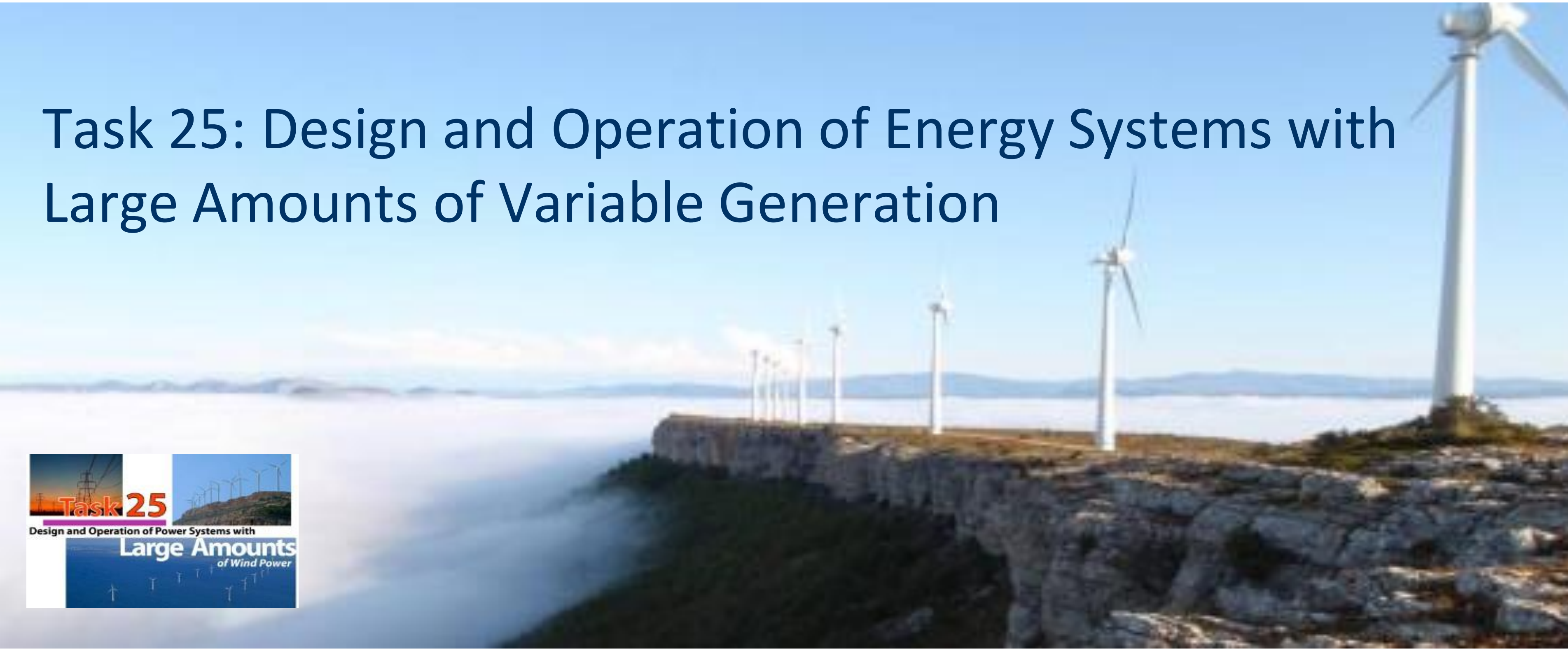
Towards 100% renewable systems

Task 25: Design and Operation of Energy Systems with Large Amounts of Variable Generation



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WIW20 Session 7A, 12 Nov, 2020

iea wind

Based on IEA WIND Task 25 collaborative articles

- **”Towards 100% Variable Inverter-based Renewable Energy Power Systems”** by Bri-Mathias Hodge, C Brancucci, H Jain, G Seo, B Kroposki, J Kiviluoma, H Holttinen, J C Smith, A Estanqueiro, A Orths, L Söder, D Flynn, M Korpås, T K Vrana, Yoh Yasuda. WIREs Energy and Environment vol 9, iss. 5, e354 https://doi.org/10.1002/wene.376
- **“System impact studies for near 100% renewable energy systems dominated by inverter based variable generation”** by
  H Holttinen; J Kiviluoma; D Flynn; C Smith; A Orths; P B Eriksen; N Cutululis; L Söder; M Korpås, A Estanqueiro, J MacDowell, A Tuohy, T K Vrana, M O’Malley , IEEE TPWRS Oct 2020 open access
  https://ieeexplore.ieee.org/document/9246271
- https://www.researchgate.net/project/IEA-Task-25-Design-and-Operation-of-Power-Systems-with-Large-Amounts-of-wind-power

