Research Opportunities in the Physical Design Optimization of Hybrid Power Plants

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TEM #101: Hybrid Power Plants: Challenges and Opportunities
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Outline

- Motivation
  - A Grand Vision for Wind (& Renewable) Energy
  - Utility-Scale Hybrid Power Plant Opportunities
- Physical Design of Hybrid Power Plants
  - Wind Power Plant Design
  - Solar PV Power Plant Design
  - Hybrid Power Plant Design
- Summary and Outlook

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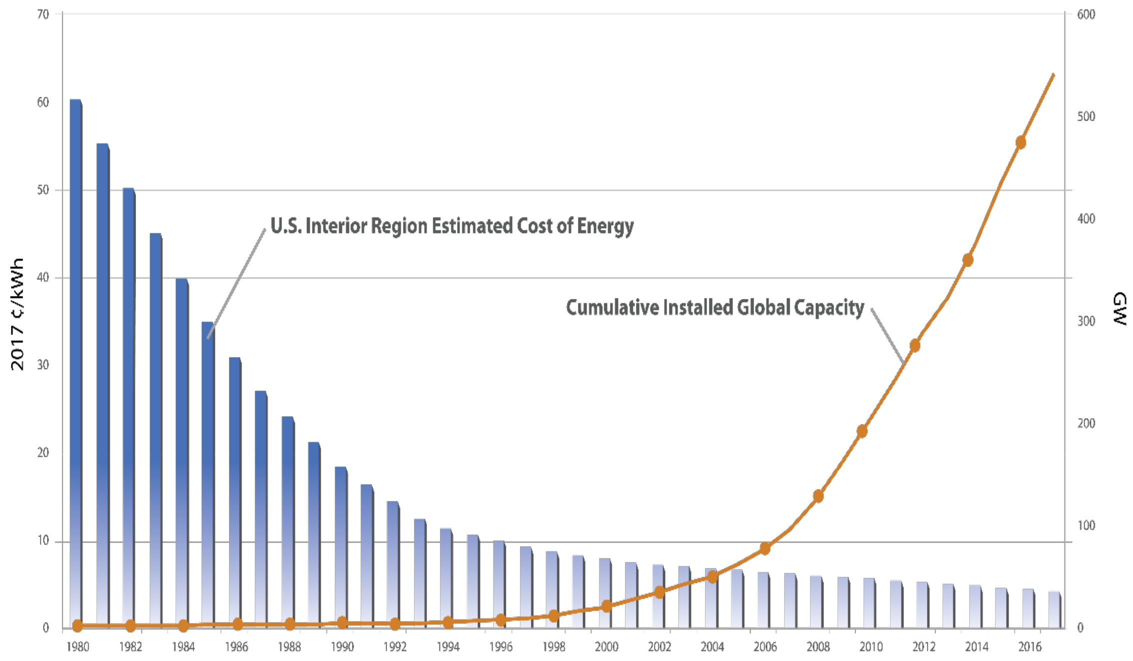
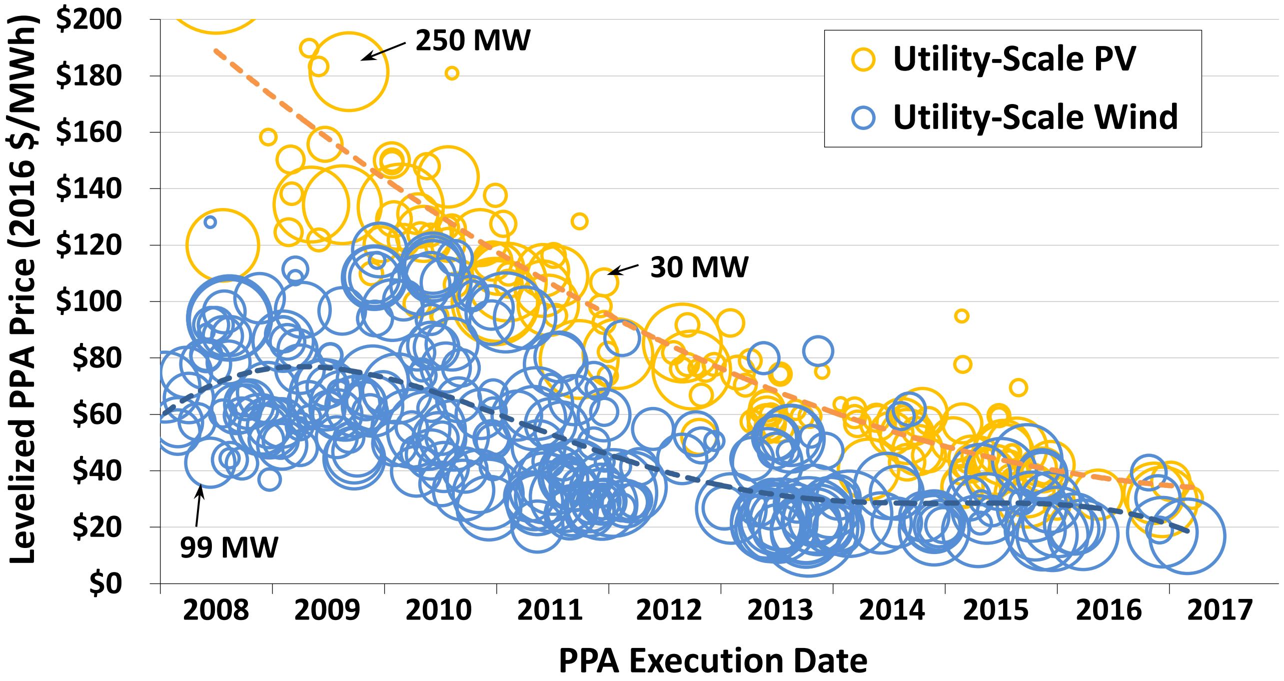
A Grand Vision for Renewables

