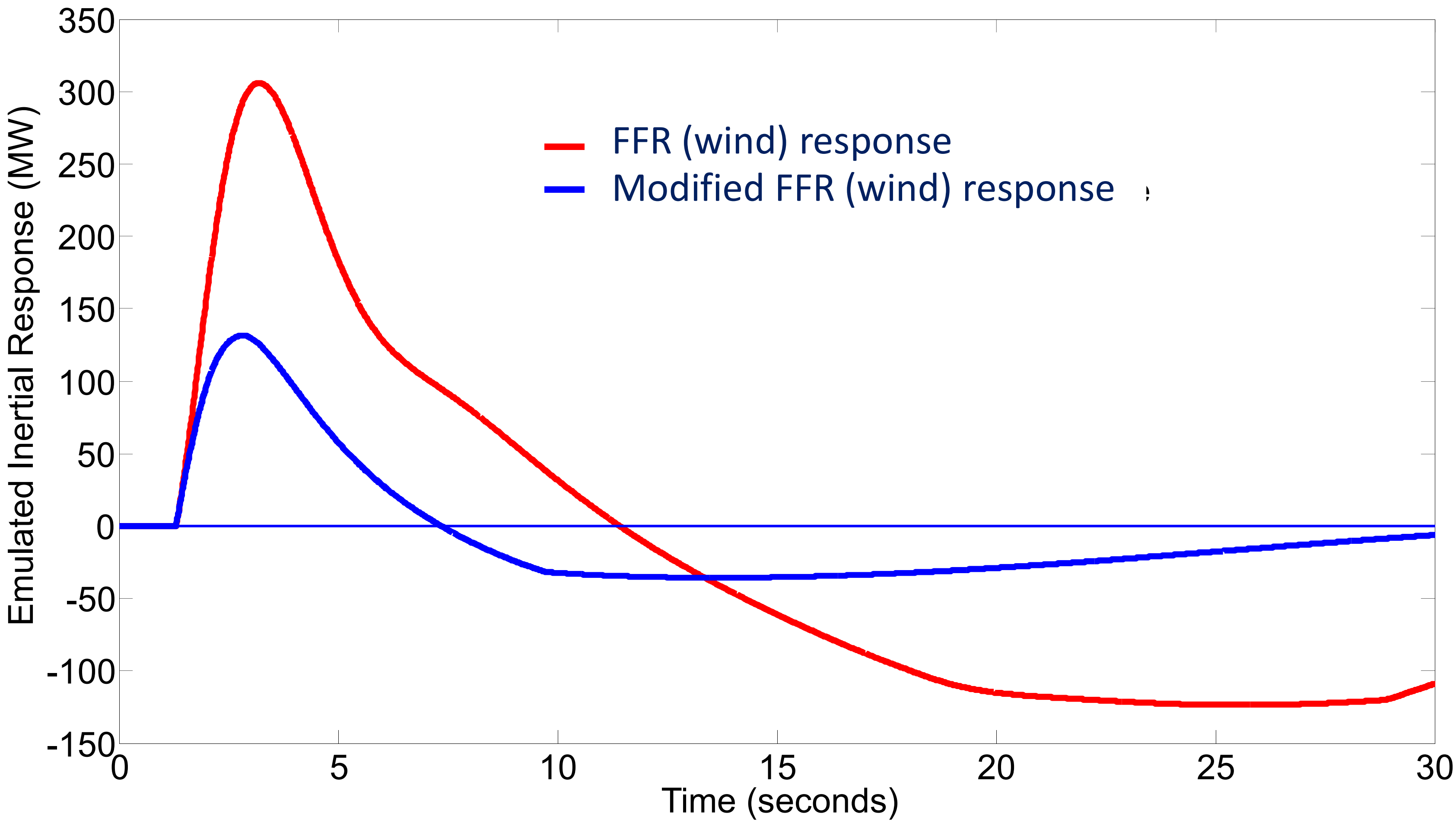
Frequency Nadir Distribution



FFR Response Tuning



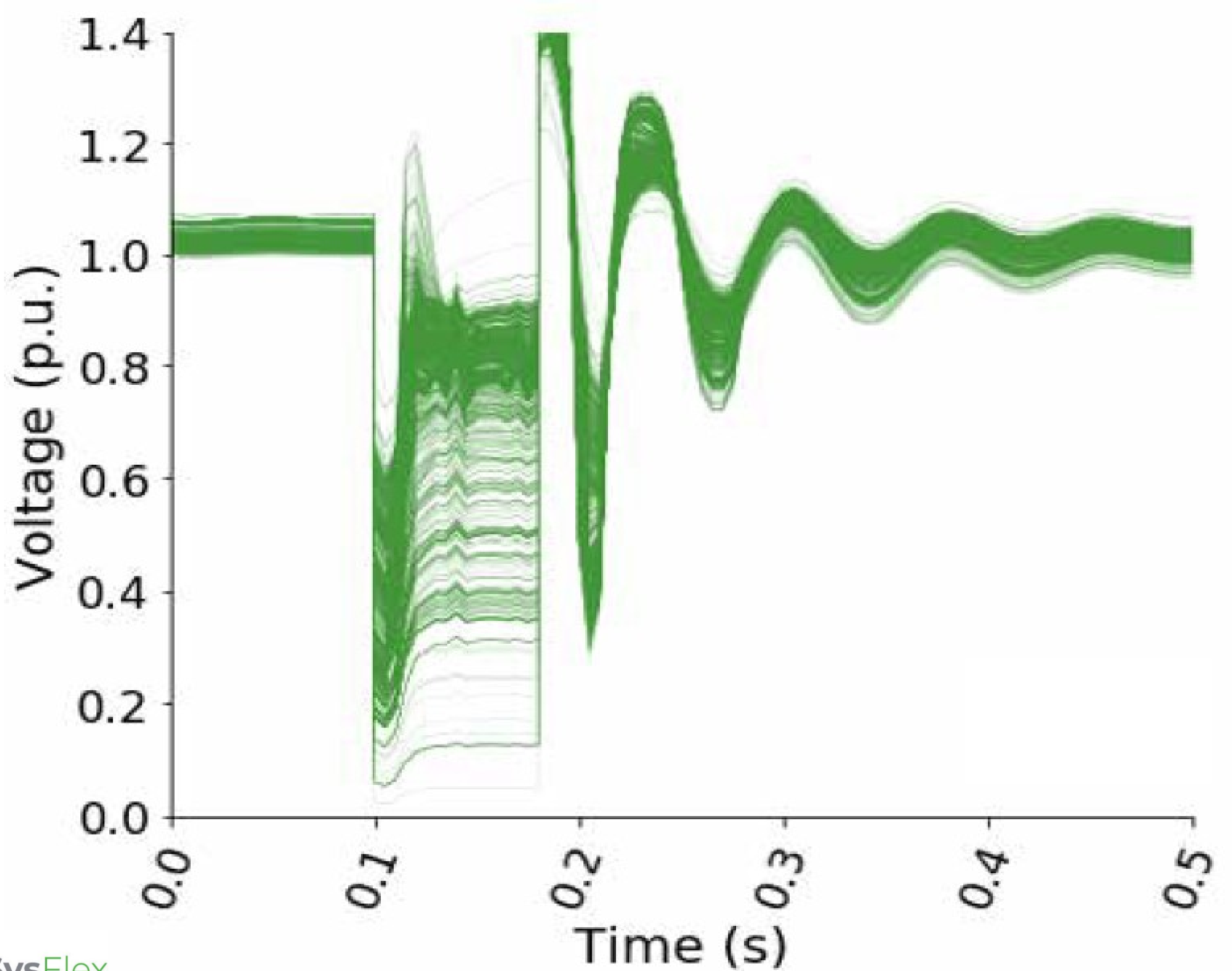
Modified FFR (Wind) Response



Reactive Power Markets

- Traditional role of transmission & distribution system operator to support network voltage
  - STATCOM / SVC / sync compensator, etc. investments
  - Dynamic line rating, power flow controls
  - High temperature low sag (HTLS) conductors
- Steady-state & dynamic reactive power products
  - Temporal scarcity + locational scalars
- In competition with the TSO / DSO?
  - Access to *effectiveness* heat maps
- *Prioritisation for zero carbon reactive sources?*