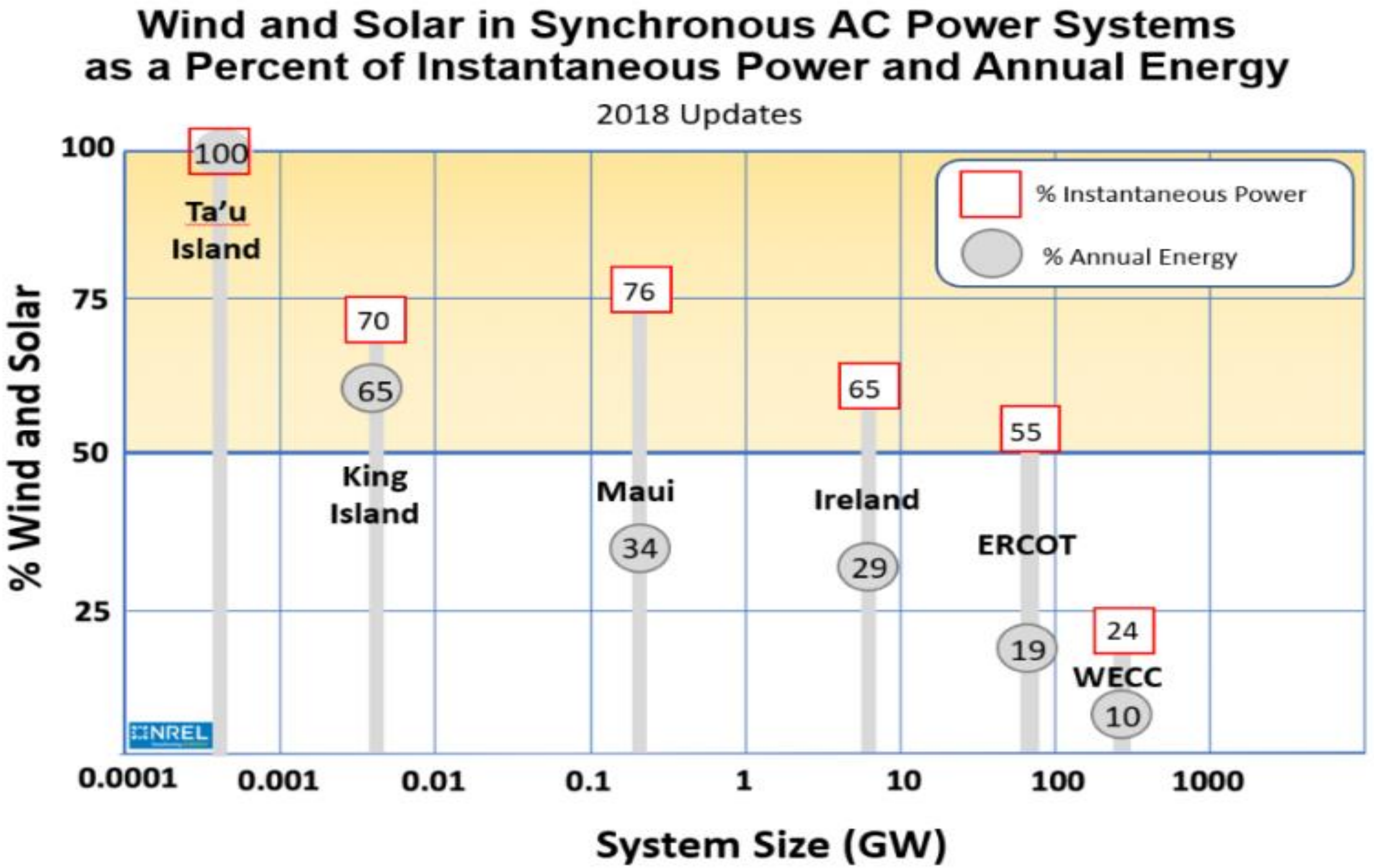
Contents

- Challenges
- Mitigation options
- Status and Gaps in simulation model tools
- First recommendations for studies

