Iowa State University
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Operating and planning electric networks with variable generation

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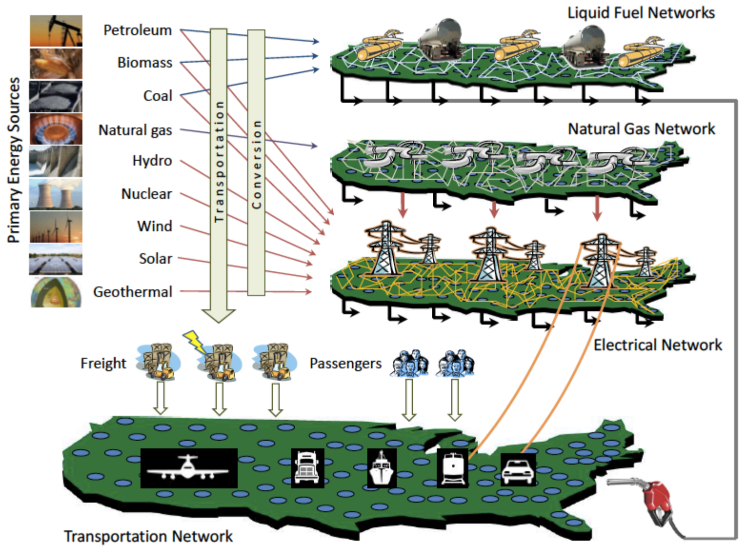
My Background

- **Education**
  - 2013: MS Electrical Engineering, UPRM
  - 2011: Graduate-level courses in Spain, UPNA
  - 2010: Graduate-level courses in Denmark, AAU
  - 2009: BS Electrical Engineering, PUPR
- **Professional Certifications**
  - Professional Engineer (PE), In progress; Passed PE exam
  - Engineer in Training (EIT), Lic. 24009
  - Certified Volleyball Referee
- **Industry Internships**
  - 2008: Lockheed Martin
  - 2007: Pfizer Pharmaceuticals
  - 2005 & 2003: Puerto Rico Electric Power Authority

Overview

Hard infrastructures



[1] Ibanez, E., McCalley, J., "Multiobjective evolutionary algorithm for long-term planning of the national energy and transportation systems," *Energy Systems Journal, 2011*

Planning process

* Criteria
* Time horizon
  - -Financing
  - -Multiple org.
  - -Land
  - -Environmental
  - -Cost of energy
  - -Reliability

Variable generation

- The existing electric infrastructure was not design for VG
- IF we do nothing about it, high penetration of VG…
  - Increases **variability** and uncertainty
  - Increases reserves requirements, transmission congestion and chances of curtailment
  - Degrades the performance of existing control performance standards
  - Reduces the total system’s inertia

Uncertainty & Variability

- **Uncertainty**: Related to the accuracy of forecasting
  - A recent investigation covered this topic
    - D. Mejia, "Robust and flexible planning of power system generation capacity", 2013
- **Variability**: Related to the *nature* of the resources
  - Studies have mainly focused on statistical methods
  - The trend is toward probabilistic approaches
  - Main focus of my work