Decreased Renewable Levelized Cost of Energy (LCOE) has led to Exponentially Increasing Deployment

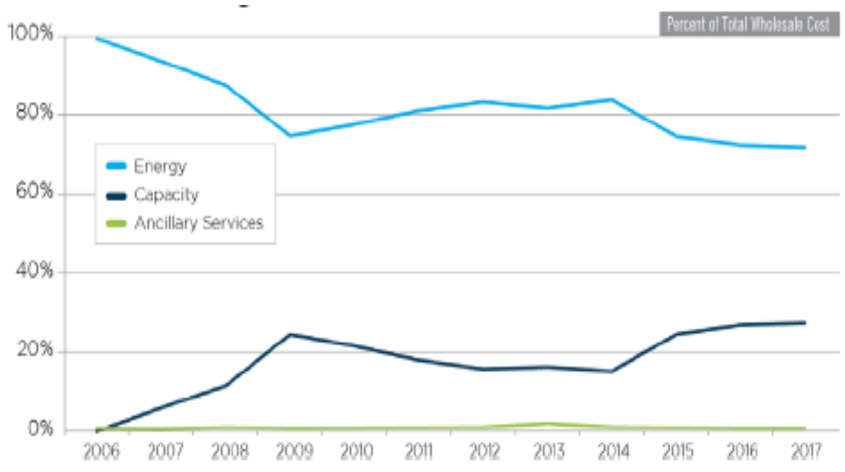




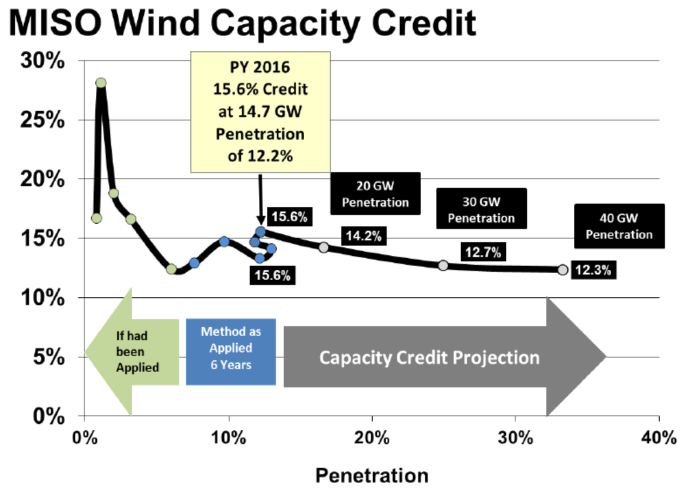
Sources: Wiser and Bolinger 2018, Wiser et al 2018, Dykes et al 2019