VIBRES – Variable Inverter Based Renewable Energy Sources

ENERGINET

Experience is growing

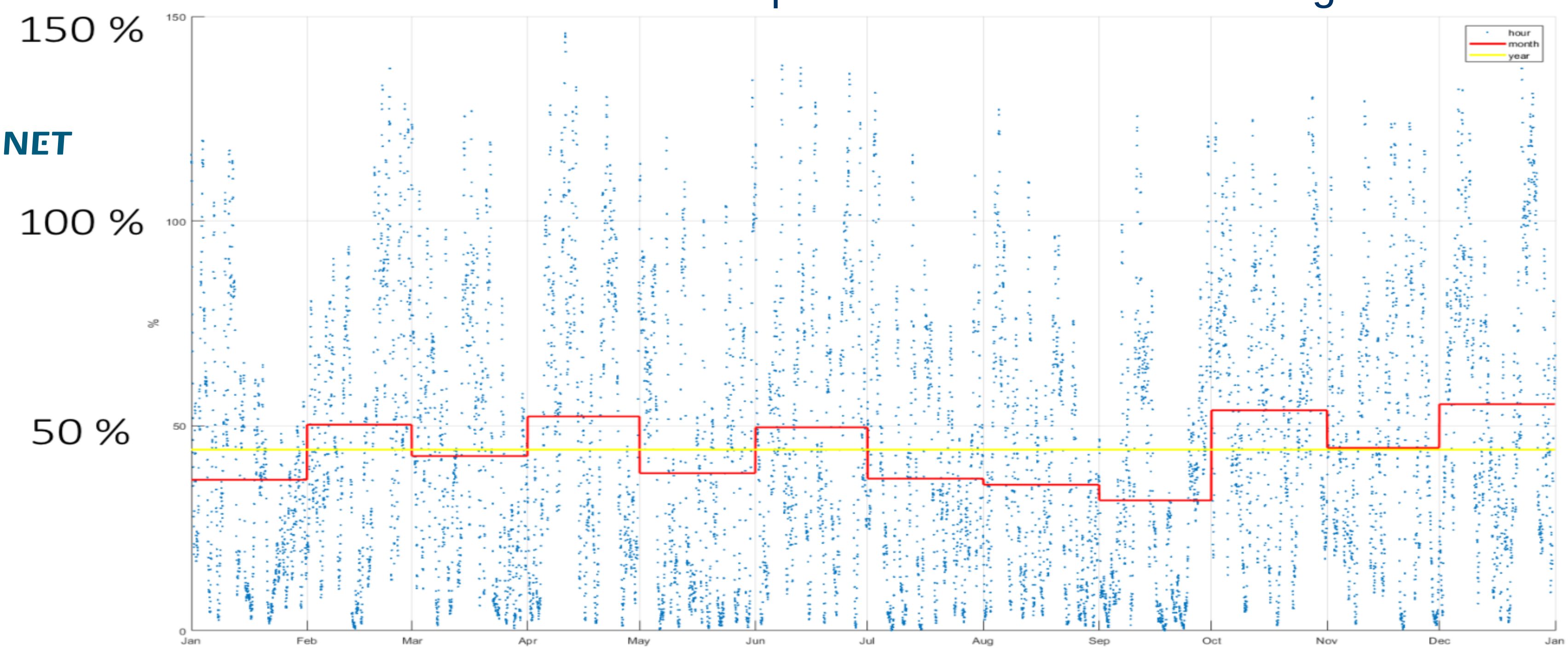


Transition to a (nearly) 100% annual VIBRES system gradually during the next decades

