Wind Technology:
Grand Challenges for the Future Grid

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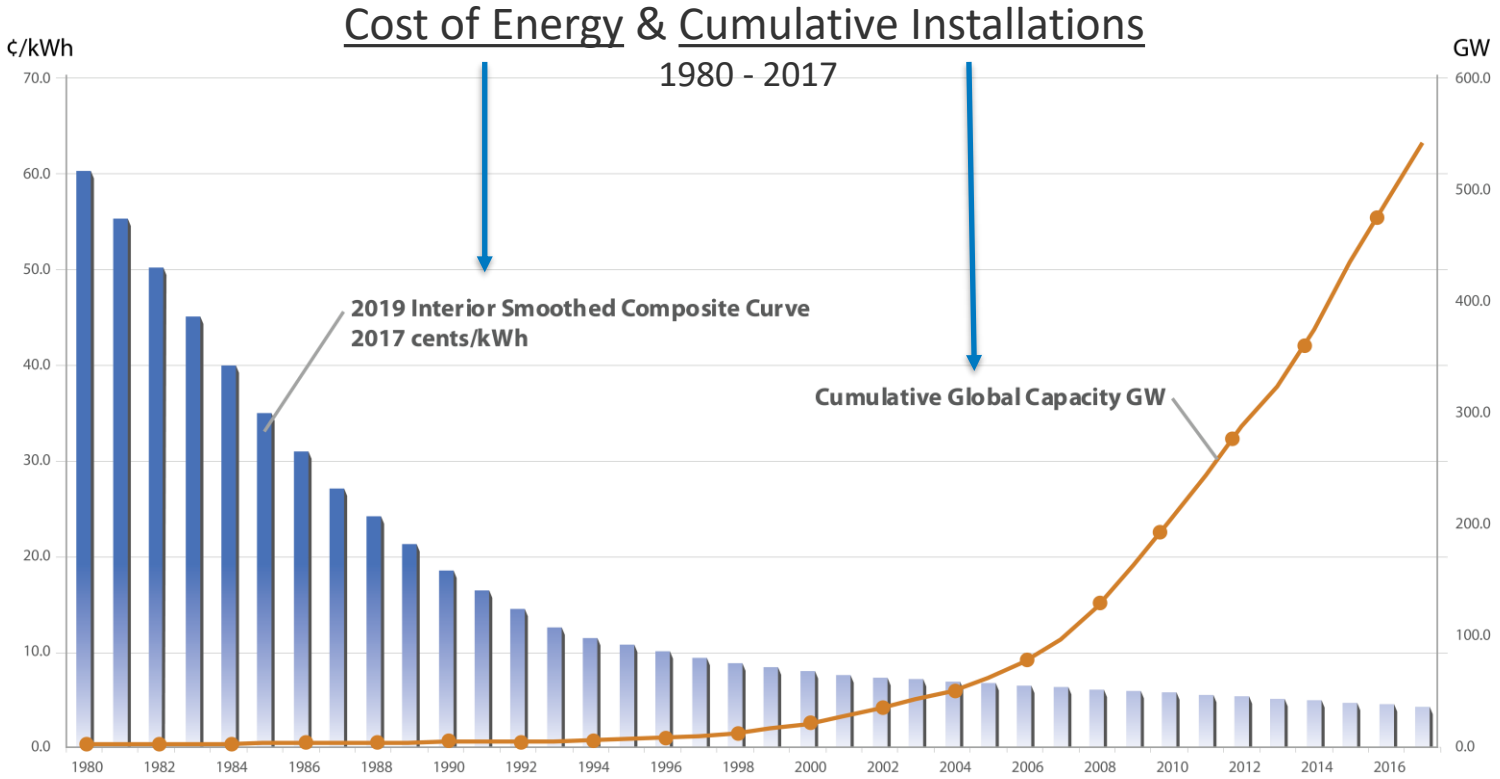
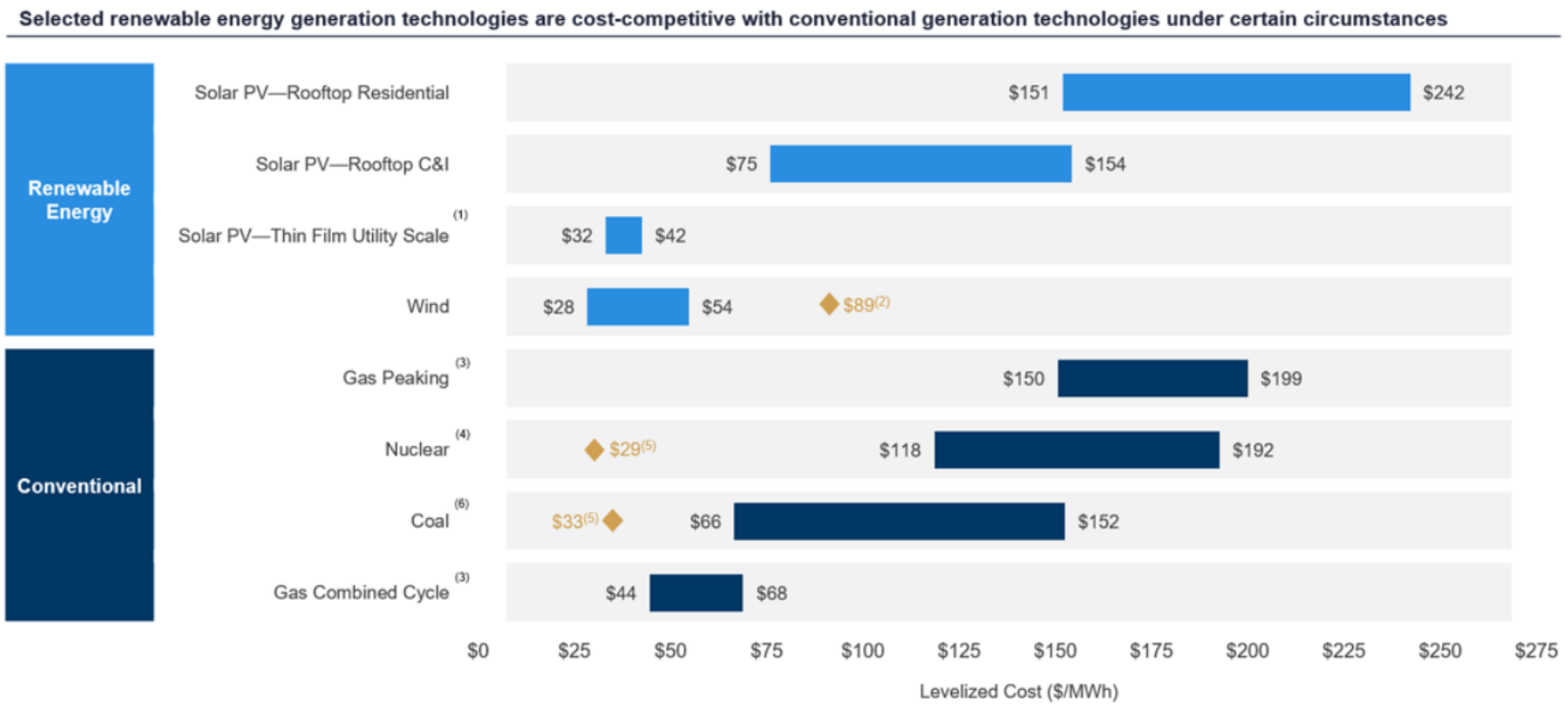
How did wind get to this point?