Dynamic Reactive Response



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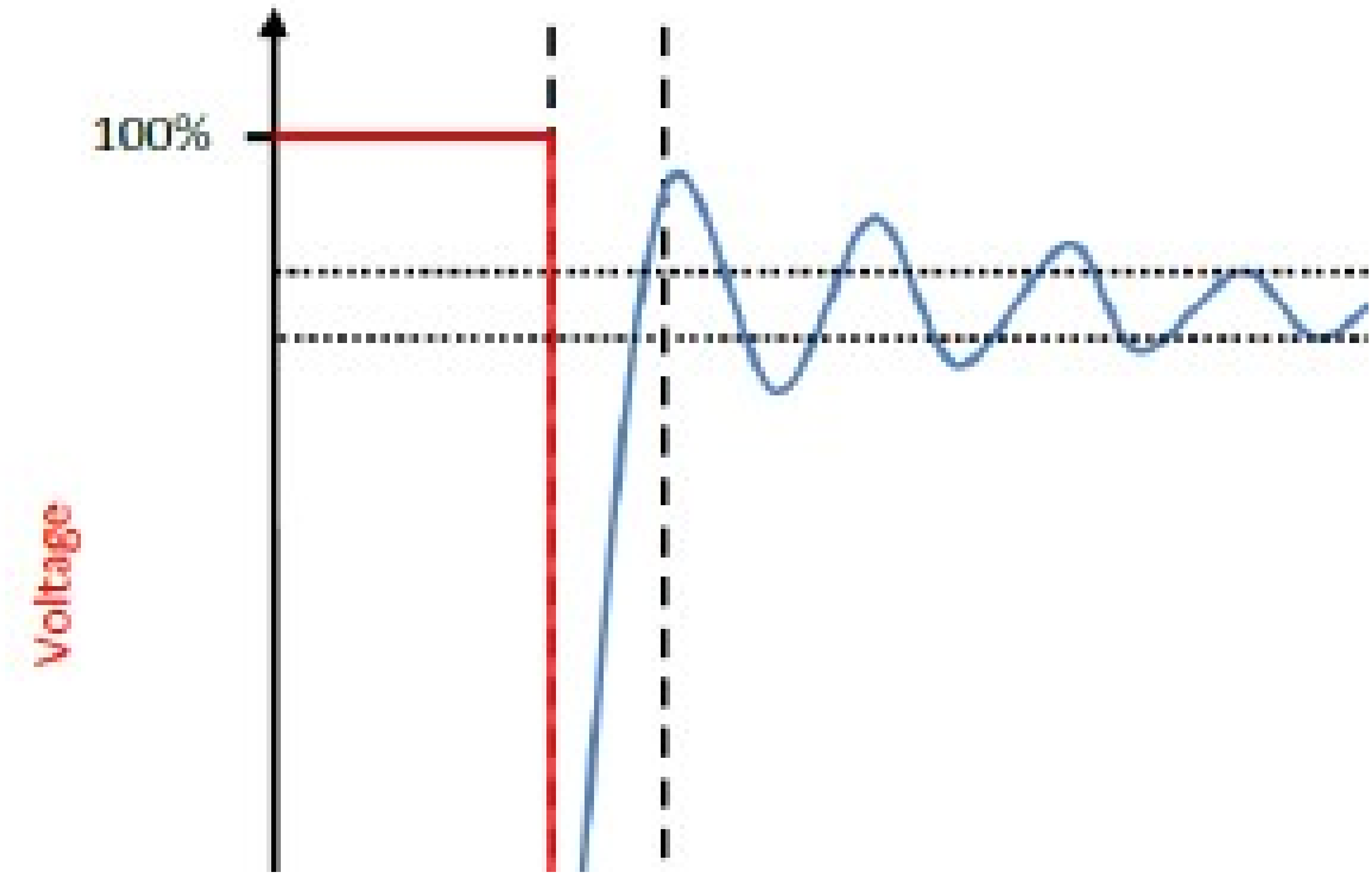