High share of VRE operation for extended times before

Instant 100% will be faced already when less than 25 % on average

Example DK 2017 43 % on average

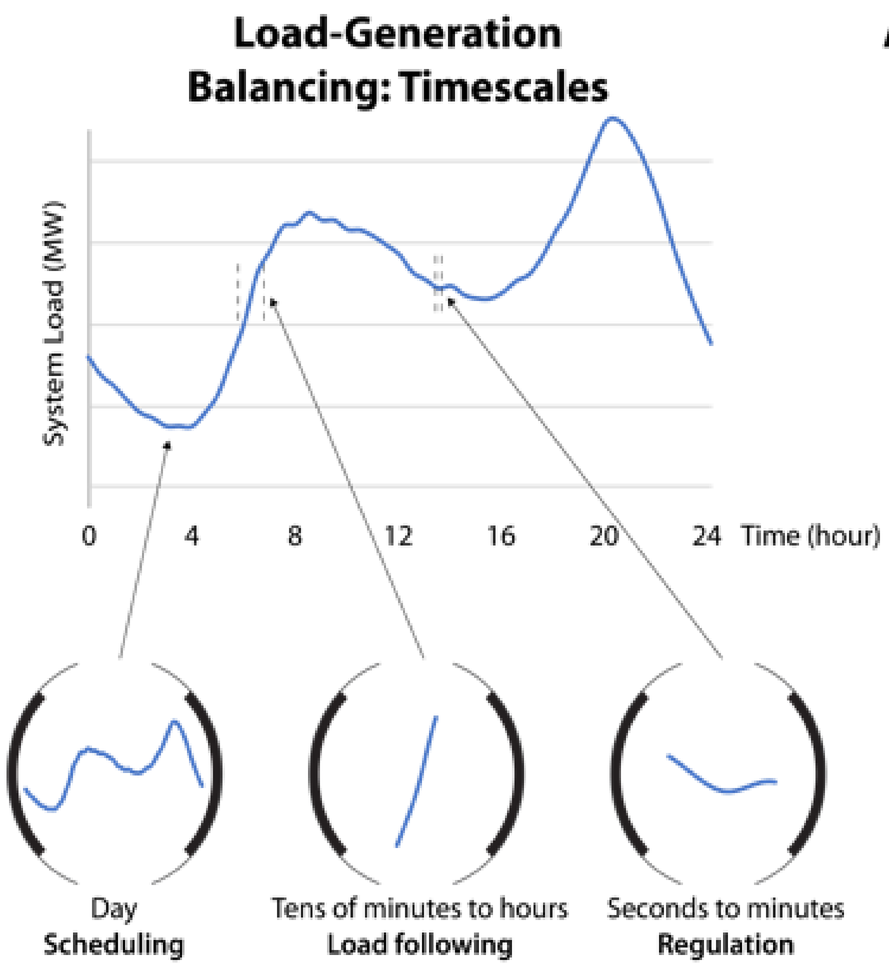


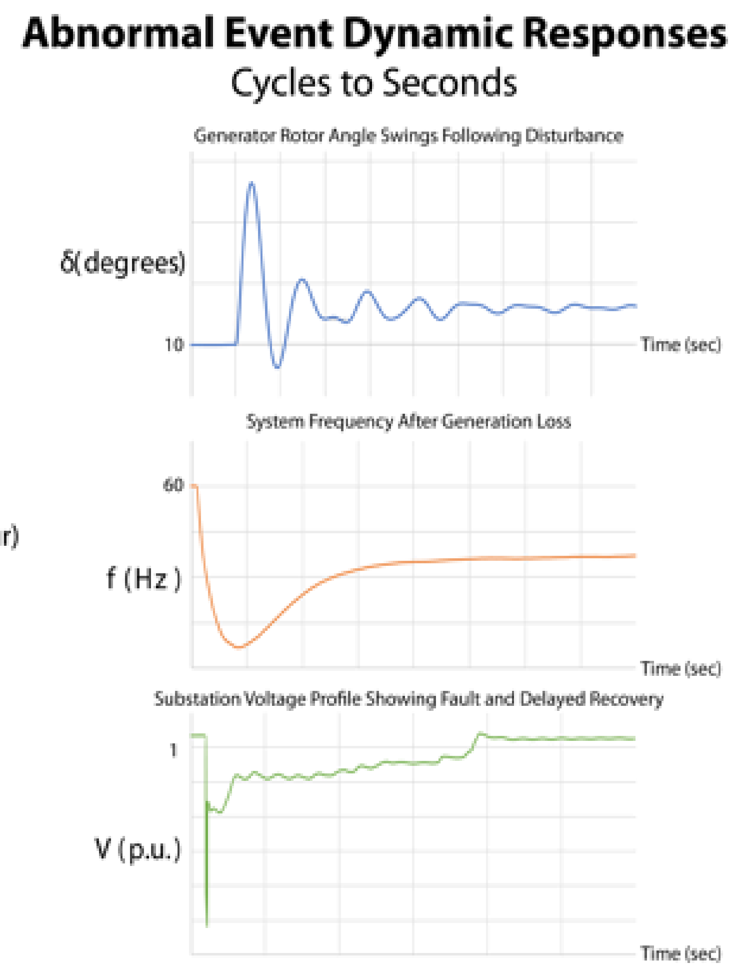
ENERGINET

Towards 100% renewables

1. 100% VIBRES region that is part of a larger non-100% VIBRES synchronous power system
   - challenges are about balancing, local aspects of stability and efficient sharing of electricity and reserves with neighbouring areas. Highlights importance of how the neighbouring regions are presented in studies
2. A synchronous system getting closer to 100% VIBRES for short periods of time
   - a challenge on top of these: system-wide stability issues
3. 100% yearly energy from VIBRES
   - a challenge on top of these: the adequacy issue, to meet high demand at low VIBRES contribution