Wind accounted for 5% of global electricity generation in 2019

(7% in the US)

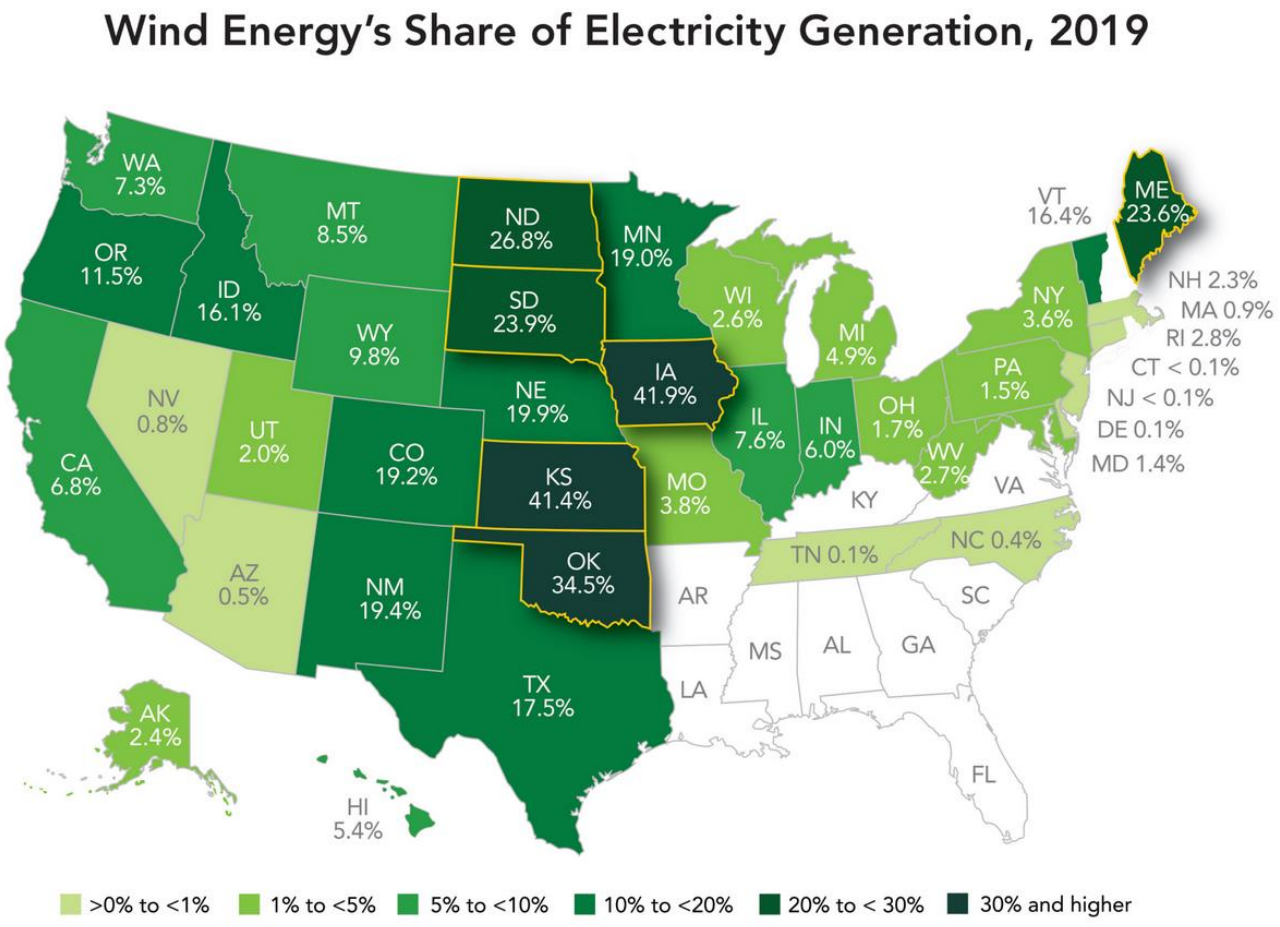
Wind - Solar PV - Gas provide the lowest unsubsidized cost electricity



