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Challenges and Mitigation Options in Stability for Future Power Systems

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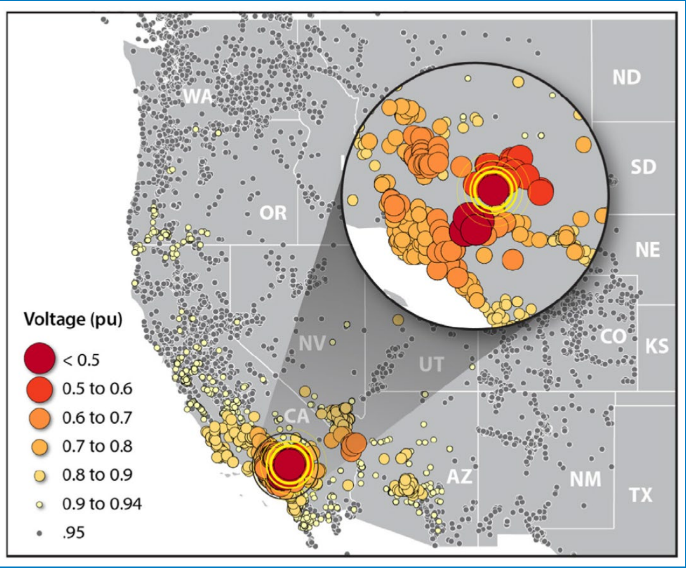
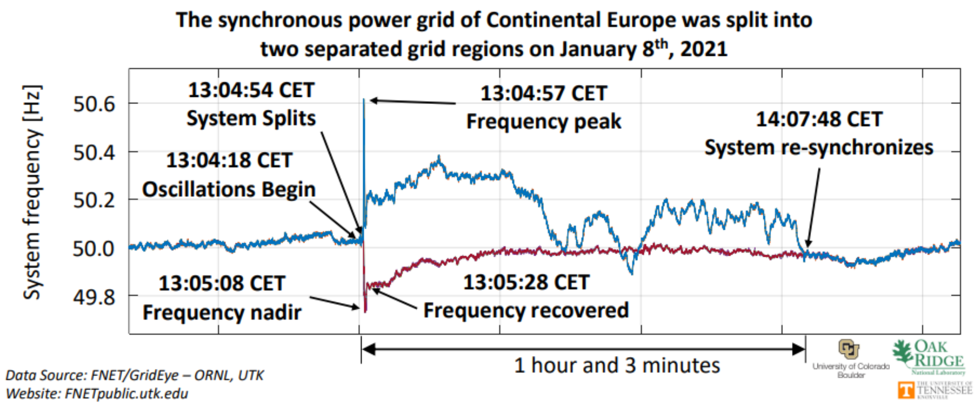
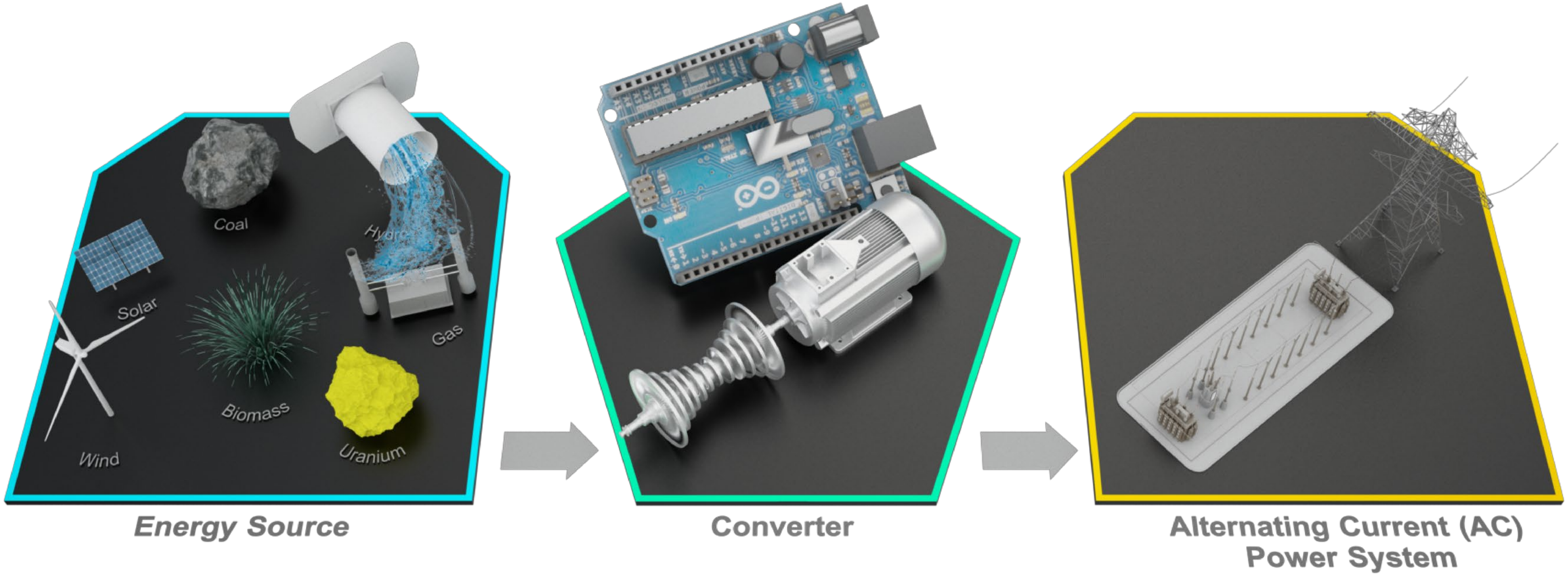
Power Systems Dynamics

