Grand challenges Grid – research needs for future grid support of wind power plants

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Design and Operation of Energy Systems with Large amounts of Variable generation

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Grand Challenges in the Science of Wind Energy

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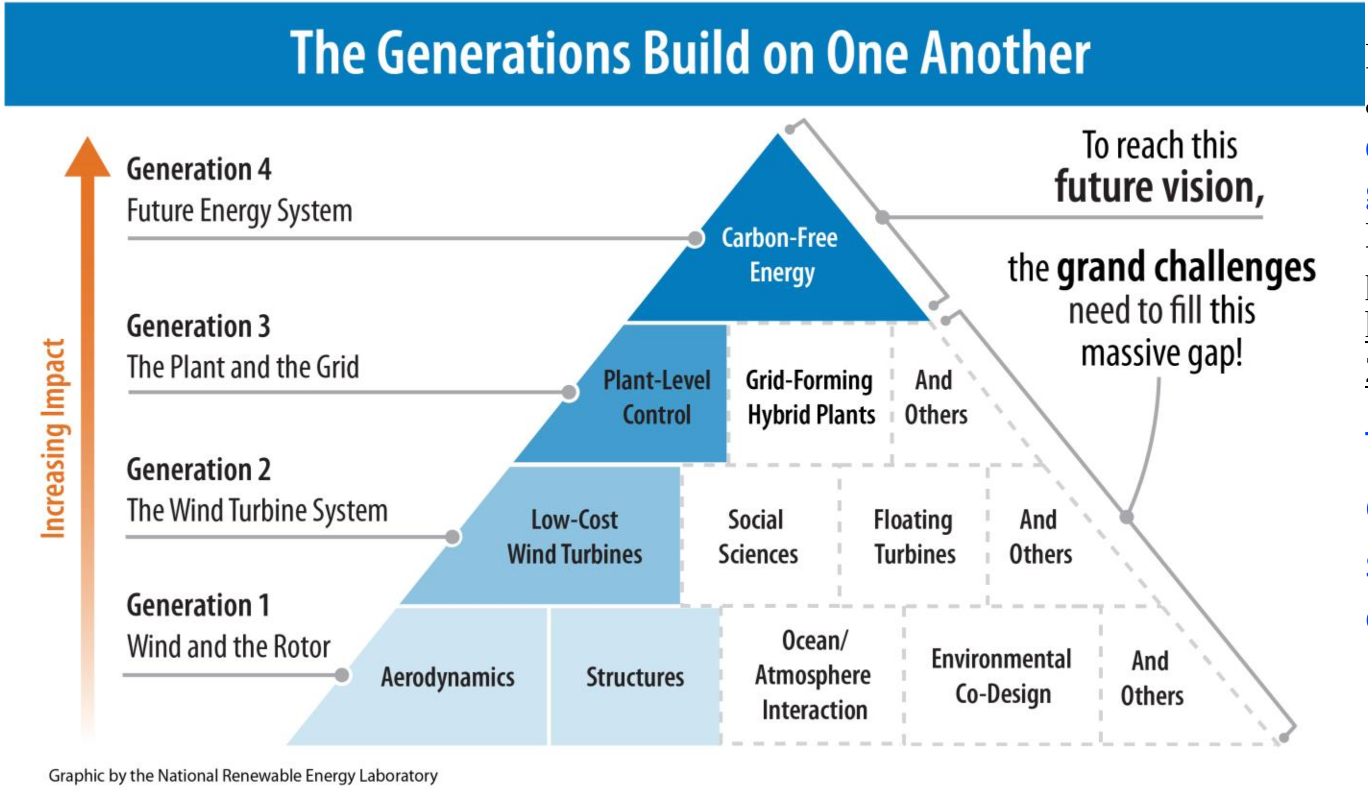

P. Veers, K. Dykes, S. Basu et al., 'Grand Challenges: wind energy research needs for a global energy transition,' Wind Energy Science, vol. 7, no. 6, pp. 2491-2496 (2022) https://doi.org/10.5194/wes-7-2491-2022