https://www.lazard.com/perspective/lcoe2019

Three States have > 1/3 of generation from Wind

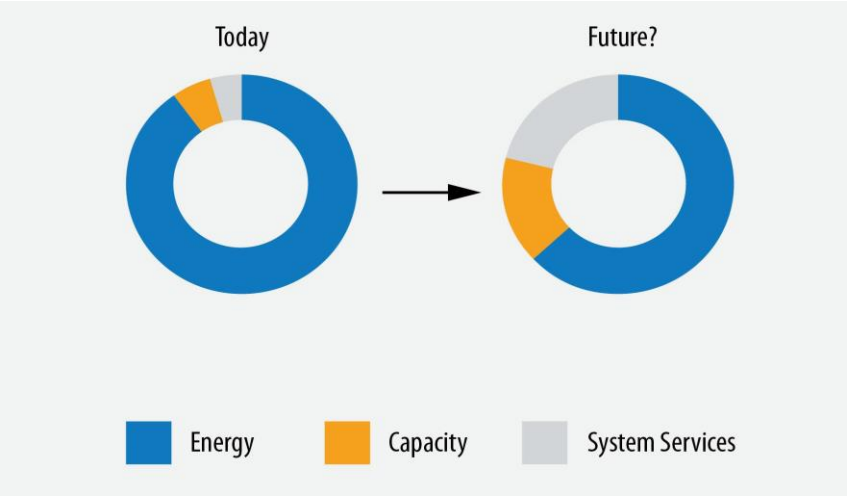
If Texas were a country, it would be #5 in the world in wind capacity.



AWEA AMERICAN WIND ENERGY ASSOCIATION

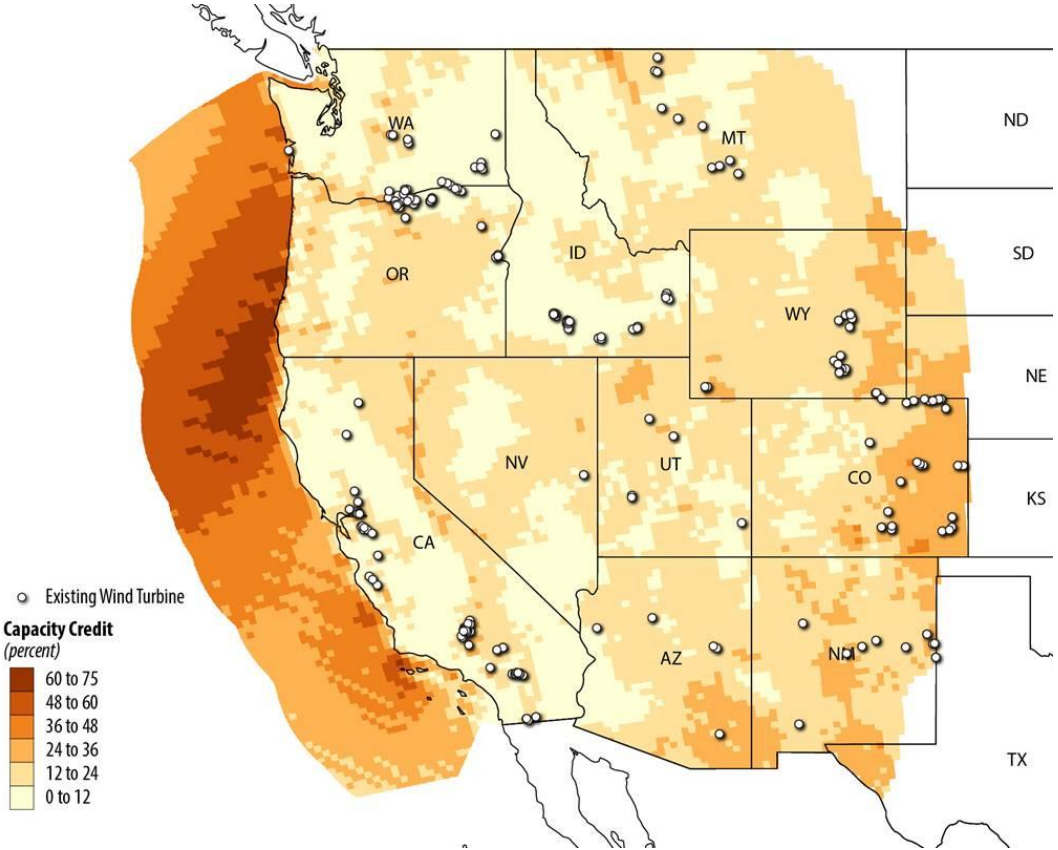
As Penetration Increases, Energy-Value Decreases

- A future scenario of with renewables supplying 80% of the world electricity supply produces a paradigm shift in system architecture, technologies and markets.
- The transition is from delivering bulk electricity to providing hybrid system control.
- The new need is “Energy System Integration”