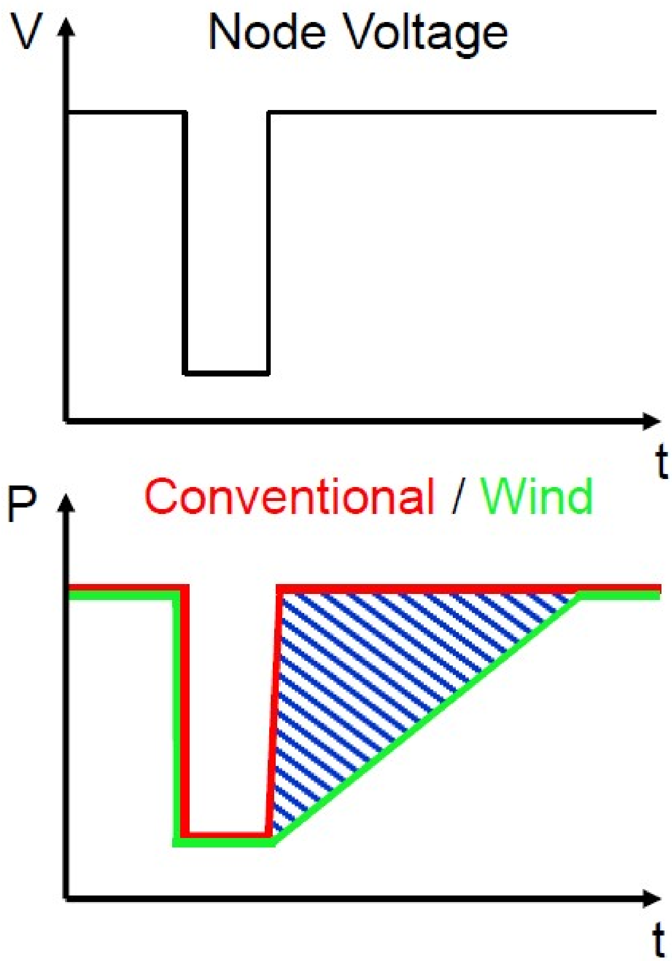
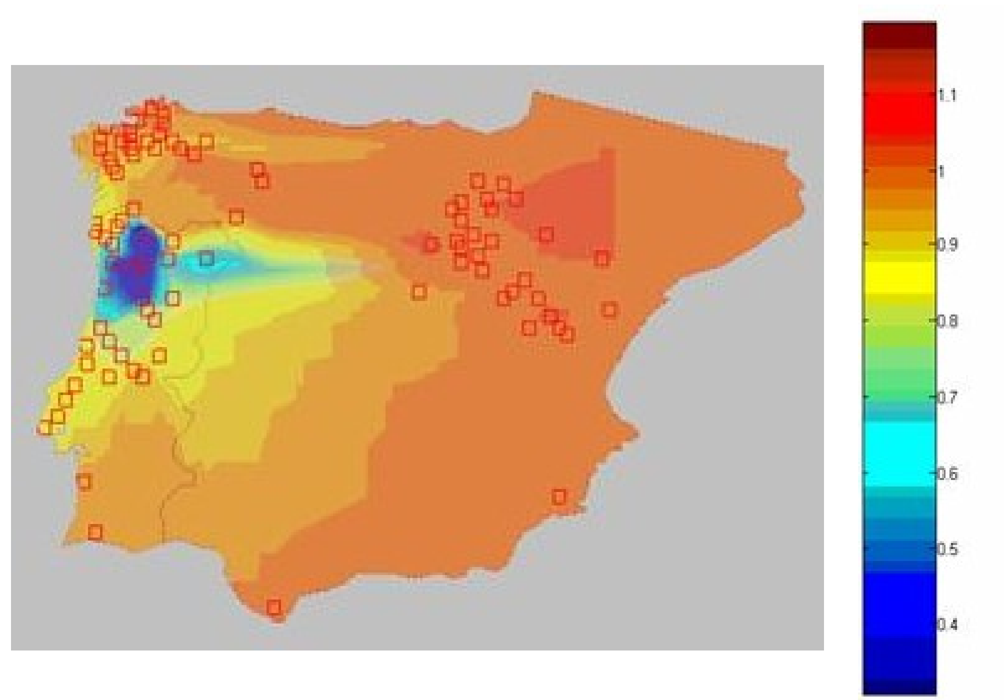
Dynamic Reactive Response