This paper is a summary of the Grid paper in this series: Meeting the needs of the Grid

https://www.wind-energy-science.net/articles_and_preprints/grand-challenges.html

Grand Challenge Grid

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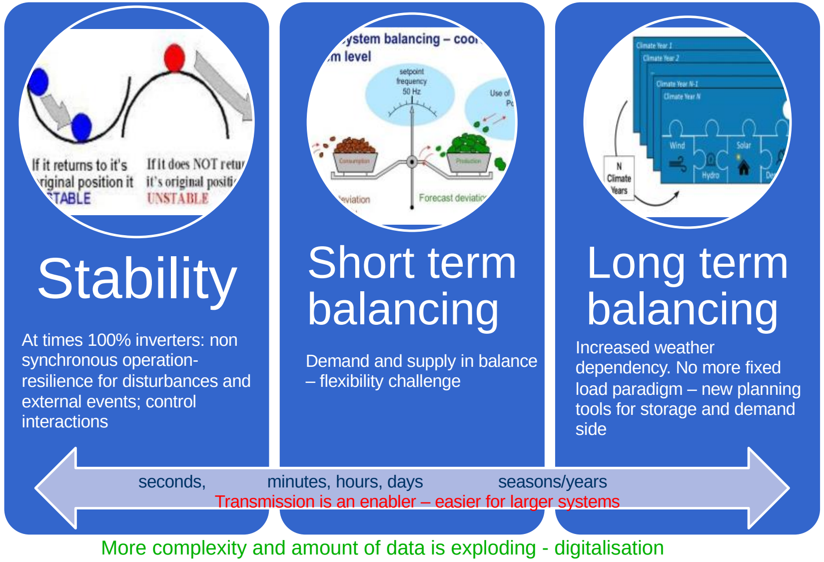
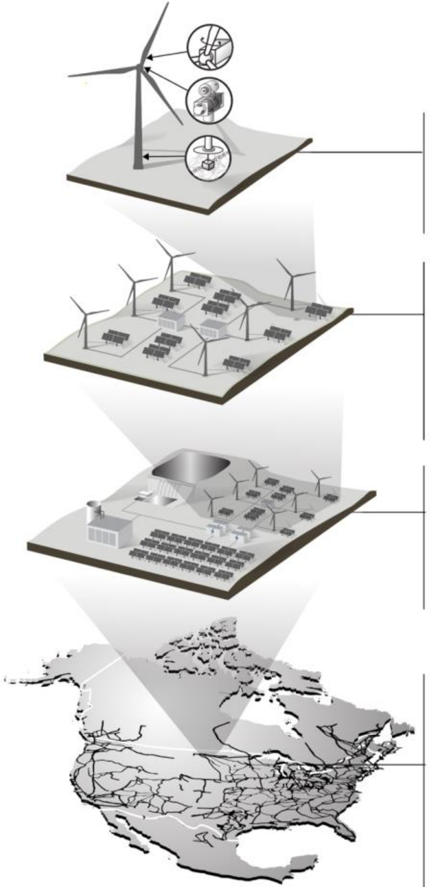
- VREs are replacing synchronous machines (SMs) - starting to become the dominant generating technology in some regions.
- Other changes occurring in energy transition: energy system coupling; digitalization; also other IBRs like solar PV, storage and demand
- System needs and services need to be revisited
  - end destination not clear - heavily influenced by RDI in electricity grids and the technologies that make up the electricity system - including wind
  - power system primary objective: all the needs are met by a set of services to a predetermined level of reliability, and at least cost



Development of wind based solutions: wind turbines, wind power plants, and hybrids

For plants and hybrids:

- **Integrating storage, and/or other RES**. The control becomes more complex, and control interactions may appear.
- **Design: including new conversion services** like H2, NH3, methanol, liquid RE fuels, power2heat. Viability of electrolyzers and turbines, AC vs. DC shared electronics, etc. , also future offshore wind systems.
- **Controllers**: for **different objectives** and designs, **Integrate state-of-the-art forecasting** across a range of timescales. Resilience-based controllers for wind-based hybrids in a region. Incorporating **atmospheric effects** and technology interactions. **Design AI/ML controllers** for improving dispatchability. **Demonstrate** controllers.