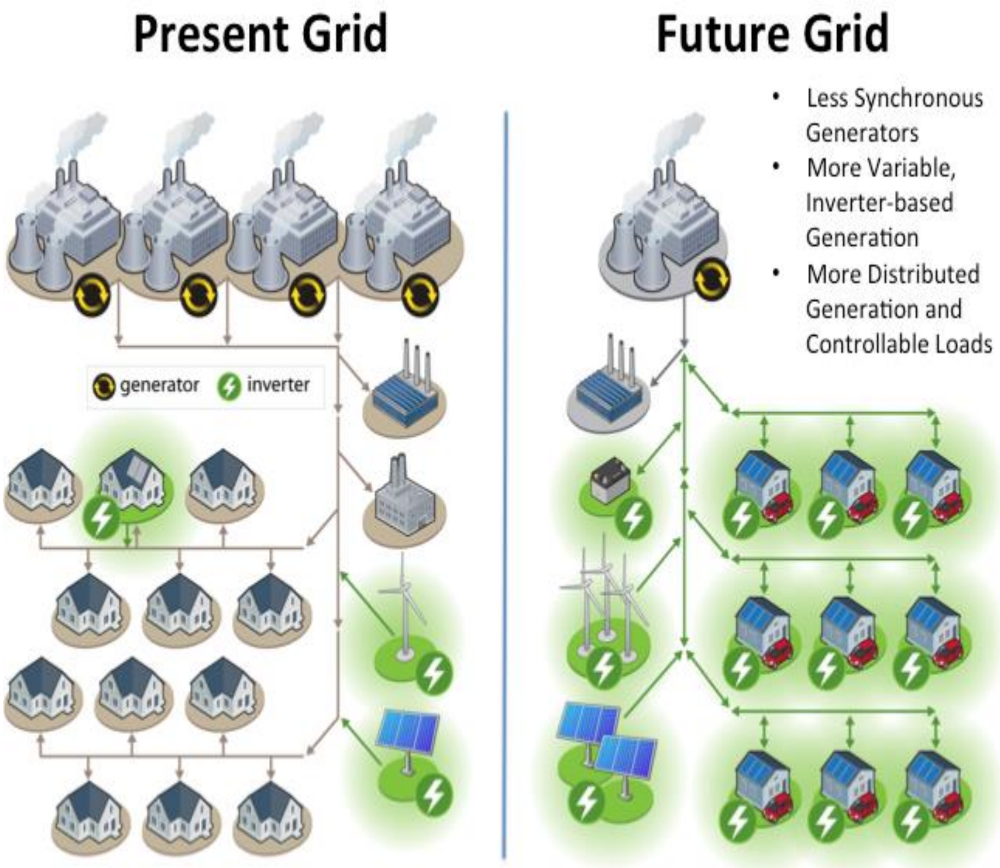
Balancing and stability





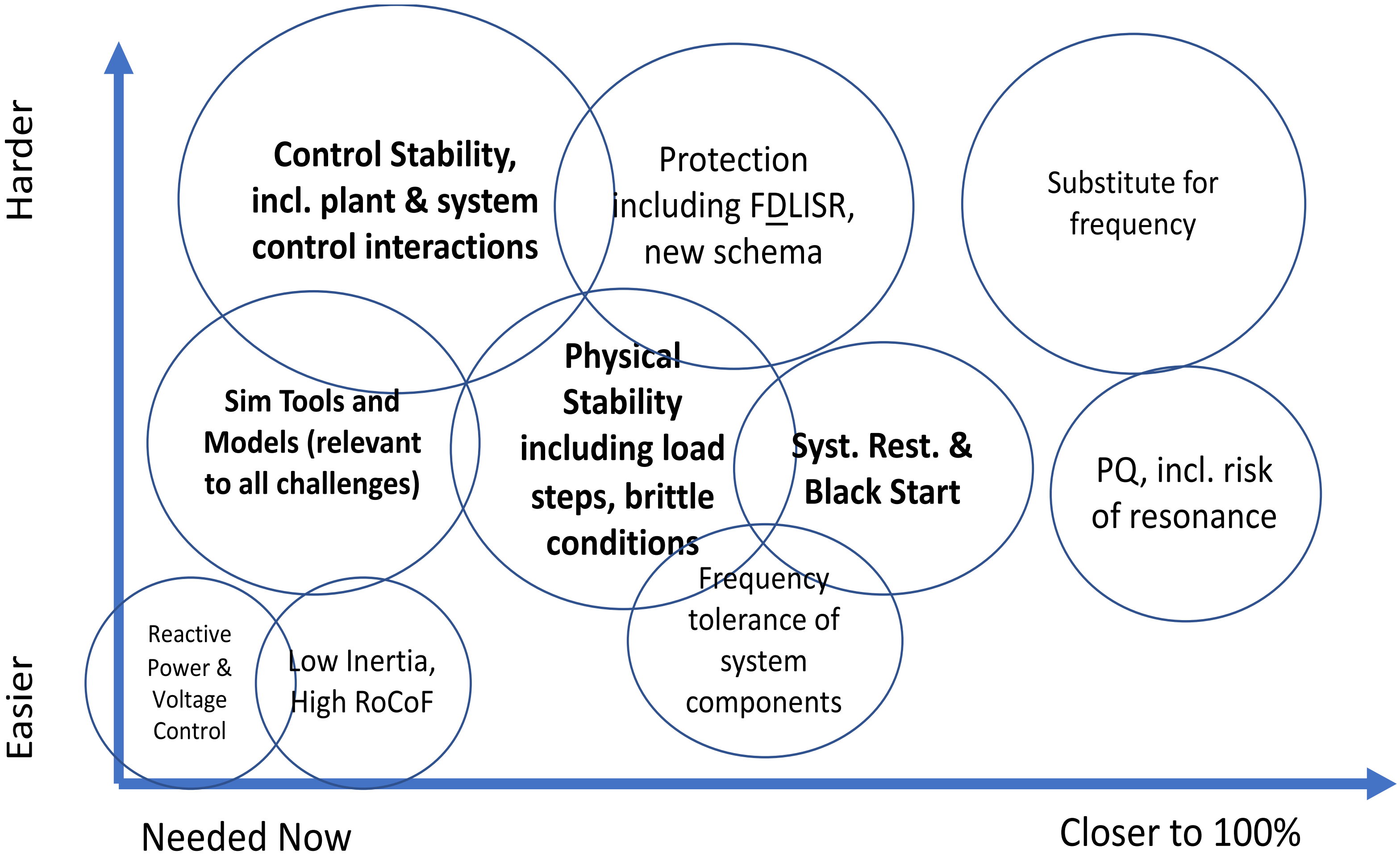
100% renewables studies so far look at days/hours time scale balancing

Challenges



- Maintaining constant steady-state voltages and frequency
- Inertia—maintaining grid stability through physical response
- Black start: Restoring power after outages
- Short-circuit analysis and protection coordination