A new stability and control paradigm

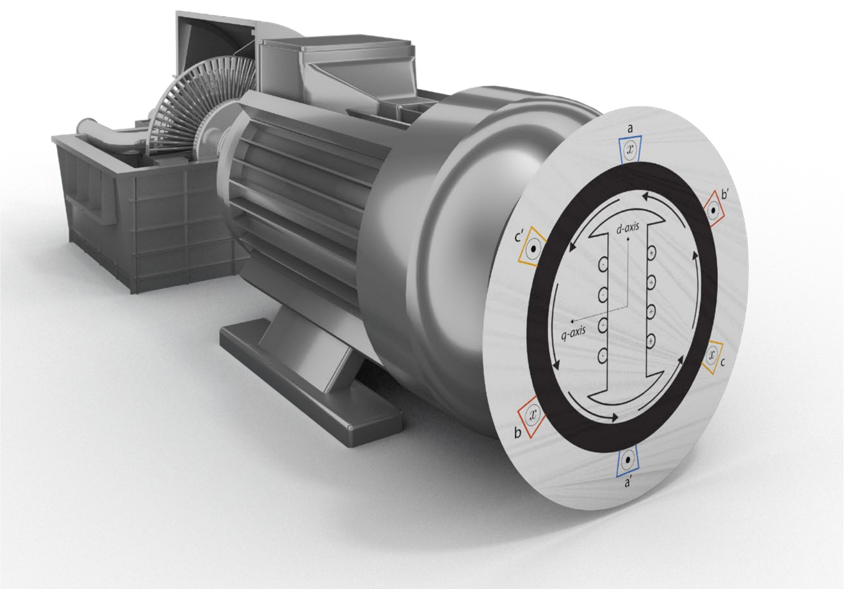


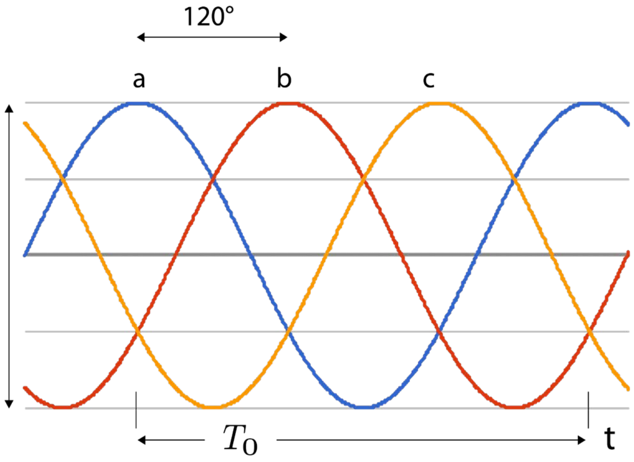