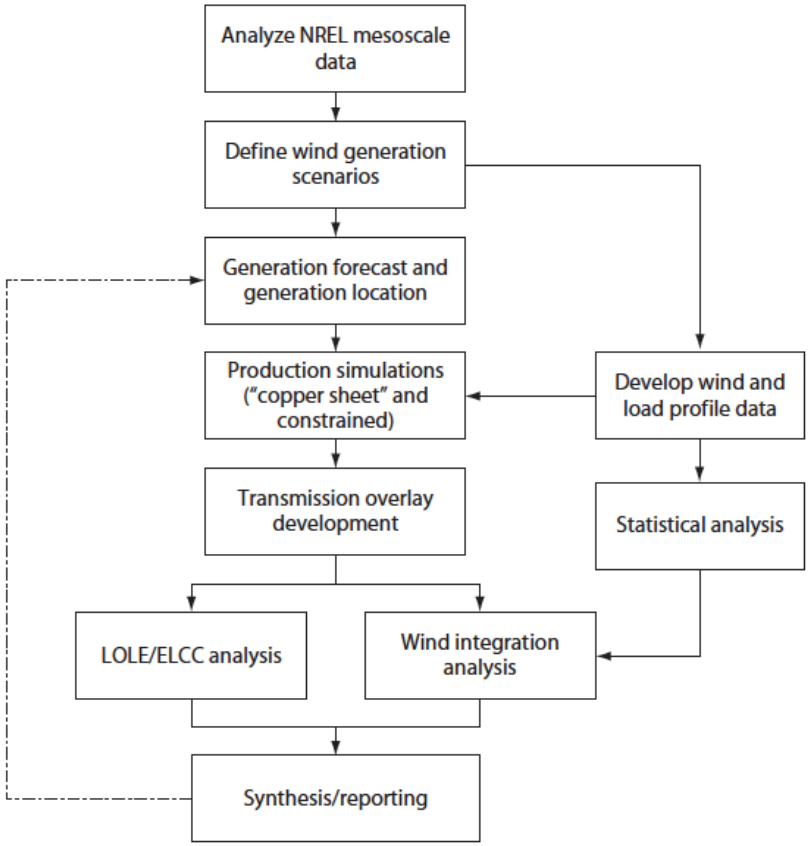
Key question

Will there be enough capacity on the electric network to manage the increased **variability**, OR whether new sources, such as fast-response conventional generation, significant levels of demand response, and storage technologies must be coordinated with VG controls to manage that **variability**?

Typical integration study

- Data recompilation/ modelling
- Develop net load time series
- 1-Yr production cost model
- Impact on reserves (regulation, load following, imbalance)

Figure C.1 Sequence of a Typical Variable Generation Integration Study



Source: Enernex Corporation 2010.
Note: ELCC = electricity load carrying capability; LOLE = loss of load expectation; NREL = National Renewable Energy Laboratory.

[2] M. Madrigal, K. Porter, "Operating and Planning Electricity Grids with Variable Renewable Generation", The World Bank, 2013

Strategies & solutions

- Improve forecasting
- Shorter scheduling intervals
- Consolidating balancing areas (BA)
- Bulk storage (e.g., PHS, CAES)
- Demand-side (DS) management
- <u>Include operational effects on long-term planning</u>

Compare cost and effectivenes (control performance) from a PORTFOLIO of options to **mitigate variability**

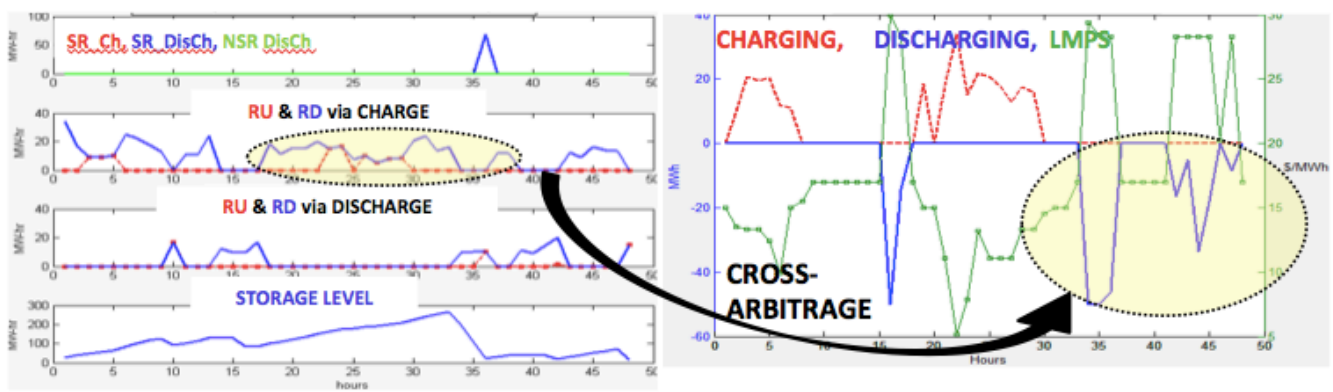
Storage

- T. Das dissertation suggested that bulk-CAES make sense at very high penetration of wind energy

Cross-arbitrage

CROSS-ARBITRAGE: Charges from the regulation market and discharges into the energy market or charges from the energy market and discharges into the regulation market

The amount of down-regulation is more than up-regulation, charging up the reservoir for energy dispatch during high LMP periods