A Grand Vision for Renewables

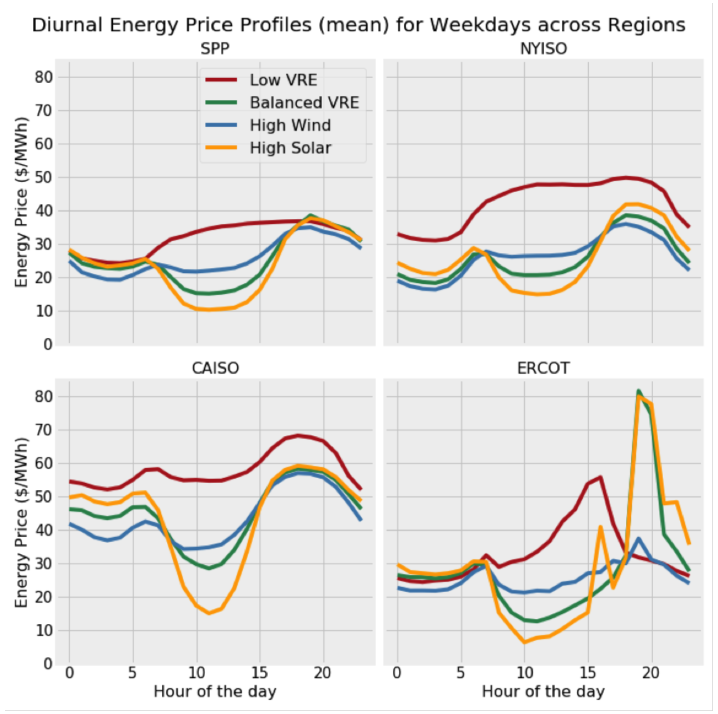
But new pressures surface…



PJM market trends through 2017 (Source: PJM 2017)



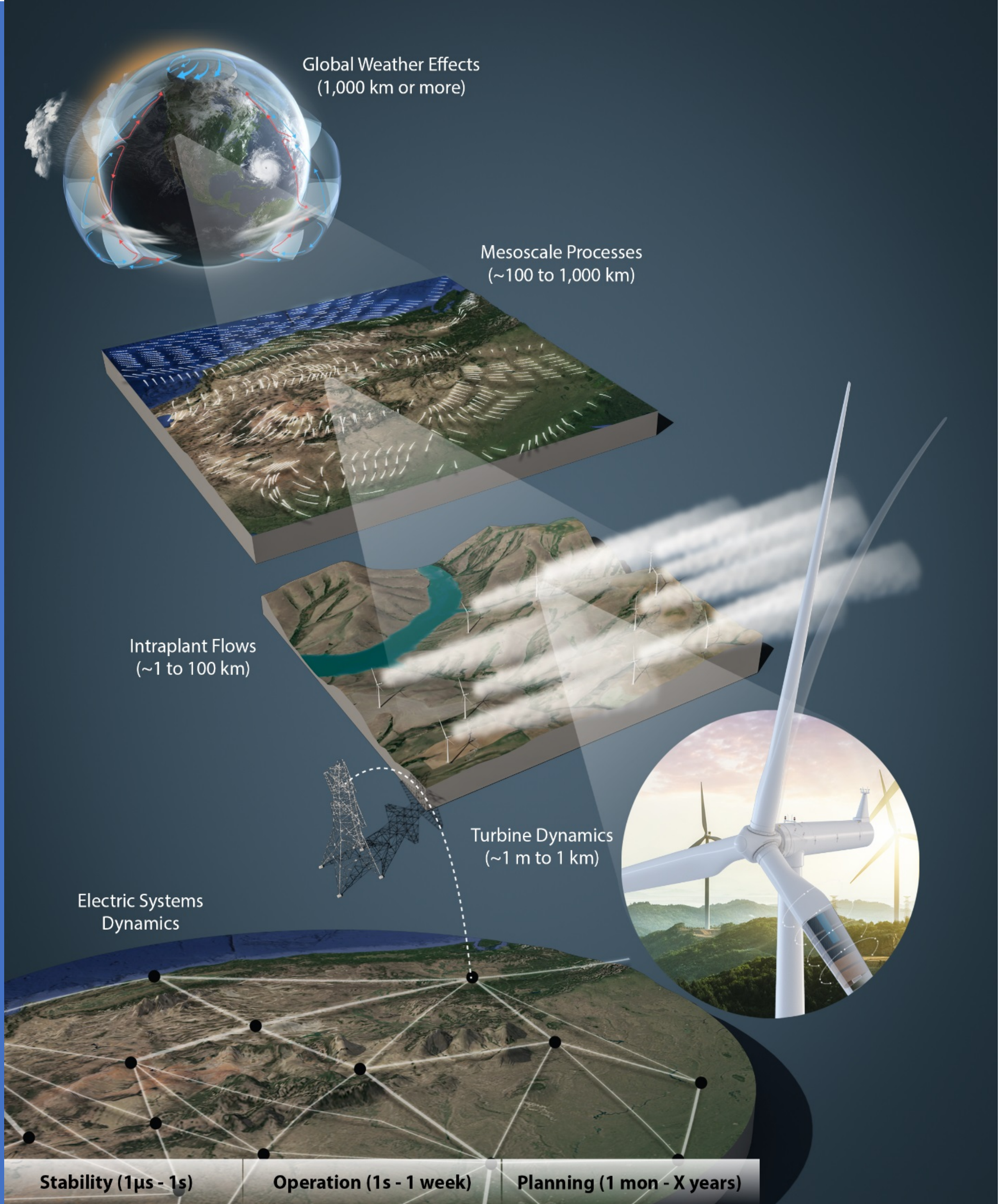
Declining wind capacity credits (Source: MISO 2015)