Turbine technology
- Aerodynamic control
- Generator control
- Plant control
- Integrated Storage
- Advanced Power Electronics

Plant level
- (Multi-Objective) optimized design and operation
- Improved Self-Accommodation and provision for grid services via Automatic Generation Control (AGC) including: Wake Steering, Panel Tilt
- Control, Integrated Storage, H2 generation during high production.
- Control systems integrated at plant level to maximize benefits.
- Combined physical sensing and advanced forecasting to help operate hybrid plant as "dispatchable" and self-accommodating power.

Hybrids
- Combination of multiple (a) utility-scale renewable energy generation sources or (b) renewable energy generation and energy storage technologies
- E.G. Wind, Solar PV, Solar CSP, Hydro, Geothermal, Storage (Battery, Pumped Hydro, Hydrogen)
- Leverage complementarity of resources and take advantage of unique technology characteristics.

System level
- "How these technologies fit together"
- Maximize the pace of deployment of renewable energy systems
- Maximize the use of interconnection points within existing transmission system
- Increase the flexibility and resilience of our generation system
- Tailor Renewable generation to location to provide important services such as baseload/peaker plants etc.

Challenge for wind

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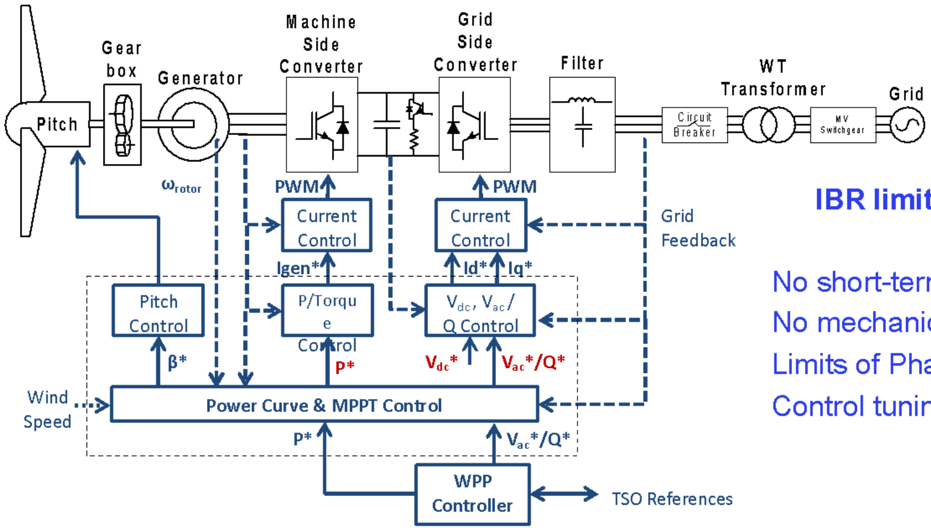
VRE limitations

Power & energy availability



IBR limitations

No short-term rating
No mechanical inertia
Limits of Phase-Lock
Control tuning

Grand Challenge Grid for Wind – R&D needs for capabilities to support future system services