Energy Conversion



Synchronous Machines





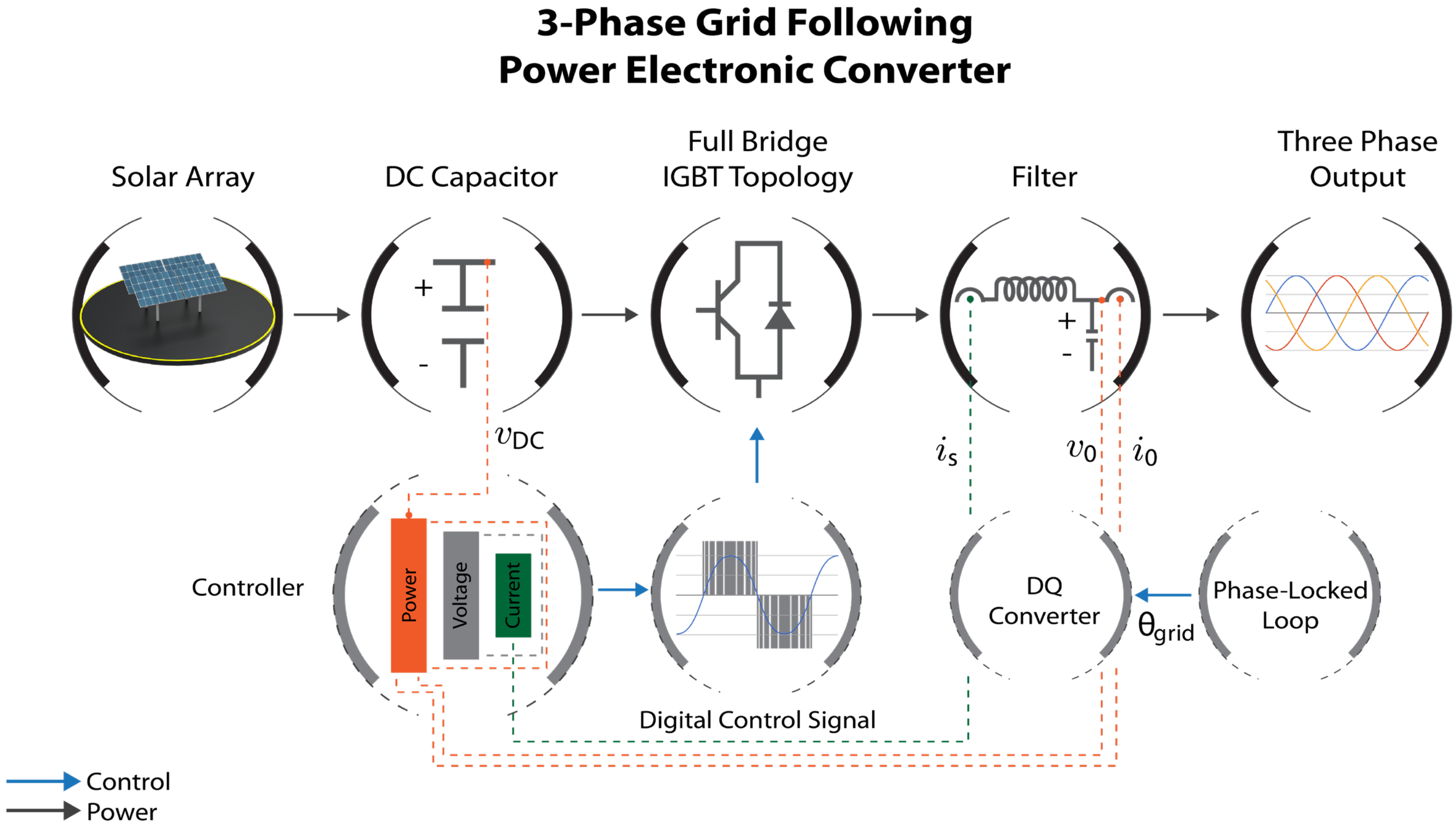
T_0 = one rotor revolution if single pole pair