The solar duck curve (Source: Wiser et al 2017)

IEA Wind Grand Vision for Wind Energy explores a future scenario of 80% of the world electricity supply coming from renewables – a paradigm shift in system architecture, technologies and markets…

… and identifies grand challenges to solve in wind energy to realize this future



Source: NREL

https://science.sciencemag.org/content/early/2019/10/09/science.aau2027

Hybrid Power Plant Opportunities

LCOE no longer a sufficient objective, how can hybrid power plants support the realization of a high-renewable-energy-system future?

What do we need to think about in terms of design of hybrid power plants to maximize their individual profitability and collective value to the larger electricity and energy system?

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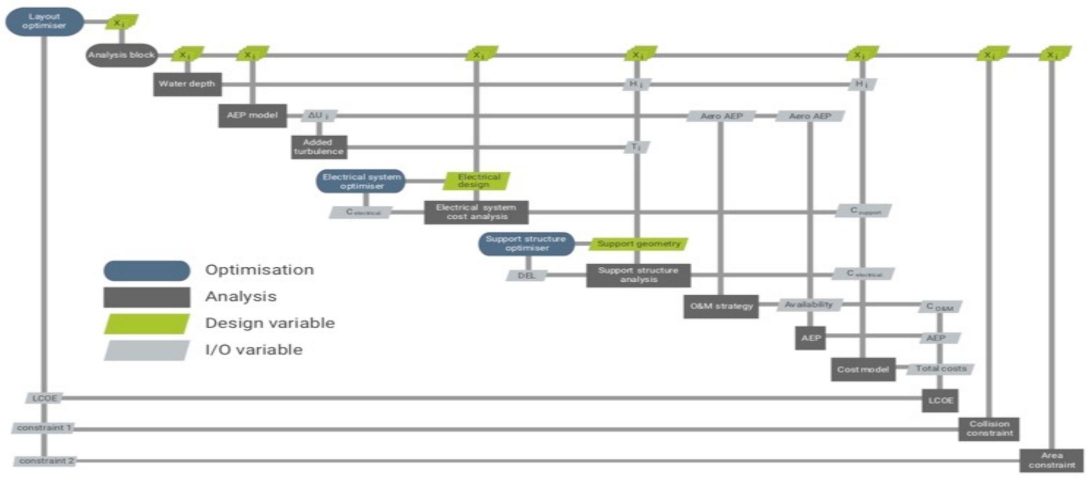
Wind Power Plant Design

Physical design of wind power plants is typically executed via complex multi-disciplinary optimization – with LCOE as a common overarching objective

Design variables often include:

- Turbine positions
- Turbine number
- Collection system topology and layout
- Advanced features including controls, etc



Example wind plant layout optimization workflow for an offshore wind plant (Source: Sanchez Perez-Moreno et al 2017)