Voltage Dip-Induced Frequency Dips





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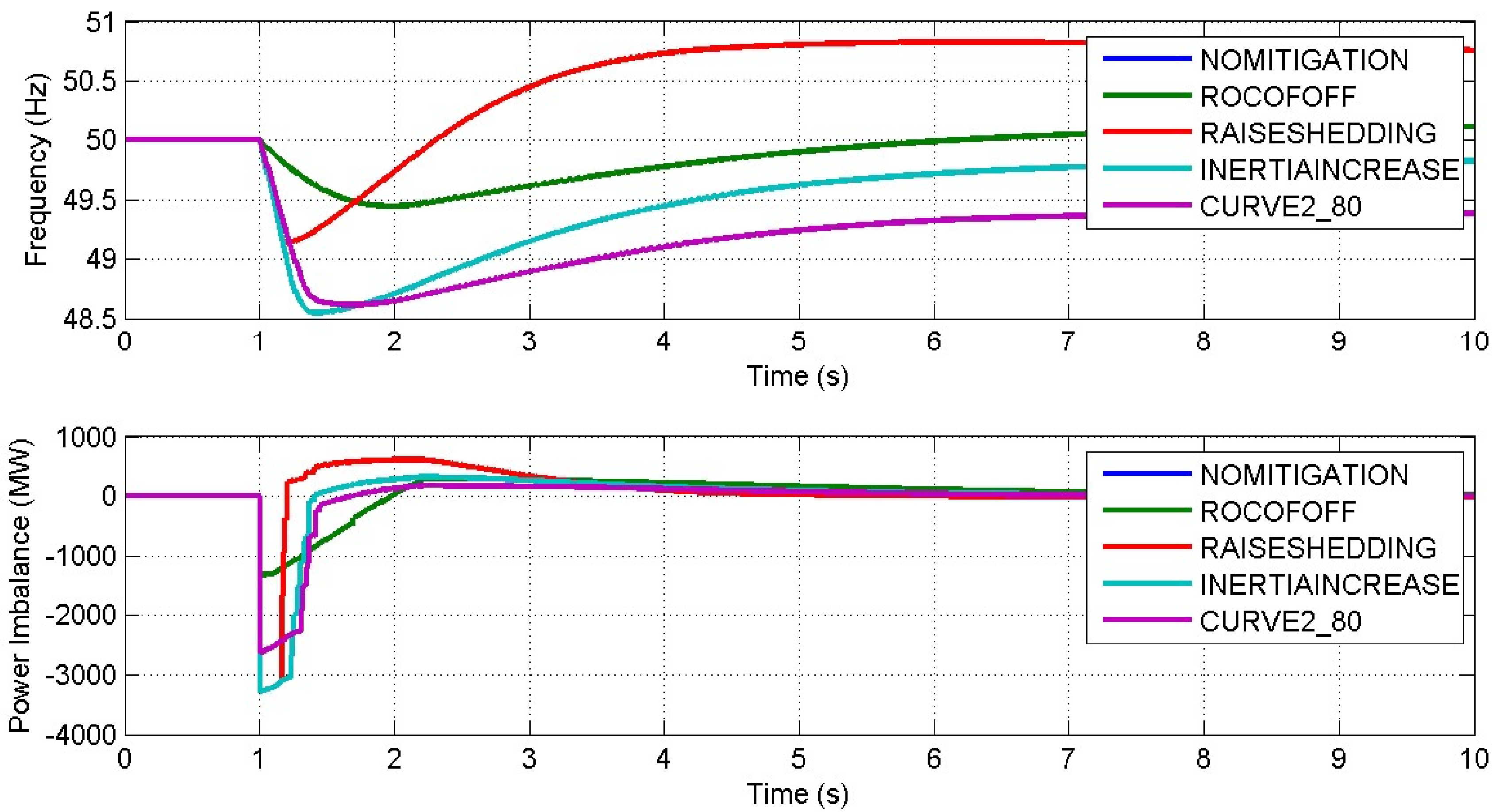
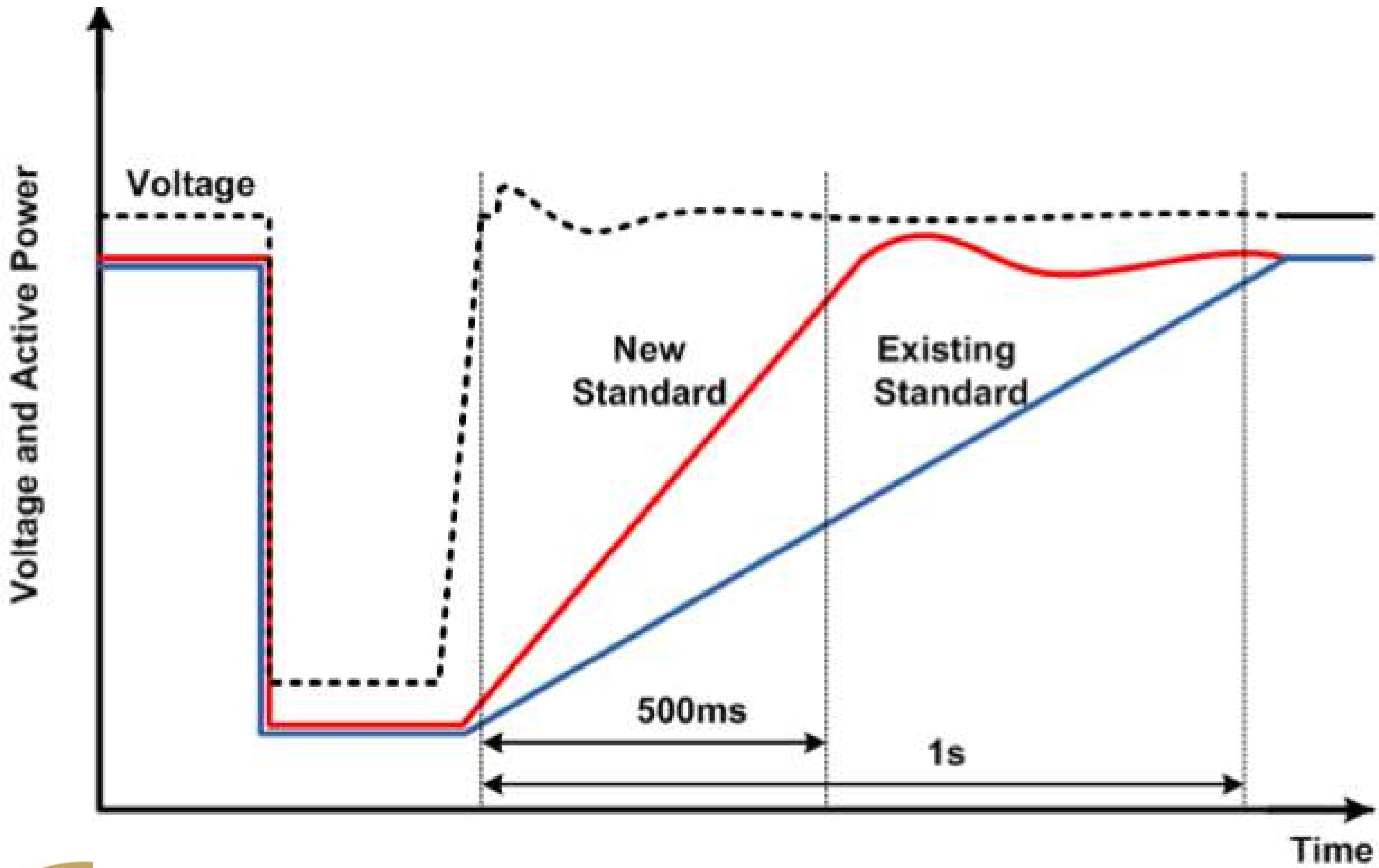
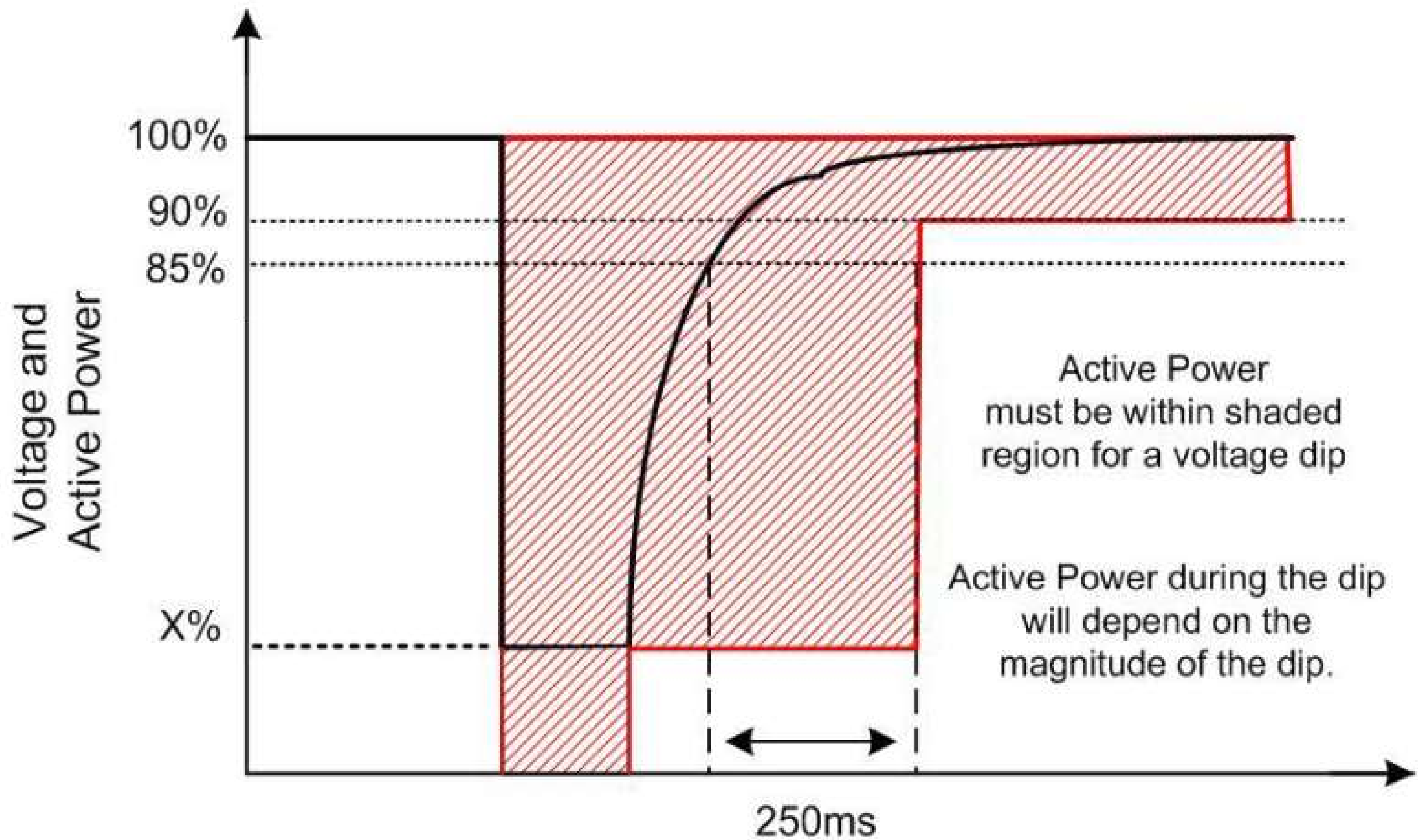