Future electricity system market structure (Source: Dykes, et al. 2019 based on Ahlstrom, et al. 2015)

Capacity Credit for Wind in the Western US



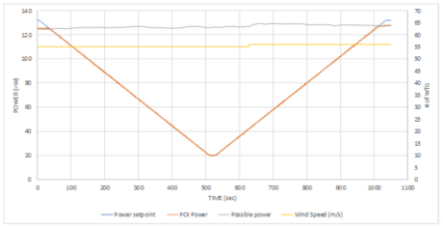
- Plant location will be influenced by Capacity Credit (CC) in addition to total resource
- There are locations of very high Capacity Credit (>60%)
  - Deep water requires Floating Turbines
  - Remote location requires new transmission

Jorgenson, J.; S. Awara; G. Stephen, T. Mai. (Forthcoming). **"A Systematic Evaluation of Wind's Capacity Credit in the Western United States"**

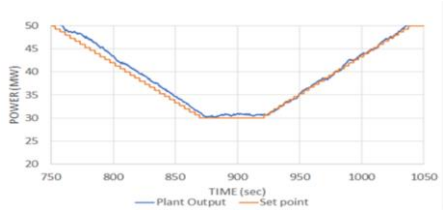
(Based on 7 years of NREL WIND Toolkit data)
https://www.nrel.gov/grid/wind-toolkit.html

Clyde Loutan (California ISO) showed how wind is now capable of delivering grid services in

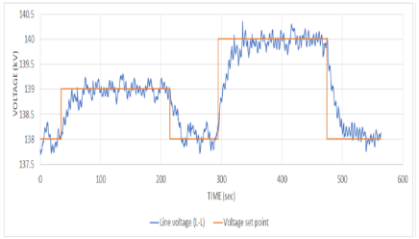
131.1 MW Tule Wind Plant



Ramping (Up and Down)

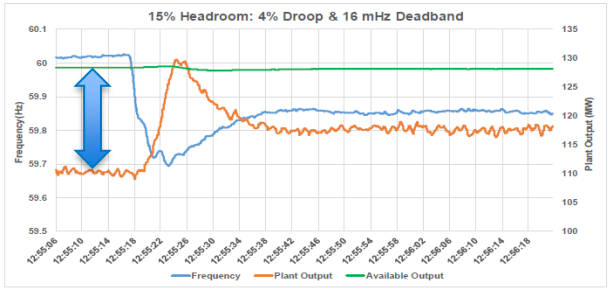


AGC within 2%

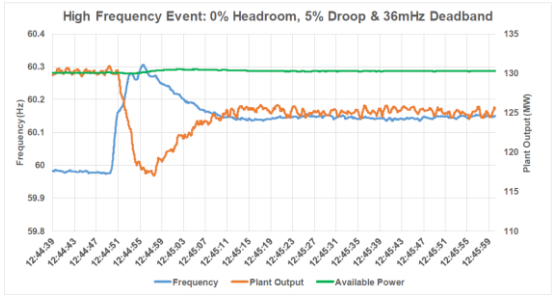


Voltage Control

Frequency Control (Low freq. event)



Frequency Control (High freq. event)



Note: The Avangrid Renewables Tule Wind Farm demonstration was a joint effort by CAISO, NREL, General Electric and Avangrid Renewables

Does this mean we are done with wind energy research?

IEA Wind Topical Experts Meeting #89: A Grand Vision for Wind Energy

- **Purpose:** Explore the advances in scientific understanding needed for wind energy to achieve its full potential (50% or greater penetration)
- **Participants:** Over 70 experts representing 15 different countries
- **Outcomes:** IEA report, "…Grand Vision for Wind Technology" and *Science* article: "Grand Challenges in the Science of Wind Energy"

