ADVANCED ELECTRIC GRID

GCEP

Global Climate & Energy Project

STANFORD UNIVERSITY

Scalable and Flat Controls for Reliable Power Grid Operation with High Renewable Penetration

Investigators

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Objective

The current electric power grid is a centralized system, built for reliability and efficiency in delivering bulk energy from large, dispatchable generators to load distribution centers. Fossil fuel-based power plants generate most of the electricity, and they emit significant levels of carbon dioxide to the atmosphere. A comprehensive solution to reduce greenhouse gas emissions requires a shift towards integrating more renewable generation technologies in the power sector. This research envisions a scenario where at least 50% of the electricity generated is from renewable sources and then focuses on developing new methods and tools for electric grid communication and control.

Background and Approach

There are several challenges to operating a power grid with a high proportion of generation based on renewable resources because these sources: (1) are less predictable than traditional fuel-based power plants; (2) may be far from load centers so power may have to flow through congested transmission paths; (3) do not generally match the daily cycle of load variation; (4) suffer from unusual operating constraints, such as rapid variation or complicated weather dependence; and (5) need to be tightly coupled to storage, which may be mobile.

To respond to this challenge, this research creates two fundamental shifts in the approach to the electric power infrastructure, namely:

- A broadening of the electric grid to consider overall end-use, so that electric power generation and delivery does not merely respond to load demand but actively controls energy delivery for plug-in vehicles, the production of fuels (e.g., hydrogen), energy storage, and end demand as needed.
- A “flattening” of the control structure that fully changes, at all levels of the power grid, the traditional control strategies. Existing energy systems today are characterized by multiple, autarchic control systems, including such systems as transient stability control, load frequency control, voltage control, power quality control, and distribution protection. These need to be replaced by a simpler, flatter structure with a local control operating within a more global context for the system.

Activities

The research will be organized as a multi-institutional effort among four universities. Research efforts where fundamental changes are needed are divided by the tasks listed below with each institution coordinating a task.

Issued February 2010

Flat control and communication framework – The proposed concept of flat control underpins the framework for reliable power system operation. Existing control systems emphasize the protection of individual components rather than protecting energy delivery. And the controls are already stretched to their practical limits. A simpler, flatter structure would consist of only two levels at each scale (see Figure 1):

- Local control in which individual components and individual loads operate in a manner that supports the best interests of the overall system, for reliability, speed, and robustness of control actions.
- Contextual control in which larger-scale controllers select one of a finite number of system-level control goals, such as efficiency maximization, cost minimization, stabilization, network recovery, or other goals that best reflect the needs based on overall system status at a given moment.

Establishing the basic theoretical framework for large-scale flat control will form the foundation for the other tasks. This work addresses issues, such as what information must be communicated, what control modes need to be considered, what performance guarantees can be given, and so on. The challenge is to characterize component responses to ensure reliable energy delivery without requiring high sophistication from consumers and load aggregators.

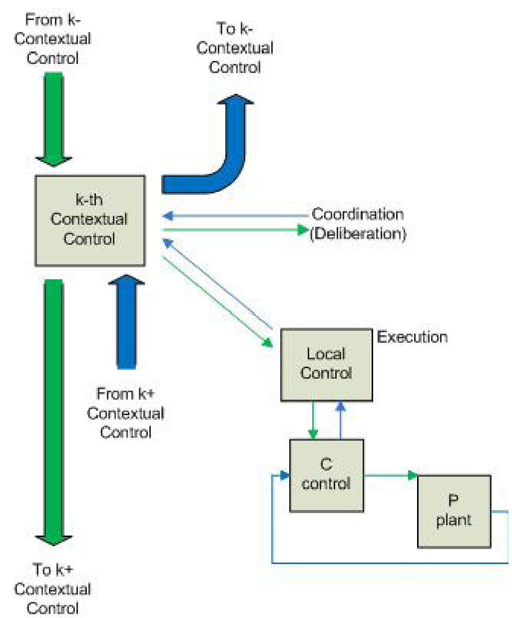

Figure 1: Structure of flat control scheme

Intelligent device interfaces – This task establishes communication requirements and device capabilities to develop controls. Communications need to achieve balance between openness for functionality and security to prevent nefarious interruptions. Devices will require low-cost interfaces to allow controllability and communication as well as the right degree of self-awareness. The goal is to achieve a plug-and-play functionality without sacrificing overall system performance.

Optimization with multi-scale energy sources and demands – Optimization methods will be developed to schedule loads, generation, and storage while respecting system limits and considering a broadening of the system to these new loads. The methods must manage the extreme dimension of the problem (decentralizing decisions for millions of loads and generators to focus on a more traditional unit commitment formulation with say hundreds of units), the stochastic nature of the problem, and scalability issues due to the uneven support of comprehensive control among the participants. Optimization will need to be distributed and managed through aggregators.

Transmission grid management and operation – The impact of flat control will be investigated, as well as the supporting controls that will be needed for dynamic restructuring of the grid to allocate resources while ensuring adequate margins throughout the system. Transmission flow limits must be determined in real-time for unusual operating conditions, and the system must be closely monitored.

Test and verification – The result of tasks mentioned above will be implemented in a test bed. Realistic systems can be simulated based on the current power grid and reasonable assumptions about the connected loads. Where necessary, detailed simulations and hardware tests will be used to verify the methods developed.