Challenges map



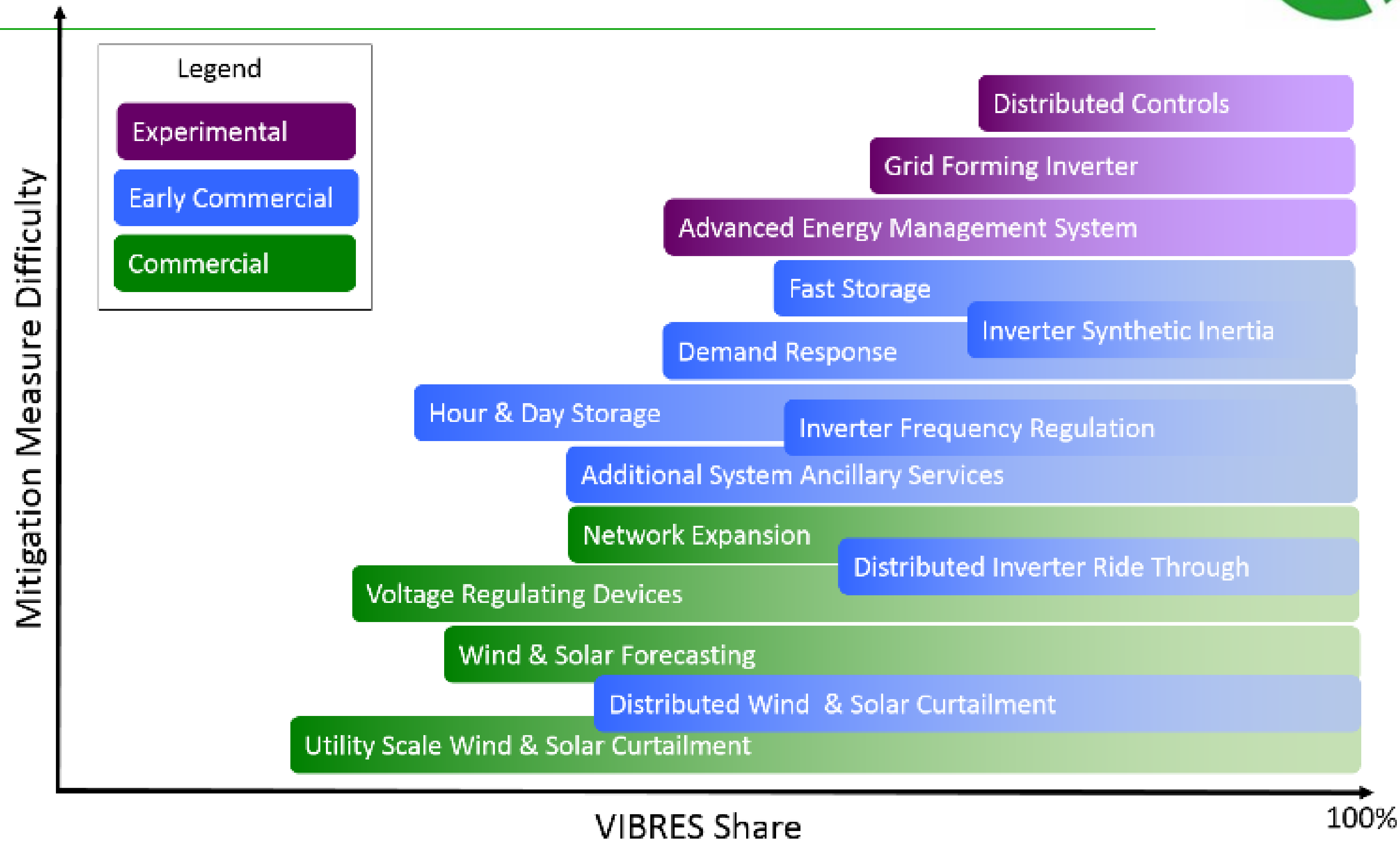
FDLISR fault detection, location, isolation and recover;
RoCoF Rate of Change of Frequency
PQ Power Quality

Supporting frequency stability

- Maintain inertia
  - Keep synchronous machines running that would otherwise not run
  - Find other sources of synchronous inertia (i.e. synchronous condensers)
- Speed up frequency response
  - Faster primary frequency response (on synchronous machines)
  - Fast frequenncy response and other clever frequency controls, especially on inverters
- Make inverter behavior “better”
  - Grid forming inverters and Virtual synchronous machines

Courtesy of Nick Miller

Mitigation options



Fundamental changes to maintaining frequency and voltages impact analysis tools

- Paradigm change for greater detail and higher resolutions with new stability analysis tools development
- Control stability, inertialess power systems and grid-forming inverters are still evolving
- Existing protection systems require modification for large VIBRES shares with different fault characteristics
- Technical disparities between inverter technologies and synchronous generators requires the development of novel control schemes for interoperability, new approaches for black-start capability, and distributed control approaches for the larger volume of generating assets

Recommendations for Stability

- Ensure models are adapted to characteristics of inverted-based generators and loads. Complex, non-linear approaches for various load categories are increasingly required.
- Update existing positive-sequence fundamental frequency planning models for more advanced functionality (FFR, FCN). Identify limiting conditions to predict control stability and fast interactions, when EMT-based models are necessary. Represent PLL control structures accurately.
- Manufacturer-specific EMT models preferred, verified generic EMT models a necessary future development.
- Consider variety of control options available, with inverters potentially incorporating multiple operating modes.
- Study potential of advanced non-linear control approaches, such as virtual oscillator controls.