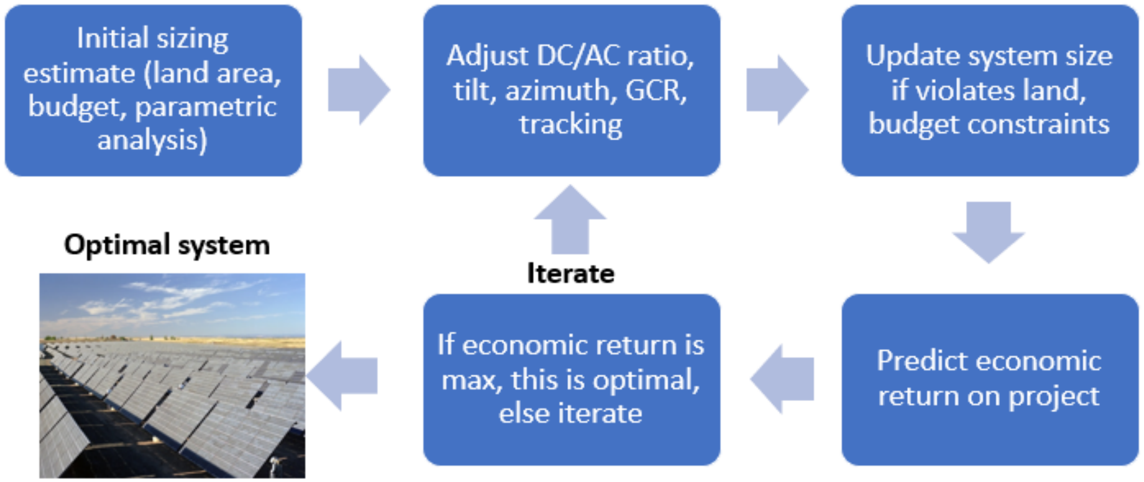
Optimization of the wind plant is a hard non-linear programming (NLP) or mixed-integer non-linear programming (MINLP) problem

Solar PV Power Plant Design

Physical design of solar power plants often uses a more manual process but with more complex design objectives (net present value or internal rate of return)

Design variables include:

- Tracking system and inverter load ratios
- Module orientation (portrait vs landscape)
- Row layout (1-up vs. 2-up)
- Bifacial vs. monofacial modules
- Inverter selection
- Module string wiring



Solar PV Power Plant Design Workflow (see Blair et al 2017)

The designer iteratively considers design using knowledge about land-area, cost targets and desired module and inverter combinations.

Hybrid Power Plant Design

Stages of the design may be broken into:

1. Technology selection
2. Technology sizing
3. Physical plant design
4. Operational strategy over the plant lifetime

A large body of work currently addresses on technology and sizing (see Cutler et al 2017, Nema et al 2009, Badwawi et al 2016)

Limited work to date addresses detailed physical design

Coupling of selection, sizing, design and operation is required to support the optimization of these systems for overall profitability over the plant lifetime

Hybrid Power Plant Design

Considerations for research on the physical design optimization of hybrid power plants

Design Process Elements	Current Practice for Single Technology and Hybrid Power Plant Sizing	Current Practice for Single Technology Physical Design Optimization	Potential Approach for Hybrid Power Plant Physical Design Optimization
Input Data – Resource	Time-series data with variable bin resolution (for a representative year)	Statistical Model of Key Resource Parameters (i.e. for wind: speed and direction joint pdf)	Limited cases that reflect temporal dependencies but also bulk statistics
Input Data - Resource	Time-series data with variable bin resolution (for a representative year)	Single power purchase price (with limited options of extension)	Limited cases that reflect temporal dependencies but also bulk statistics
Technical Models – Solar, Storage and Wind	Simplified parametric representations of technology performance and cost	Detailed physical models of the technologies for cost and performance	Detailed physical models of the technologies for cost and performance including interaction effects (i.e. turbine shading of panels)
Technical Models – Balance of Plant and Operations	No or highly simplified parametric representation of infrastructure and operational costs	Broad range of fidelity in terms of modeling the infrastructure and plant operations	Important to adapt existing single technology models for hybrid power plant implementations with various topologies of coupling in the plant collection system
Optimization Problem Formulation – Design Variables	Technology types, capacity sizing and operational strategy	Technology types, number, placement, interconnection topology, control strategy, and more	Technology types, number, placement, interconnection topology, control strategy, and more (for all technologies)
Optimization Problem – Design Constraints and Objectives	Objectives on profitability (NPV, etc) as well as potentially resiliency etc. Constraints on sizing and operation of the different technology components.	Objectives on LCOE typically. Locational and technology usage constraints.	Objectives on profitability (NPV, etc). Locational and technology usage constraints.
Optimization Problem Formulation – Workflow Architecture and Algorithms	Monolithic MILP	Monolithic (mostly) NLP or MINLP (can include sub-optimizations that are typically NLP) (both gradient-based and gradient-free)	Monolithic (mostly) NLP or MINLP (can include sub-optimizations that are typically NLP) (both gradient-based and gradient-free)

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Summary and Outlook

- Hybrid power plants have potential for improving value and profitability of renewable power plants in a changing electric system

- The viability of hybrid power plants depends on the inherent synergies of different generation technologies, resources and market opportunities

- Coupling of sizing, physical design and operational strategies presents a research and commercial application area with a lot of innovation potential to advance and enable deployment of hybrid power plants

Thank you!

https://www.nrel.gov/docs/fy20osti/74115.pdf