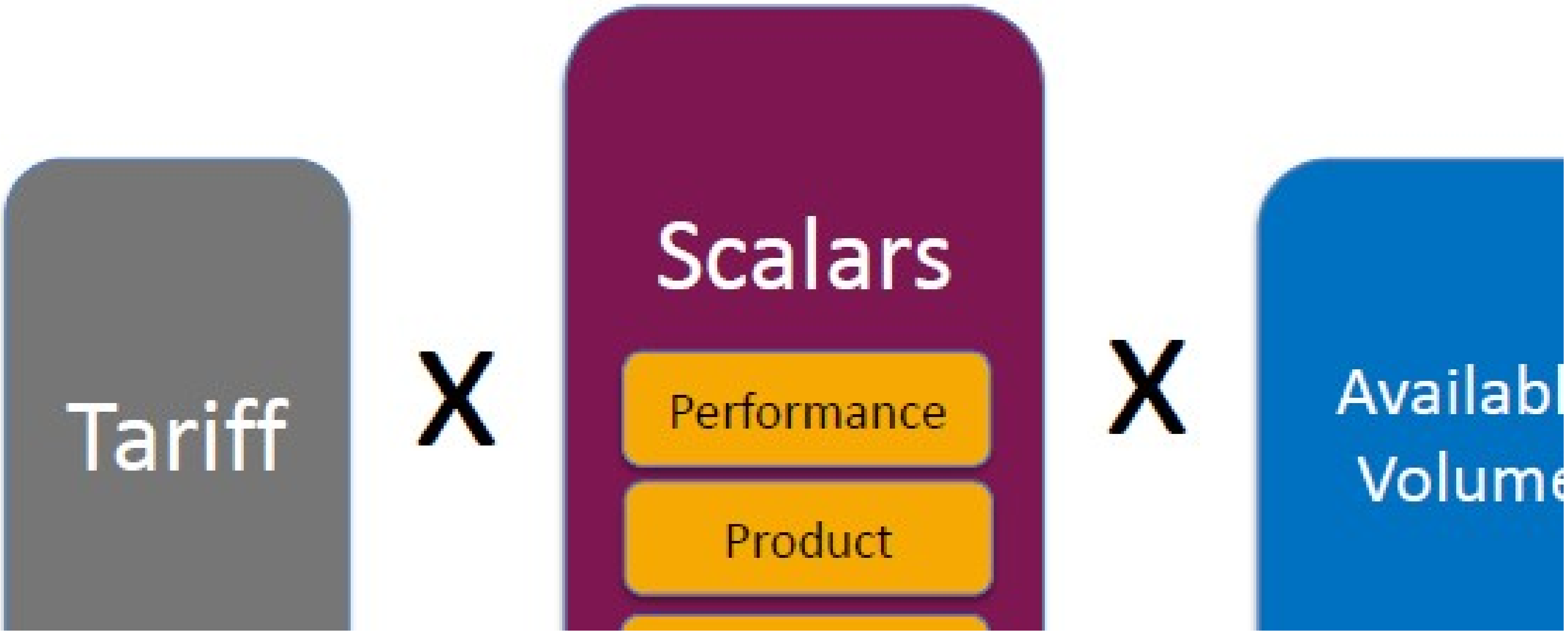
Post-Fault Active Power Recovery



Post-Fault Active Power Recovery

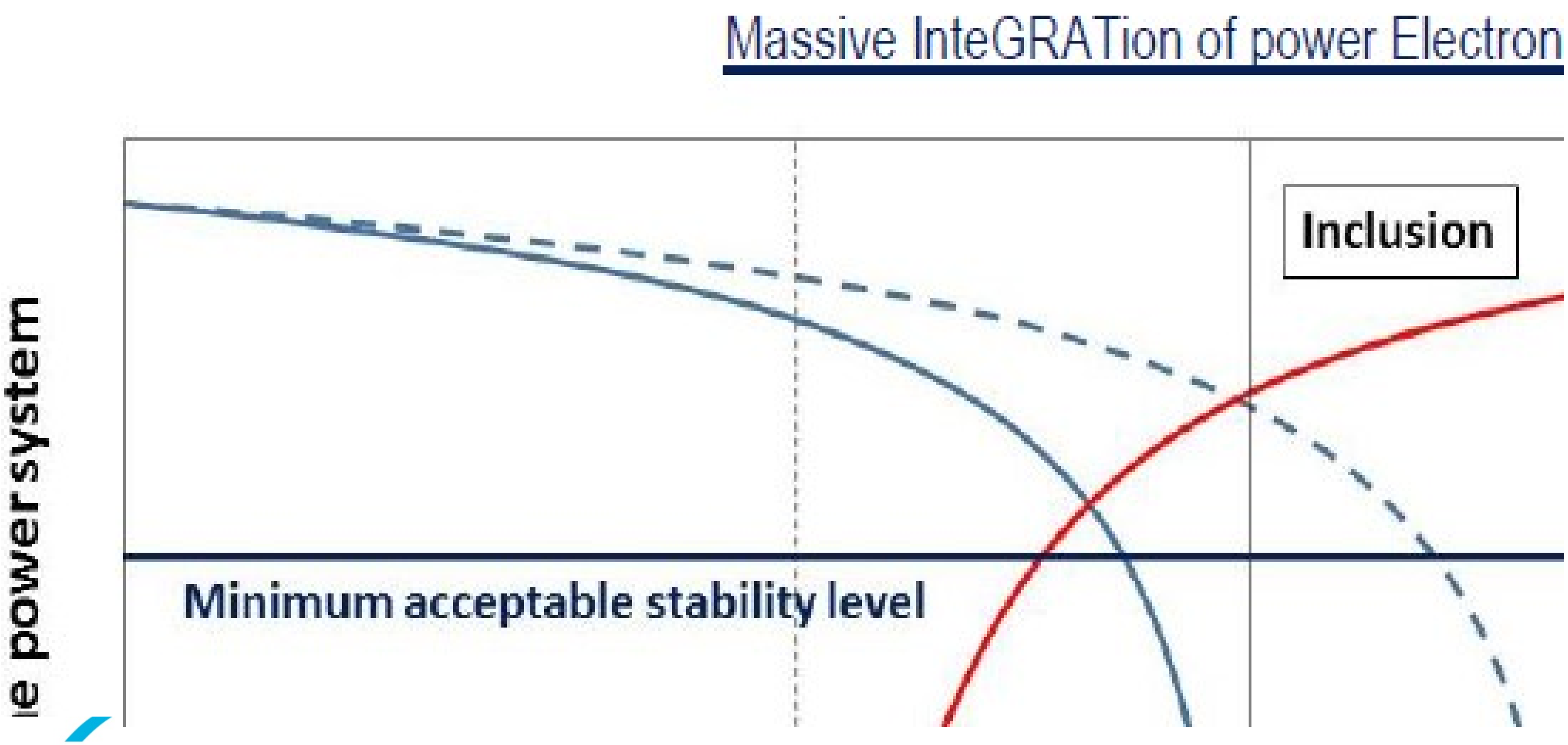


Payment Arrangements

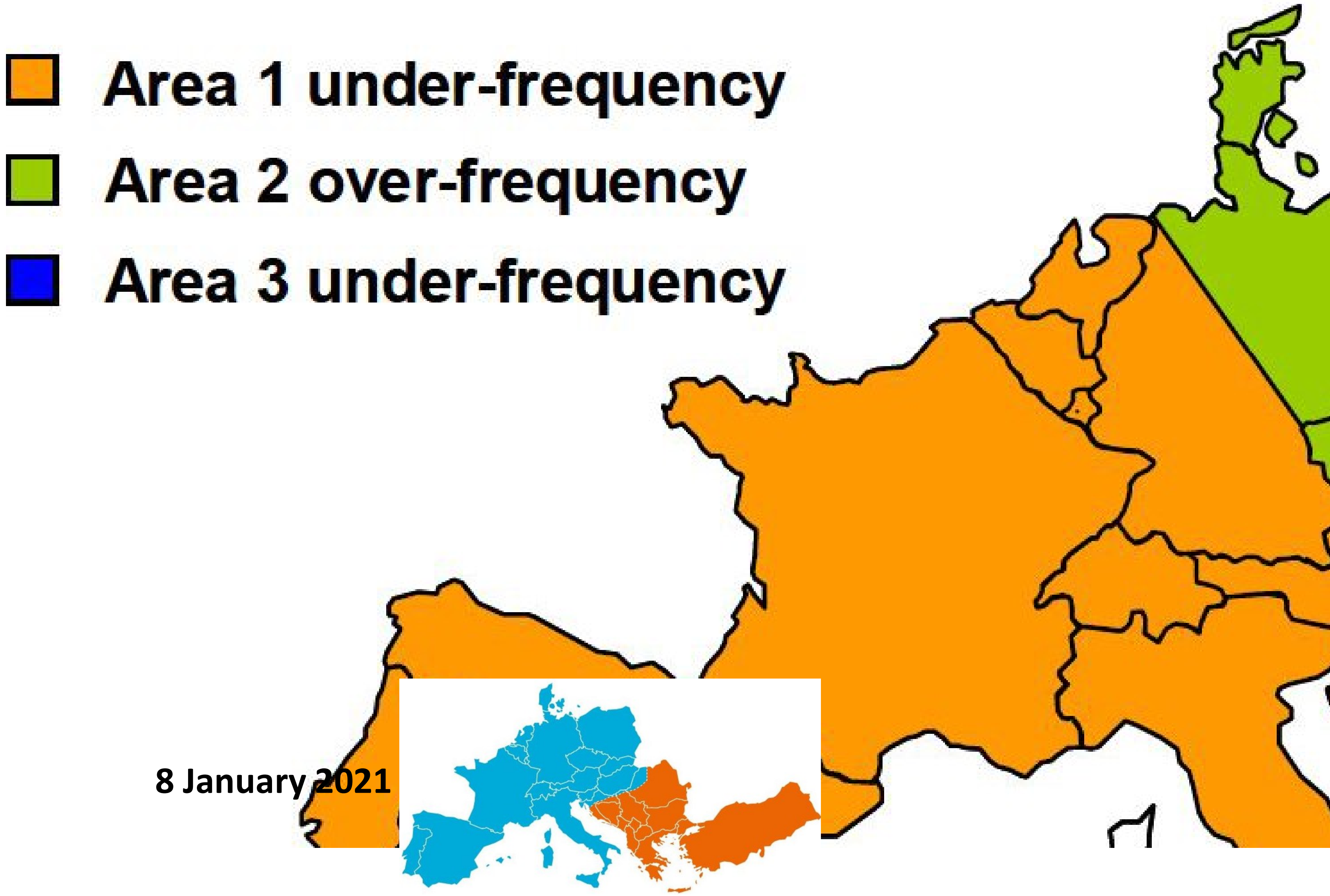


Performance scalar ~ Reliability of service
~ Speed of response
~ Dynamic response (non-stepped)
~ Enhanced delivery (multiple products)
~ Scarcity of supply (temporal and locational)
~ Availability forecast accuracy ?