Create steam or hot air by burning or fissioning fuel, use this fluid to rotate a generator

$$\omega_0 = \frac{2\pi}{T_0} = \frac{P}{2}\omega_{Shaft}$$

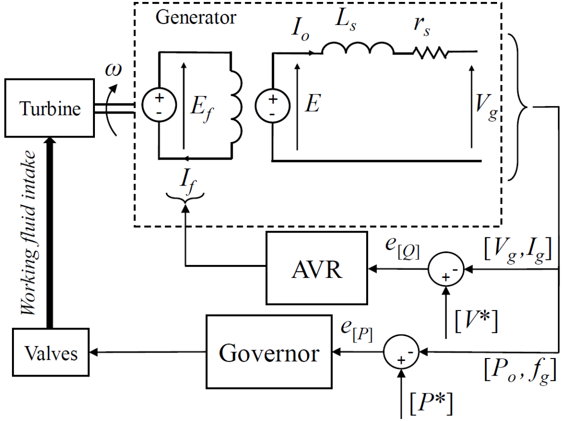
… hence, synchronous

Grid Following Inverter

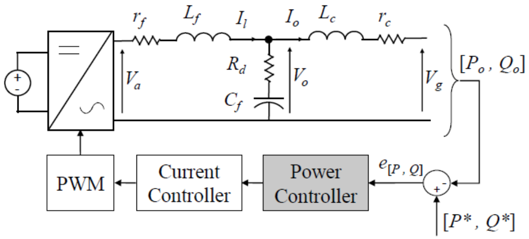


What’s Changing?

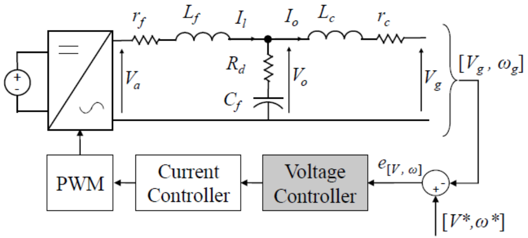
Synchronous-machine



Inverter-based (IBR)



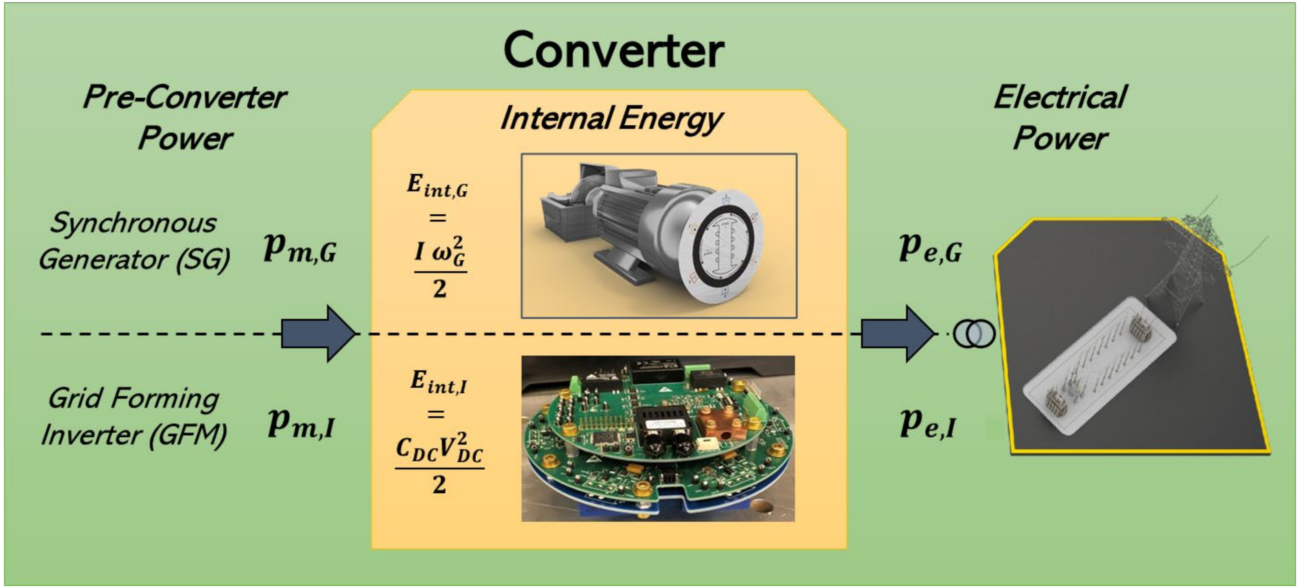
(a) GFL



(b) GFM

Synchronous-machine	Inverter-based (IBR)
Mechanical	Digital
Deterministic	Stochastic