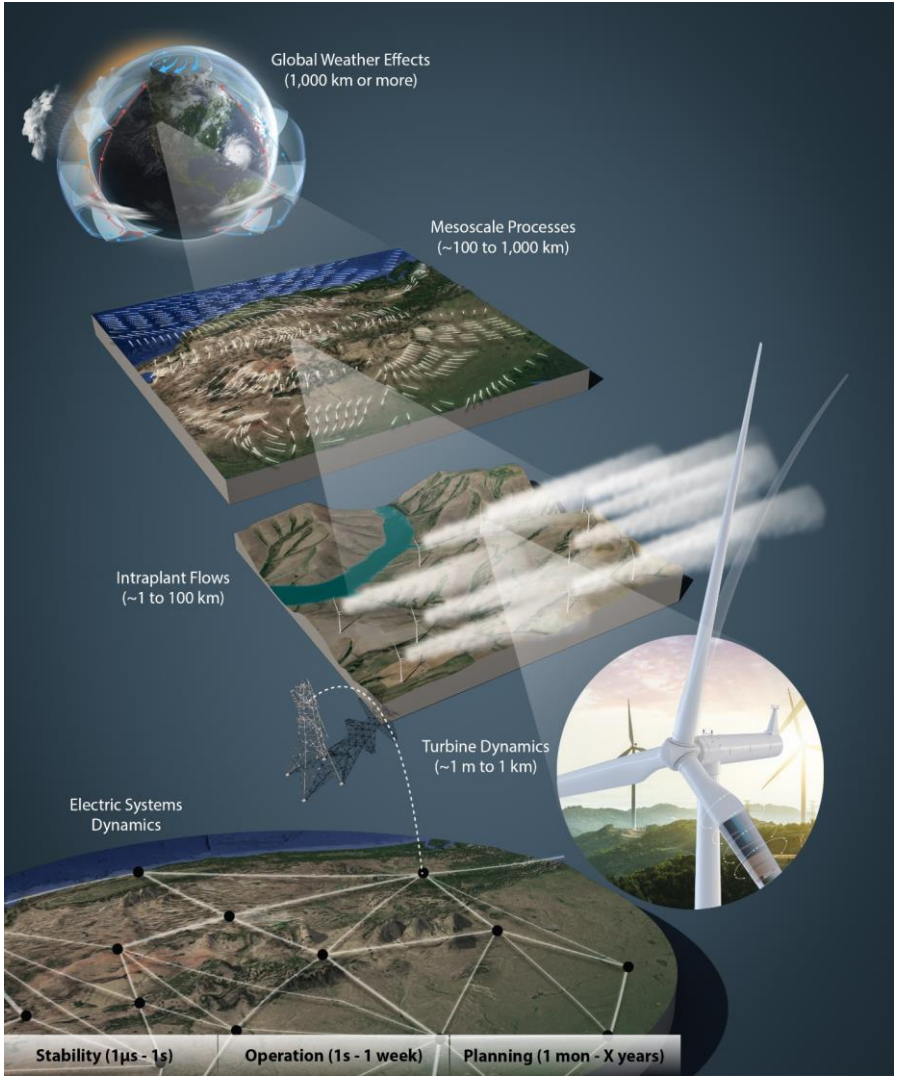
https://www.osti.gov/biblio/1508509-iea-wind-tcp-results-iea-wind-tcp-workshop-grand-vision-wind-energy-technology

https://dx.doi.org/10.1126/science.aau2027

The wind energy system extends from the global weather system to the microstructure of materials, and from yearly forecasts to sub-second power system stability.

Three Grand Challenges

1. Unknown zone of the atmosphere
2. Ultra-large turbine dynamics and materials
3. Optimization and control of plants for grid support and stability

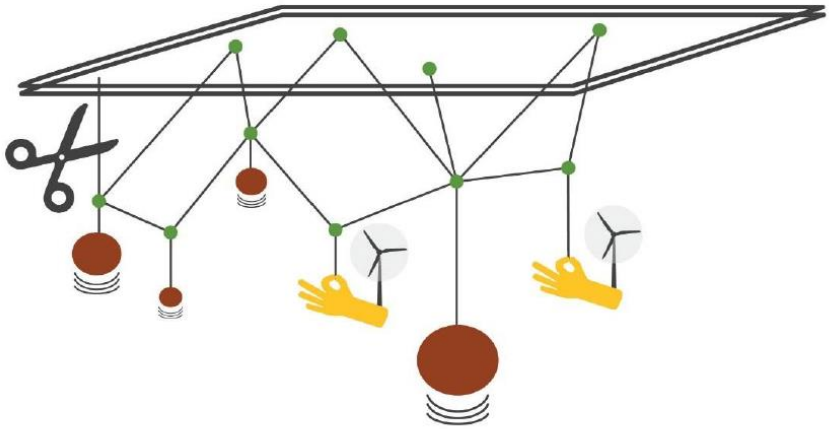


Source: NREL

The future grid operates on data instead of inertia

Is it stable?*

- Fossil plants have been inertia driven
- Renewables are inverter connected with software control
- Need to provide
  - fully dispatchable and flexible energy,
  - essential reliability services
  - resiliency services (black start, islanding, etc.)