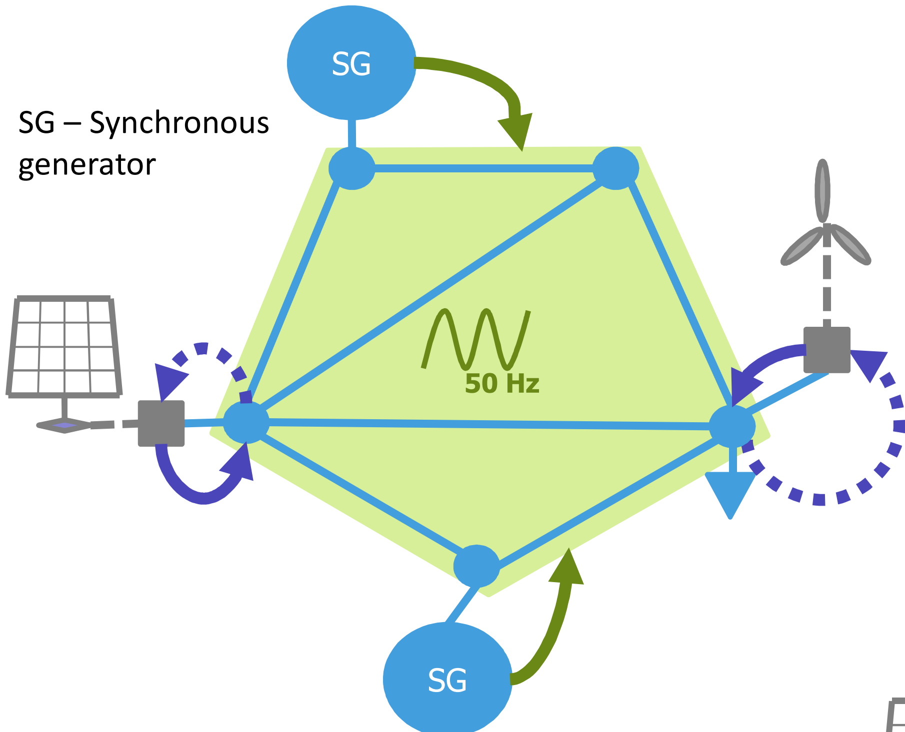
Power System Transition



4 November 2006



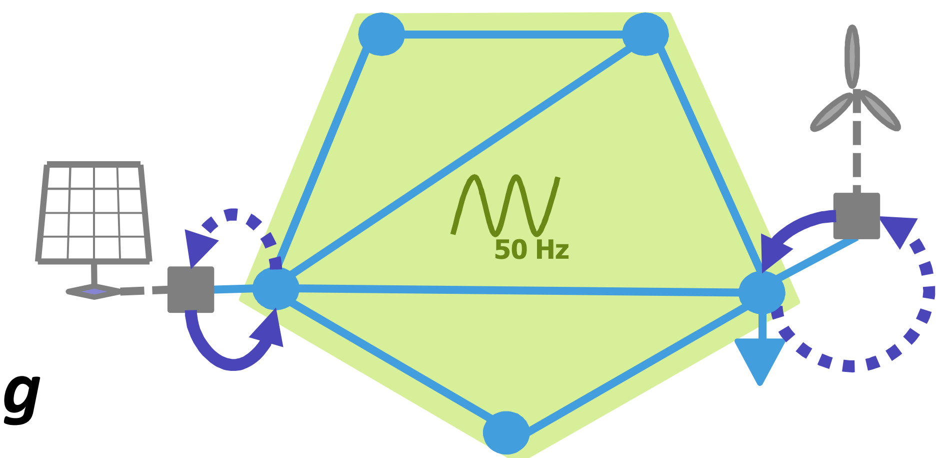
Grid-Forming Converters



Existing (wind + solar) converters are *grid-following*

What to *follow*?

Some / many* future converters need to be *grid-forming

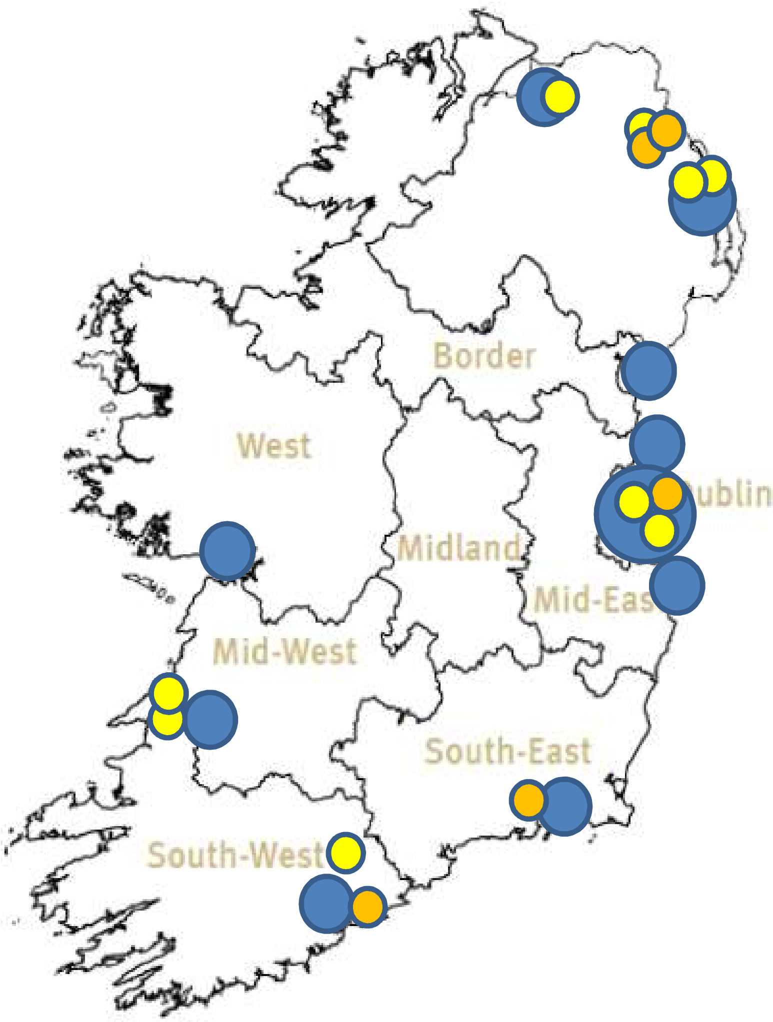


100% Converter-Based Grids

Wind + Solar

- No conventional synchronous generation
  - Rotational inertia? Voltage support? Fault contribution?
- What is meant by system frequency?
- Achieving load balancing with ‘local’ controls?
- Operational rules in a ‘100%’ state?
- Requirement for (new) system services?

Minimum Grid-Forming Share



- Major load centres
- Grid-forming converter
- Grid-following converter

System grid-forming ratio

$$SGFR_{100} = \frac{GF}{GF \ldots}$$

System non-synchronous penetration

$$SNSP = \frac{P_W + P_{H}}{P \ldots + P}$$

Grid-Forming Questions

- How should grid-forming be *future-proof* defined?
  - Black start capability?
- Grid-forming a (future) requirement or an option?
  - Role for synchronous condensers?
- Should grid-forming be the (sole) responsibility of the system operator?
- Should grid-forming capability be mandated through grid codes?
- Can grid-forming capability be *robustly* supplied through system service arrangements?

... Some Open Questions

- How best to achieve cost effective operation while maintaining system stability with increasing RES?
- Can we avoid building new lines while facilitating demand growth and new generation?
- Growth and nature of *self-consumption*?
- How to incentivise plant portfolios which maintain system adequacy?
- Need for and desirability of seasonal storage?
- *Should CO_2 reduction objectives outweigh economic / least cost motivations?*

Power System Operation, Stability and Markets

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