Device Level Power Mismatch



$$\ddot{p}_{m,G} \propto p_{e,G}$$

$$\dot{p}_{m,I} \propto p_{e,I}$$

- A multi-loop droop GFM inverter has a lower order relation between pre-converter power and electrical power, as compared to an SG. A GFM device makes a first order exchange of energy with the system; there is no second order transfer of energy as in a SG, which is the source of substantial overshoot and oscillations.
- An SG only modifies pre-converter power after a change in frequency is registered; a GFM modifies frequency after changing pre-converter power. They are inverses of each other

Why is this distinction important?

Grid Forming

Grid Following

Power

100% Grid Forming
0% Grid Following

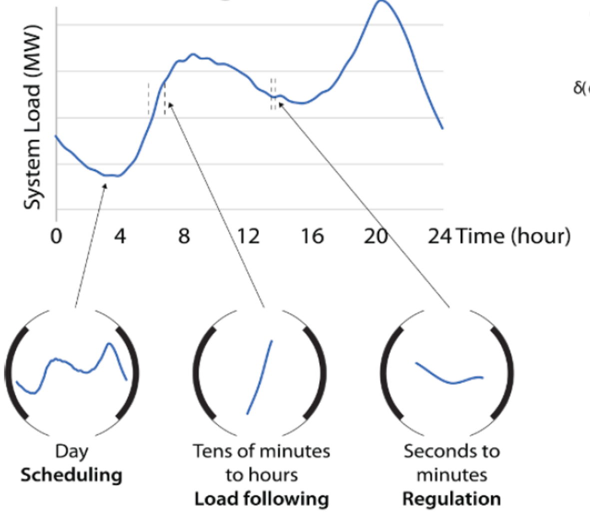
75% Grid Forming
25% Grid Following

25% Grid Forming
75% Grid Following

0% Grid Forming
100% Grid Following

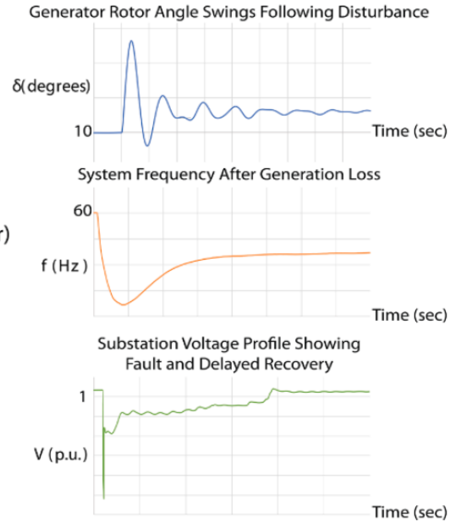
Power System Transient Stability