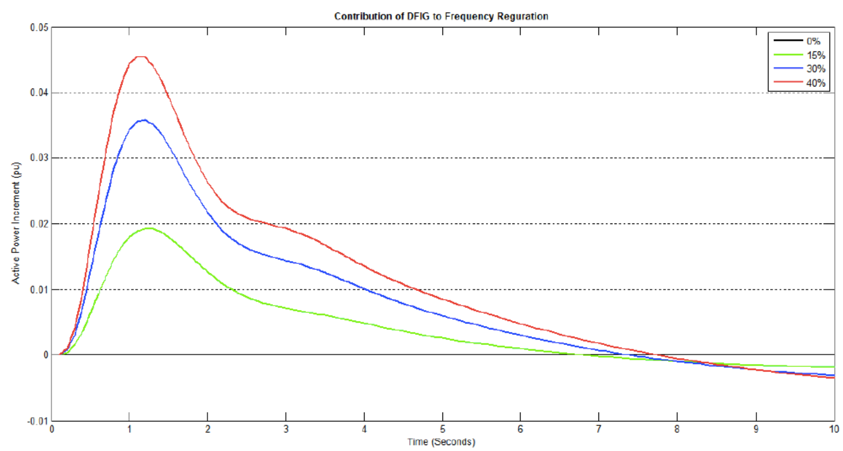


[3] J. McCalley, “Resource technologies-Storage”, Power System Planning course, Fall 2013

VG controls

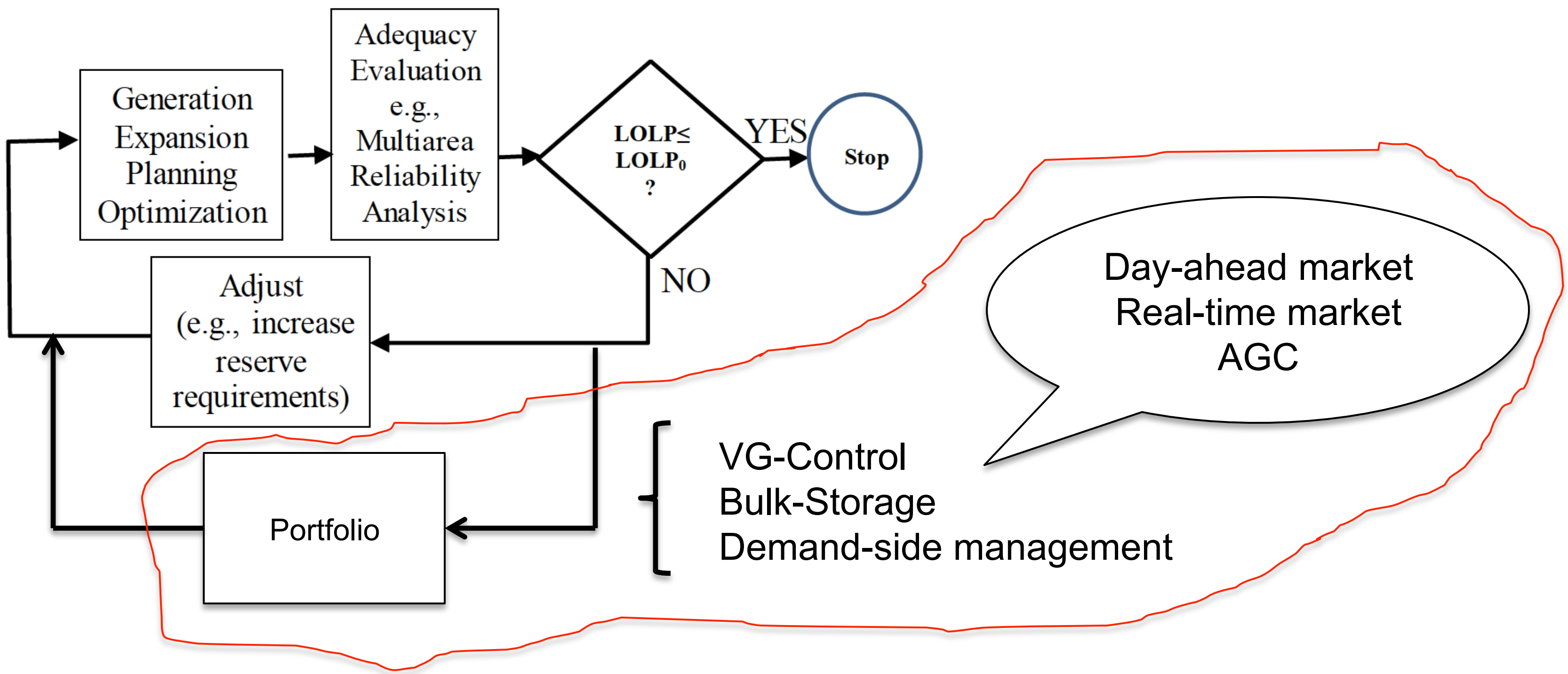
- Inertial emulation (limited, but effective); Secondary effects must be evaluated
- Primary governing (Cycling issues; blades degradation)
- Coordination between WT's in a wind power plant is *key*
  - Moreover, coordination between VG, storage, conventional generation, and demand-side management is *crucial*