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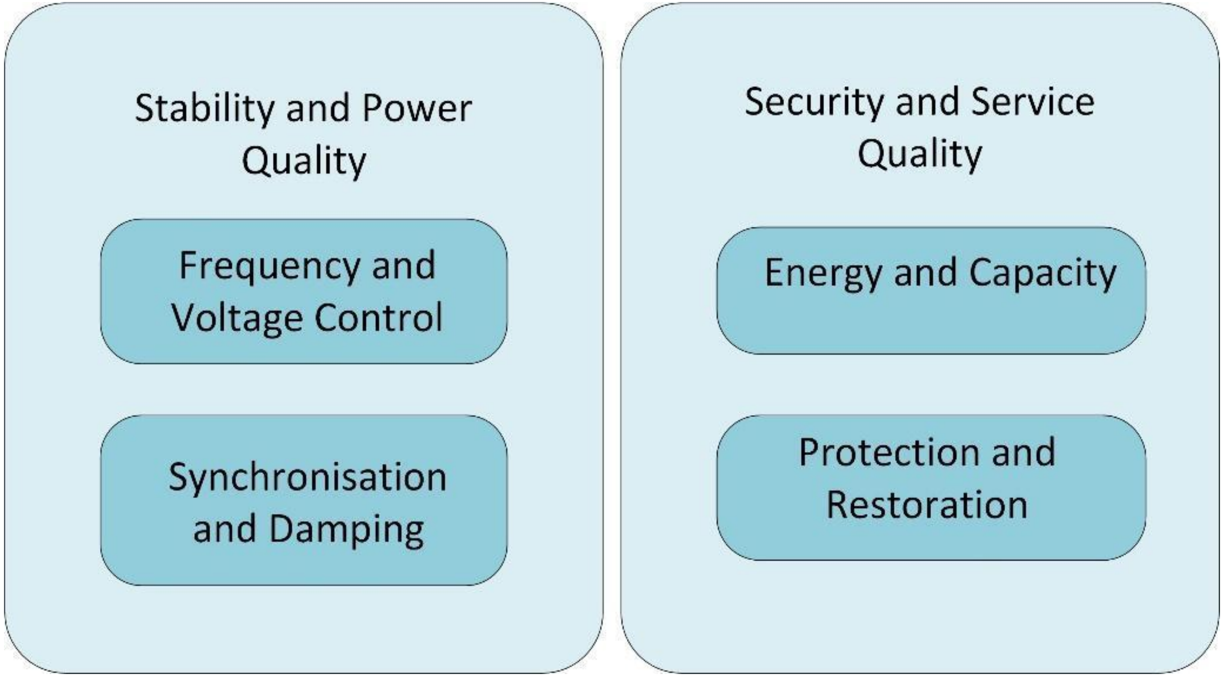

Capabilities, Challenges, R&D needs: Energy& Capacity

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- Status: currently provided
- Challenges:
  - Variability and uncertainty
  - Low-capacity value
  - Metrics for resource adequacy applicable for high shares of wind
- R&D Needs:
  - Forecasting: especially seasonal weather forecast accuracy
  - Diversity of wind turbine technology: low wind turbines and long term potentially airborne wind power plants
  - Long-duration storage: hybrids, also direct power-to-x application at WPP

Capabilities, Challenges, R&D needs: Frequency control

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- Status: currently provided (in some locations); capability for faster and slower frequency support, either from curtailed operation or wind-based hybrids. Inertia-like responses from the stored energy within rotating blades
- Challenges: Availability of active power (affected by weather); Coordinating services with required energy; Revenue loss from energy curtailment; Mechanical impacts
- R&D Needs:
  - Rapid frequency response, also for grid-forming operation of wind turbines
  - Mechanical impacts on drive trains when procuring inertia-like response
  - Forecasting for frequency control services, including available power from WPPs
  - Plant controls: improved operation with service provision
  - Hybrids: controls, optimizing the operation
  - Stability related impacts: regional WPPs

Capabilities, Challenges, R&D needs: Voltage control

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- Status: currently provided (in some locations); capability for voltage control, reactive power control, and power factor control
- Challenges: Fluctuating nature of wind power; Coordinating services with required energy;
- R&D Needs:
  - coordination of wind turbines to enhance voltage support capabilities.
  - grid-forming operation to enhance voltage support capabilities
  - operational efficiency of power electronic devices within large-scale offshore WPPs

Capabilities, Challenges, R&D needs: Synchronisation

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- Status: currently not provided ; capability as long as available energy
- Challenges: Availability of active power which is affected by weather and leads to variable output of wind power plants. Coordinating various services with the required energy
- R&D Needs:
  - wind turbine overloading capability for providing synchronization
  - optimised operation of wind-based hybrid systems and battery storage connected to the wind turbine/plant

Capabilities, Challenges, R&D needs: Damping

- Status: currently not provided ; capability as long as available energy
- Challenges: Availability of active power which is affected by weather and leads to variable output of wind power plants. Coordinating various services with the required energy. Mechanical impacts to drive train from active power modulation.
- R&D Needs:
  - Power system oscillations, finding their source, and providing correction method
  - Mechanical impacts to drive train from active power modulation.
  - Optimised operation of WPPs and wind-based hybrid systems and battery storage connected to the wind turbine/plant