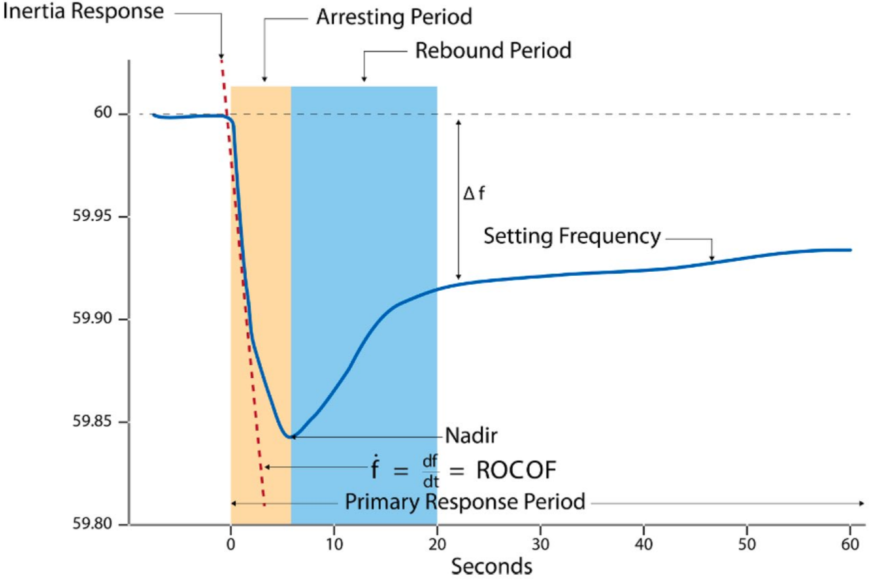
Load-Generation Balancing: Timescales



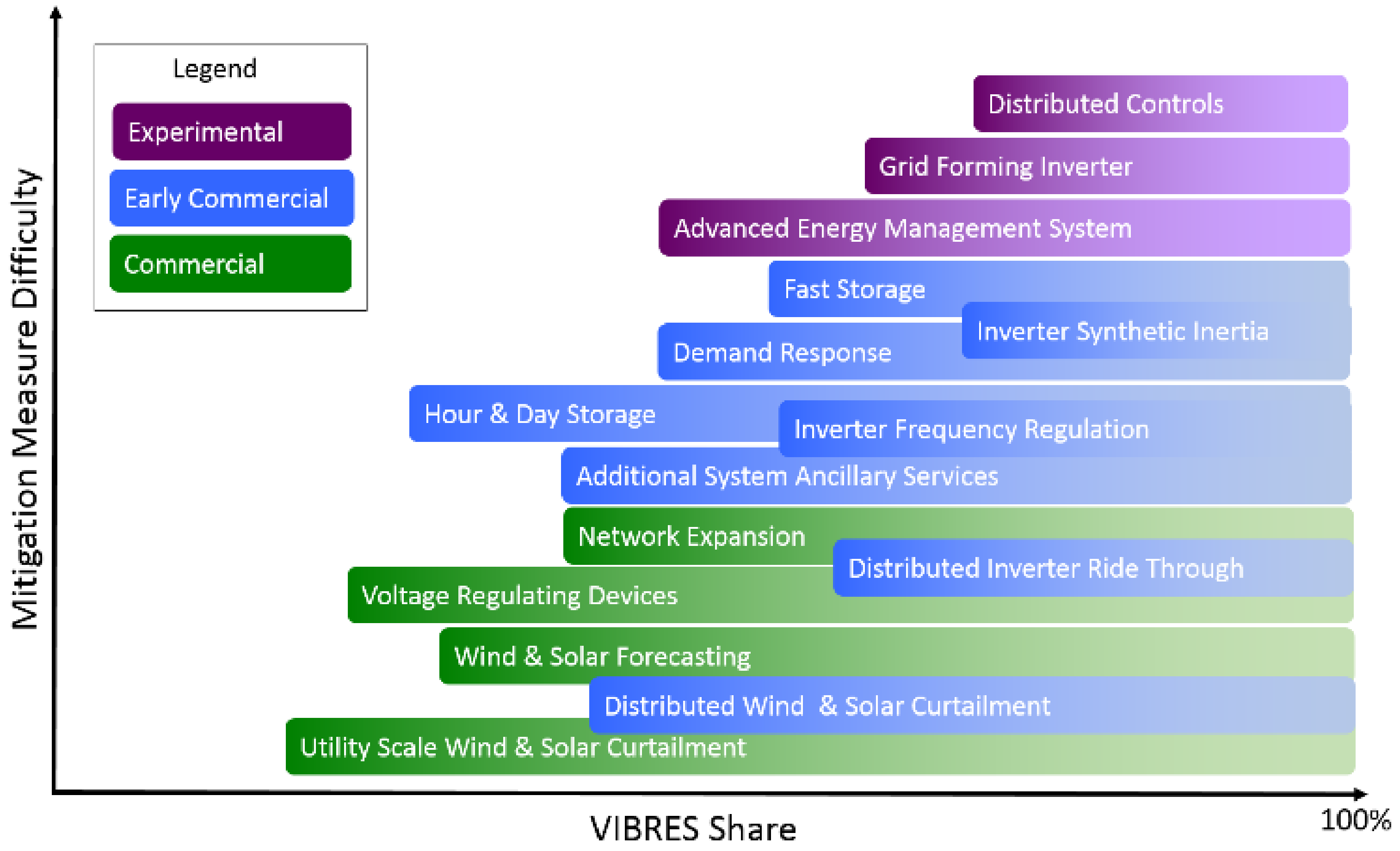
Abnormal Event Dynamic Responses

Cycles to Seconds

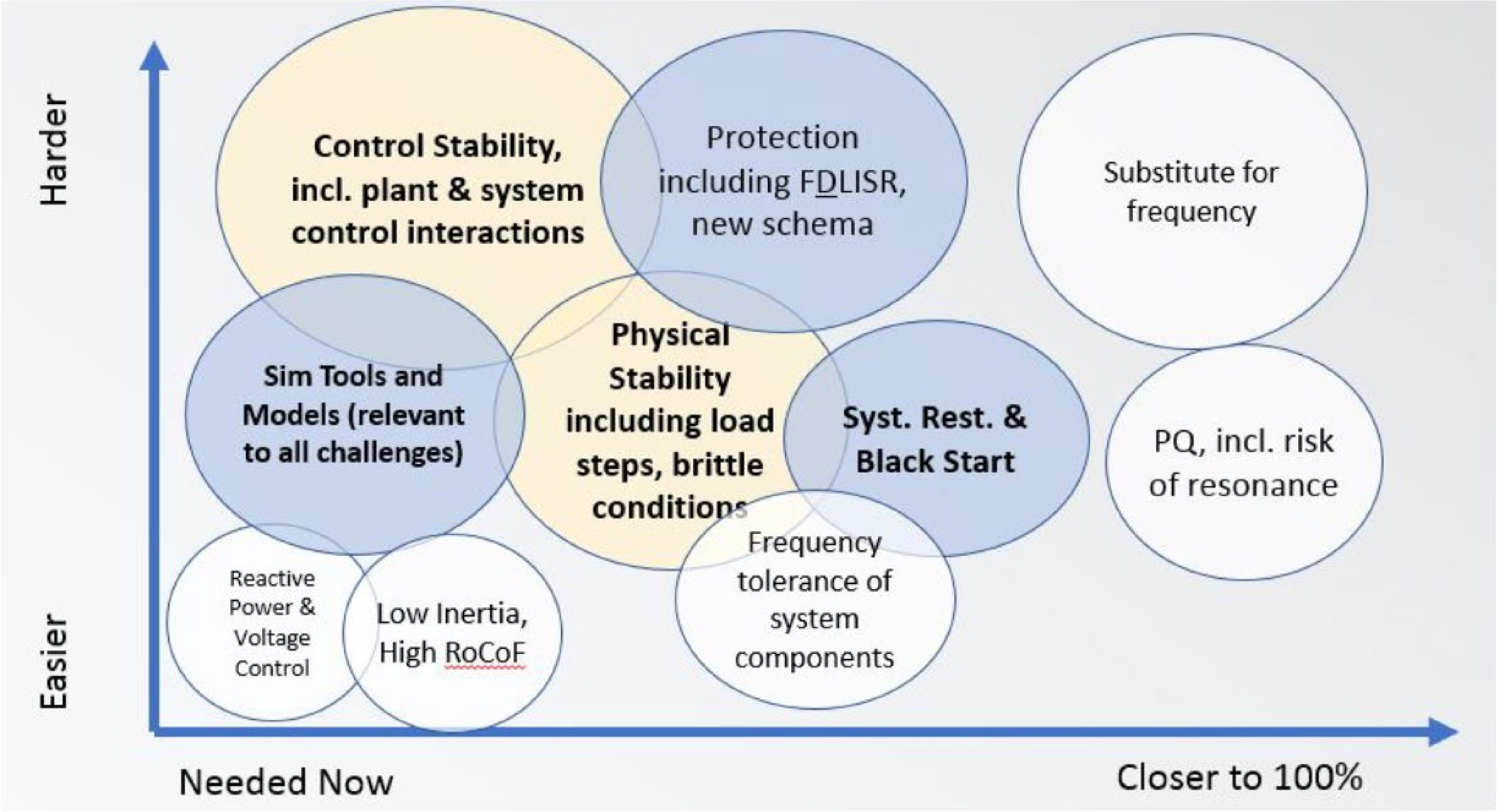




Mitigation Measures



What Changes are Needed When?



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

Task 25
Design and Operation of Power Systems with
Large Amounts
of Wind Power

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.