$$J\frac{d^2\theta}{dt^2} = T_m - T_e = T_a$$



VGEP

- Variable-Generation Expansion Planning



Relevant publications

- Wang, C., McCalley, J., “Impact of wind power on control performance standards”, *International journal of electrical power and energy systems*, 2013
- Das, T., “Performance and economic evaluation of storage technologies”, *PhD dissertation at ISU*, 2013
- Mejia, D., “Robust and flexible planning of power system generation capacity”, *PhD dissertation at ISU*, 2013
- Ibanez, E., McCalley, J., “Multiobjective evolutionary algorithm for long-term planning of the national energy and transportation systems,” *Energy Systems Journal, 2011*

Research hypothesis

Coordination of conventional generation, VG-controls, bulk-storage, and demand side-management in the regulation and day-ahead market together with long-term investment *strategies* will provide the qualitative assessment required to evolve from 20-30% to >50% VG penetration scenarios.

Research plan

- Develop a method to include >50% VG into the existing generation expansion planning (GEP) model
- Include operational impact (e.g., control performance) into long-term planning models
- A method to compare *system* economics between increased production costs from curtailed wind, and increased production and investment costs from using storage and conventional generation.
- Tools: Production cost programs, AGC, Stochastic SCUC

Main assumptions

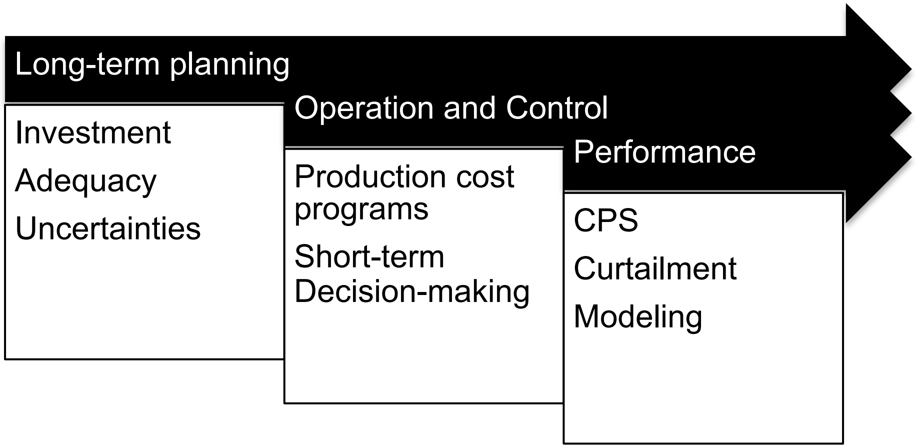
- Next Class of WTG
  - Different materials/topologies (e.g., permanent magnet, superconducting) 5-10 MW Inland, ~10 MW Offshore
- Wind turbines have inertial emulation, primary governing and ramp-rate control capabilities
- Solar PV inverters have reserve capabilities (by operating at a lower MPP)
- Significant demand-side management participation
- Storage technologies with arbitrage and *cross-arbitrage* potential

Potential constraints

- Simulation: Very extensive computational time
- Practical: Modern technologies lack of data due to low maturity level

Summary

- Variability can be managed with existing technologies. But what is the optimal portfolio?
- A coordinated control in the intra-hour time frame is required for higher penetration levels (e.g. >50%)
- Operational effects should be included into long-term planning models



Questions?