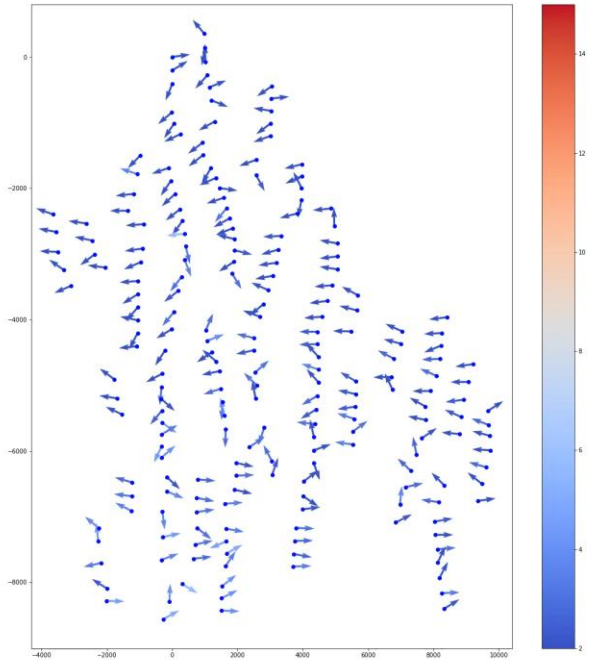
Source: NREL based on a figure created by Nick Miller, formerly GE Energy Services

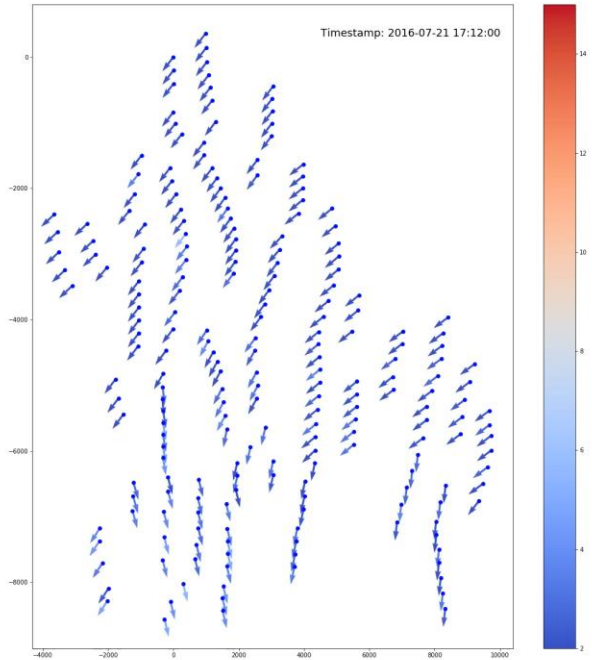
*Wind turbines are all brains, no mass

So… maybe even better than physical inertia!

- Hybrid systems will be prevalent
- Initial steps into the world of integrated control

First Steps to Integrated Energy Systems Consensus Control





Microgrid Operation at NREL Flatirons Campus

Image by Josh Bauer, NREL

Image from Flatirons Campus meteorology research tower camera

Substation device failure forced stand-alone microgrid operation at NREL Flatirons Campus

Controlling the Grid on Renewable Assets is the New Grand Challenge

- Controlled 2MW of generation with 1MWh battery and 0.2-0.3MW load
- Hybrid microgrid operation integrating Wind, Solar, and Battery Energy System Storage
- Seamless transition from 2MW emergency generator to renewable system
- Black Start off renewable assets

Thank You

www.nrel.gov

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