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

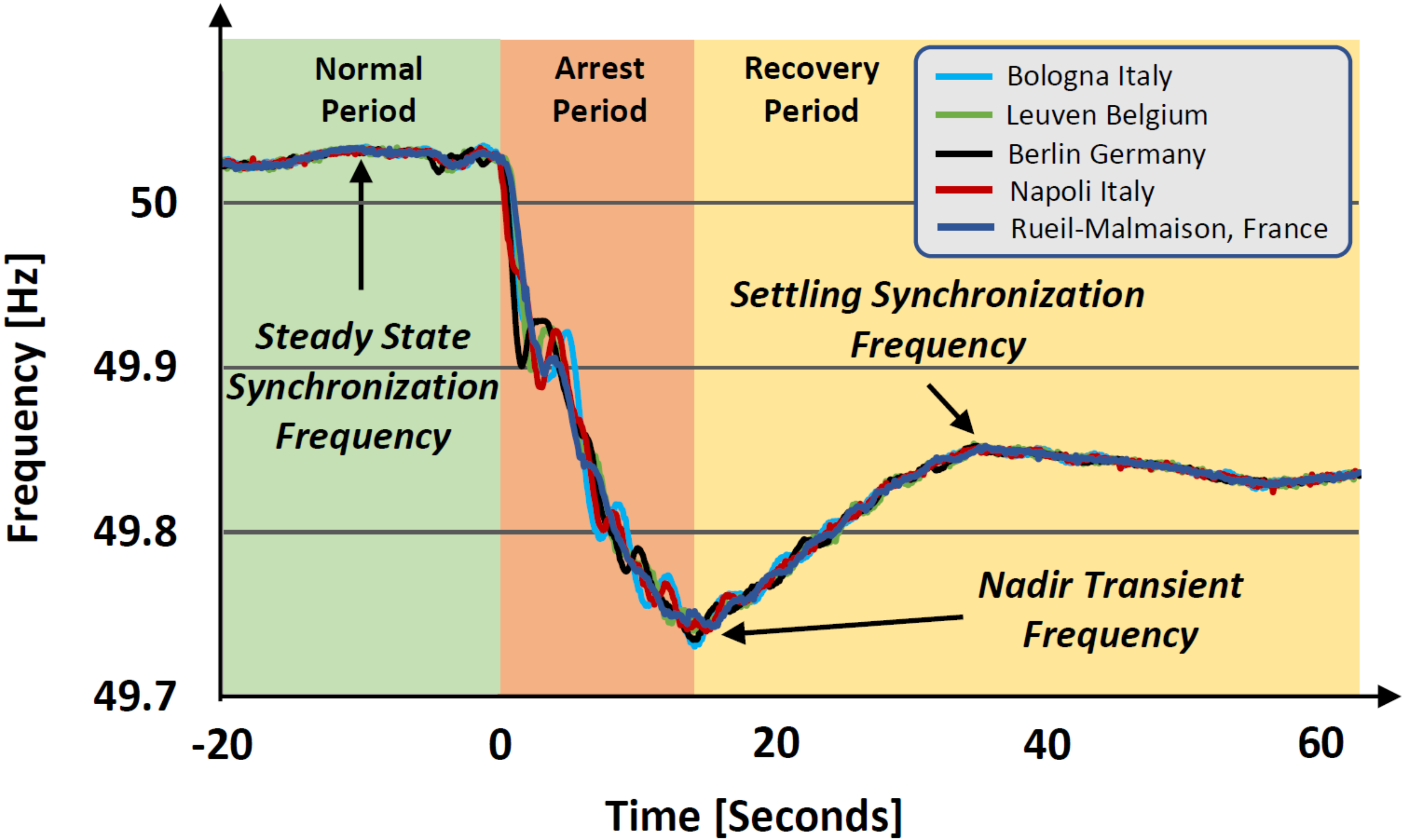
Cost vs. risk

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

Acknowledgements

- IEA Wind Task 25
- Dr. Amir Sajadi – CU Boulder
- Wallace Kenyon – CU Boulder
- Dr. Benjamin Kroposki – NREL
- Matthew Bossart – CU Boulder

Thank you!


Normal Period
Arrest Period
Recovery Period
Bologna Italy
Leuven Belgium
Berlin Germany
Napoli Italy
Rueil-Malmaison, France
Steady State Synchronization Frequency
Settling Synchronization Frequency
Nadir Transient Frequency
Frequency [Hz]
50
49.9
49.8
49.7
-20
0
20
40
60
Time [Seconds]