Capabilities, Challenges, R&D needs: Protection

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- Status: currently not provided; capability from DFIG wind turbines to participate in fault current
- Challenges: Restricted inverter current overload capacity; Provision of negative-sequence current during asymmetrical faults; How to specify the fault current behavior of grid-forming wind when reaching the current limit
- R&D Needs:
  - Different wind technologies' capabilities to provide more fault current: type 5 turbines, hybrids, larger fleet of wind/solar plants,…
  - Alternative protection schemes that don't require overload current inverter capacity

Capabilities, Challenges, R&D needs: Restoration

- Status: currently not provided; capability being tested from grid forming turbines
- Challenges: Availability of active power which is affected by weather and leads to variable output of wind power plants. Small and large signal stability issues of grid-forming wind turbines in restoration scenarios
- R&D Needs:
  - Bottom-up grid restoration with the help of grid forming wind turbines and hybrid power plants
  - Optimising the location of wind turbines that will be used to help restoration,
  - Weather forecast accuracy and role in the restoration process
  - Small and large signal stability assessment of grid-forming wind turbines in restoration scenarios
  - Weather resilient wind turbines

Conclusions

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- *Fundamental change in power systems* driven by the replacement of SMs with wind and other IBRs is presenting new challenges to the objective of maintaining supply demand balance reliably at least cost. Paradigm changes to design and operation of power systems is a truly Grand Challenge for Grid.
  - *It is not just wind*: All the simultaneous changes of future power systems – increasing wind, solar PV, batteries, HVDC etc. and electrification - lead to a high dimensional situation : from unidimensional "grid integration" challenge to multidimensional energy systems integration challenge.
- *Wind technology:* Shifting the goal towards more holistic minimisation of power system costs while ensuring higher value of wind and improving grid reliability.
  - Technology to adapt competitively and take advantage ability to fast responses
  - →multiscale research and design challenge at the individual turbine and plant level, with mechanical, electrical and/or control centric solutions to the provision of services and a technical/economic comparison with other potential sources of services to meet the grid needs

Wind R&D needs – crosscutting for several services

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- **Challenge: Availability of the extra active power needed** for several services
  - **Hybrids** –energy management systems for optimizing. Power to X for longer term storage
  - **Plant controls**, including wake steering and the impacts on available power for wind power plants operating in curtailed mode.
  - **Coordination** of simultaneous needs (during re-synchronization period, frequency control, damping etc.) which makes the coordination highly complex
  - **Impacts of providing grid support services on mechanical WT components** (the drivetrain) from temporary active power, and active power modulation for damping.
- **Challenge: variability and uncertainty**
  - **Forecasting** – short term for services and longer term for resource adequacy
- **Challenge: grid integration, power system needs**
  - **Tools** for wind power plants and power system analysis (planning and operational)
  - **Grid forming adaptation** of power electronics and controls to WPPs

Wind R&D needs – on top of crosscutting, service specific

- **Capacity: Diversification** of turbine types: low wind turbines, new technologies like airborne
- **Frequency control: faster responses**, like the ability of measuring, computing and transmitting the frequency signal to the wind turbine/plant controller fast enough.
- **Protection/fault currents**: Short circuit current – use of different types of wind turbine technology. Ways to use the whole installed capacity of wind (and solar PV), for providing the same fault current demand, could be explored.
- **Restoration**:
  - **Control and design modification** needed, as well as stability analysis methods and proper controller tuning methods.
  - **Resilience**: wind turbines that can withstand extreme weather events.

Wind relying on/collaborating with other technologies R&D

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- **Power Electronics**: fundamental principles of IBR controls - implementation in wind turbines will need to be adjusted or tailored to their characteristics. Leverage the unique capabilities of the power electronics that interfaces wind to the grid. R&D with the power electronic community
- **Storage**: The variability and uncertainty force a need for a balancing resource like storage, interconnection etc. Therefore, this is pushing wind research towards hybrids and storage. Optimised solutions including storage from batteries and power-to-X electrolysers with e/fuel storage options in future wind power plants
- **Grid connection**: cables, collection network and substations for offshore floating wind power plants, as well as optimization of offshore grids

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