Gaps in planning and operational models

- Insufficient consideration of 3 sub-problems of reliability, flexibility and stability
  - New constraints in existing models or the ability to link models with more detailed analytical tools
  - No need to be complex, but must address costs and constraints that impact dispatch (or investment) decisions. Setting up approximations with offline studies
- Increasing need to consider energy sector coupling
  - requires that not only the 'production' side of a generator modeled, but also the fuel storage and consumption side, as the fuel might be delivered by, or have alternative uses in, a different sector
- Analysing energy adequacy
  - previously of interest to hydro dominated systems, but for near 100% renewable energy systems this will become more important
  - Scheduling models need to run for decades to capture this

Recommendations: UCED

Grid and stability constraints

- capturing bottlenecks and curtailments for locations
- Stability constraints: inertia by system non-synchronous share or rotational stored energy (MWs) limits; frequency control by sufficient frequency reserves, and voltage stability by sufficient equipment in relevant locations

Probabilistic models

- deterministic and probabilistic assessment approaches for risk-based operation, using new optimization methods and advances in computation

Wind and solar resource

- Temporal and spatial detail, long dataset
- forecast uncertainty integrating weather-dependent parts of the system in multiple decision cycles

Loads and storage

- Represent other relevant energy sectors
- Represent energy storage and price-responsive loads within system service. Potentially complex constraints relating to service availability, requiring more detailed models of distribution systems or aggregation of distributed resources for bulk systems

Markets

- Expand market options/products for flexibility trading

Recommendations: capacity expansion

Demand and storage

- Improve representation of demand flexibility, energy storage and sector coupling to obtain better future price predictions for systems with high VIBRES

Short-term balancing

- Include short-term balancing in order to see the impact of VIBRES forecast uncertainty on the optimal capacity mix

Grid

- Improve representation of grid limitations
- Include expansion costs
- for optimal VIBRES capacity in different areas

Markets

- Improve models to account for different market aspects, such as price signals for end-users, revenue sufficiency, TSO-DSO interaction and local markets.

Recommendations: adequacy

New adequacy metrics

- Reliability target - which critical loads must be served
- Use LOLH (Loss-of-load Hours) and LOLE (Expectation), and as a first proxy to price responsive demand how much EUE acceptable

Chronological models

- to ensure flexibility
- to include load and storage flexibility
- Flexibility metrics

Inter-annual resource variability

- Energy reliabilty
- Improve data, and sensitivity to capture extreme events.

Neighboring areas

- Recent model developments using Monte Carlo

Summary of recommendations

Larger areas

- the entire synchronous system for stability
- sharing of resources for balancing and adequacy purposes

Complexity

- increasing computational burden capturing VIBRES detail
- higher resolution for larger areas, with extended time series for weather dependent events

Demand and storage

- new types of (flexible) demand and storage,
- further links through energy system coupling

