Hierarchical Coordinated Control of Wind Energy Resources and Storage for Electromechanical Stability Enhancement of the Grid (2.2)

Thrust 2, Task 2:

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Fundamental Objective for Thrust 2

Original Thrust proposal stated its goal as:

"Define the overall concept for hierarchical coordinated control and protection of the smart grid."

Today, place this in context of an overall objective PSERC's Future Grid Initiative, that of enabling higher penetrations of renewable generation and other future technologies into the grid, while enhancing grid stability and reliability.

Overview of Challenges and Opportunities

Many challenges to present-day control and protection practice come with growing penetration of distributed and renewable generation.

• Greater volatility in injections/operating conditions;

• Less clear boundary between roles at bulk transmission versus distribution level. More (and more diverse) participants impacting grid control. **Goal here** – allow diverse resources to contribute to electromechanical stability enhancement

Overview of Challenges and Opportunities

Rapid improvements in grid communication and sensor technologies offer opportunities to manage new resources, but also present challenges.

- Need a well organized architecture to coordinate flow of data that informs grid control.

Overview of Challenges and Opportunities

Similarly, tremendous opportunities in expanded computational and signal processing power available to distributed controllers and protection devices, but new design challenges here as well.

- Need coordinated hierarchy, balancing greater ability to operate locally, enabled by more powerful local computation, with opportunities to use select wide-area measurements available via high-bandwidth communication.

Specifics of Task 2: Control Architectures for the Future Grid

Task 2: "Hierarchical Coordinated Control of Wind Energy Resources and Storage for Electro-mechanical Stability Enhancement of the Grid."

• Focused on characteristics of power-electronically coupled wind, and on battery storage. This gave structure to the work, producing control designs specifically useful for these technologies.
Goal today: show that it also produced a more broadly applicable control architecture.

Future Grid Control: Motivation

- New technologies contributing to generation, and to grid control, present dramatically different interconnection characteristics than traditional synchronous generators.

- Widespread recognition that power electronically coupled generation (without advanced controls) lack inertia characteristic of synchronous machines. Inertia is typically a stabilizing effect, so grid stability challenged when it decreases.

Future Grid Control: Motivation

- More generally, the future grid will have a much wider variety of technologies contributing to its control, with much wider variety of characteristics. In terminology of control design, we will have a much more diverse set of *actuators*.

- Some wind controllers today seeks to make new "actuator" behave like the old – to mimic traditional machines' inertia. **Better approach**: optimize for new characteristics, don't mimic old.

Future Grid Control Architectures

- **Question:** in thinking about control architectures, suited to widely diverse control resources, how to rigorously describe the characteristics that define different actuators?

- **Our Answer:** bandwidth, and very importantly, limits on the range of available control action.

  At risk of oversimplification, we'll motivate by similar to challenges in home theater design!

Why Grid Control is Like Home Theater: Bandwidth and Saturation

- A speaker is a multi-actuator device, with goal of controlling sound pressure delivered to listener's ear.

- Each actuator is responsible for different portion of audible range (woofer, mid-range, tweeter).

- Each actuator has different hard limits on its mechanical excursion/ saturation ("long-throw" on woofer, less than ± 1 mm on tweeter)

Why Grid Control is Like Home Theater: Bandwidth and Saturation

- Lower-end speakers use relatively simple linear filtering (crossover network) to direct **different portion of the control signal bandwidth to different actuators.**

- Higher-end devices use bi-amplification, to apply separate, appropriate power levels to each actuator**, to respect each one's saturation limits.**

Why Grid Control is Like Home Theater: Bandwidth and Saturation

- Project used industry standard models of the pitch power control of type-3 wind turbines, characterizing control response bandwidth and saturation limits (commanded change in power as input, achieved change in active electrical power as output). Similar concept for speed-based power control.

- Project also used SAFT International models for high power lithium-ion batteries with power electronic interface, characterizing response from commanded power as input, to grid-interface power as output.

Bandwidth and Saturation Issue in Future Grid Control Architectures

- This project used Linear Quadratic (LQ) Optimal control design, to make best effective use of each actuator, in contributing to formal objective of stable grid frequency regulation.

- Our LQ control design used recent advances in the control system literature, that allow optimal design within the hard constraints of limits on the control actuators. For grid examples, limits included charge/discharge rate of batteries, battery energy storage limits, max/min limits on wind turbine blade pitching.

Importance of Estimation – Grid vs Home Theater Analogy again…

- Home theater designers recognize actuators operate into a network that greatly impacts performance in controlling sound pressure to listener's ear: the room.

- Traditional designs involved picking fixed designs that were robust to a range of rooms, and engineering rules of thumb to tune to specific installation. Perhaps not unlike traditional grid control design.

- Modern home theater includes microphones to measure room response, estimate its parameters, and tune amplifier/speaker characteristics to suit the room.

Importance of Estimation in Future Grid Control

- Similar challenge in optimizing grid control action effected through widely diverse resources exercising control: need estimate of system *dynamic* state.

- High sampling rate, synchronized phasor measurements (PMUs) open the door to make such estimation possible.

- But even with PMUs, need caution in making fast time scale controls dependent on large number of wide-area sensors. In coordination with Task 1 of Thrust, need to treat communication bandwidth, latency, and security.

Importance of Estimation in Future Grid Control

- Work in Task 2 developed multiple, distributed dynamic state estimators/"observers."

- To keep communication needs modest (and to allow for graceful degradation when remote measurements not available), each observer seeks to estimate just low degree of freedom dynamic behavior, not full state (observe and control small number of system "modes").

- We developed model-based measures of observability, to decide which sensors to best "feed" a given controller (will also allow decision when communication loss makes a given mode no longer observable).

Summary: Task 2 Contributions to Future Grid Initiative

- Developed control designs to make best use of generation and control resources with widely diverse terminal characteristics. Demonstrated on Type-3 wind turbines and lithium-ion batteries as test cases, with a design architecture that is broadly applicable.

- Complemented controllers with a distributed estimation architecture: a local state observer for each controller. Each uses local measurements, plus (when available) very modest number of remote PMU measurements.

- Methodology for quantifying modal-based observability, for measurement selection and graceful degradation.