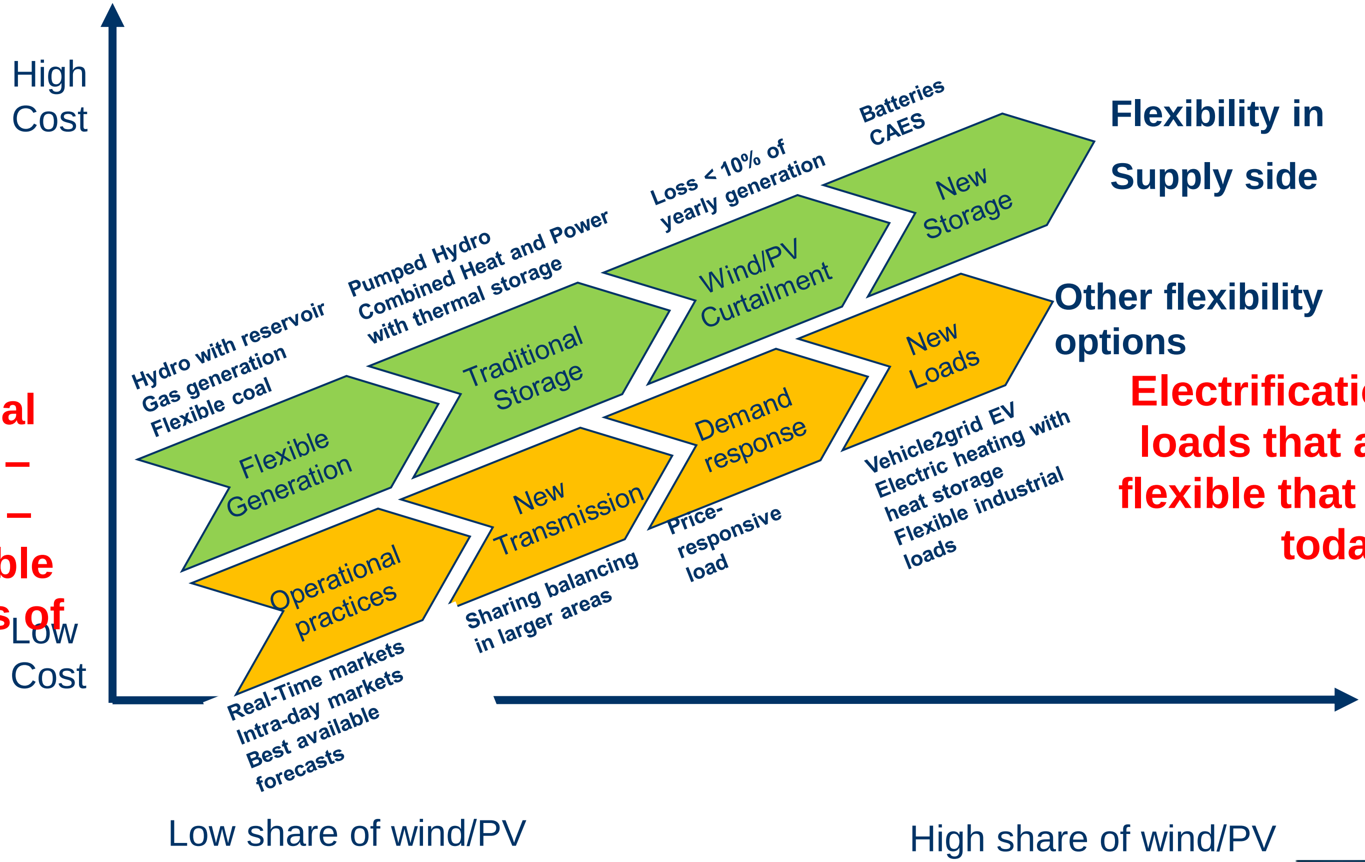
Model integration

- integrated planning and operations methodologies, tools and data. Greater overlap btw operational and planning time scale models
- Flexibility needs and plant capabilities within adequacy methods, and stability concerns for network expansion planning and operating

Cost vs. risk

- reliability interface needs revisiting
- evolution of flexibility and price responsive loads

Balancing challenge: Using more of the flexibility solutions we know



Operational practices – and tools – key to enable high shares of VIBRES

Electrification – new loads that are more flexible than the loads today

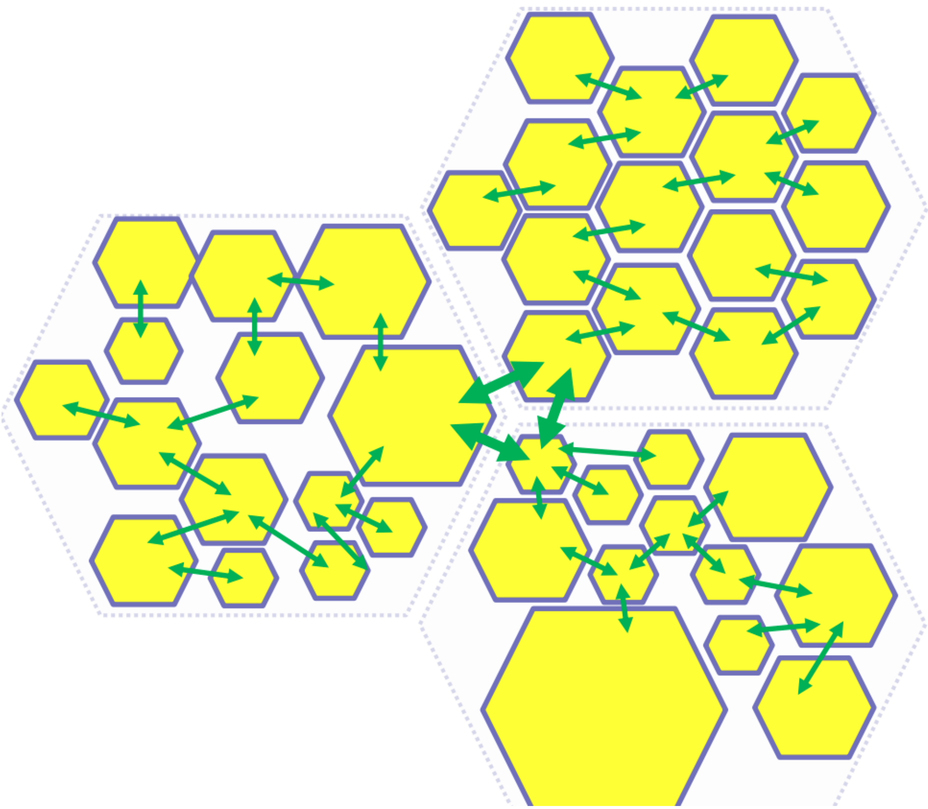
VIBREs – and loads and electrical storage can provide the system support services provided by generators today

Long term flexibility challenge

- Traditionally build gas turbines for back up – expensive use as peakers <1000h/a
- With wind/solar dominating, this will be expensive. Two other pathways possible:
  - Load becomes flexible – also in weeks time scale, electrolysers for power2X, thermal storages for heat etc
  - Electric storage becomes very cheap, and new seasonal options for storage developed
- Probably a mix of these three?

Using the local flexibility to system benefits

- Market based DSO/TSO collaboration through local flexibility markets
- Flexibility value as price signals to DER
- Vision: web of cells, with local smartness, utilising large system benefits when no grid bottlenecks



EERA
European Energy Research Alliance
Smart Grids Joint Programme

Task 25
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Thank You!!

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IEA Wind Task 25 – Best practice of VG integration

- Started in 2006, now 17 countries + WindEurope participate to provide an international forum for exchange of knowledge
- State-of-the-art: review and analyze the results so far (Jan 2019)
- Formulate guidelines- Recommended Practices for Wind/PV Integration Studies (RP Ed.2 July 2018)
- Fact sheets and integration study time series (wind, solar, load…)

https://community.ieawind.org/task25