Carnegie Mellon

Optimal Integration of Intermittent Energy Sources Using Distributed Multi-Step Optimization

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Electrical & Computer ENGINEERING

Objective

To enable the integration of intermittent energy sources into the electric power grid by:

- Coordinating across control areas
- Using distributed multi-time step with forecasted load and wind data
- Optimally utilizing available storage in overall system to minimize ramp up/down of conventional generators and balance renewable intermittency

Motivation

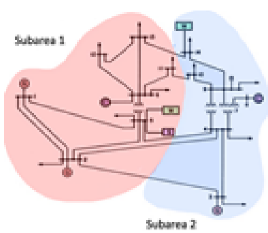
- The increasing unavailability of fossil fuels and their detriment to the environment encourages a push towards renewable sources. To increase the amount of renewable generation utilized, a method must be developed to more efficiently integrate this type of generation

- Different devices in the power system which are located in separate control areas are usually not willing to fully exchange system data. The use of distributed control will account for this reality

- Predictive control will help limit the use of environmentally-unfriendly generation and ramp/up down of generators, resulting in an overall more efficient system

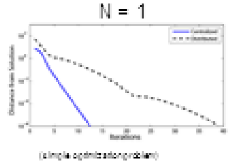
System Decomposition

System decomposition and optimization is performed using Optimality Condition Decomposition (OCD) [1], a method based on Lagrangian theory



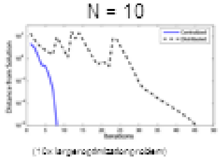
Distributed Vs. Centralized Convergence Rates

N = 1



(single optimization problem)

N = 10



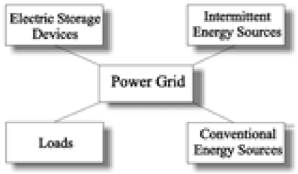
(10x larger optimization problem)

Approach

System Objective and Constraints

- Objectives:
  - Minimize cost of generation
  - Maximize use of renewable sources
  - Minimize emissions

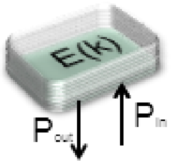
$$\sum_{i=1}^{numGen} a_i P^2_{Gi} + b_i P_{Gi} + \eta_i P^2_{Gi} + \xi_i P_{Gi}$$



- Subject to:
  - Physical AC power flow constraints
  - Storage limits, power generation limits

Storage Devices

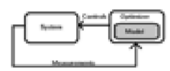
- Helps integrate sources which are intermittent
- Excess generated energy will be stored instead of curtailed
- Allows optimal usage of available transfer capacity

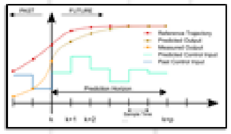


$$E(k+1) = E(k) + \alpha \cdot T \cdot P_{in} - T \cdot P_{out}/\alpha$$
$$P_{in} \cdot P_{out} = 0$$

α = conversion factor
T = time scale

Multi-Step Optimization





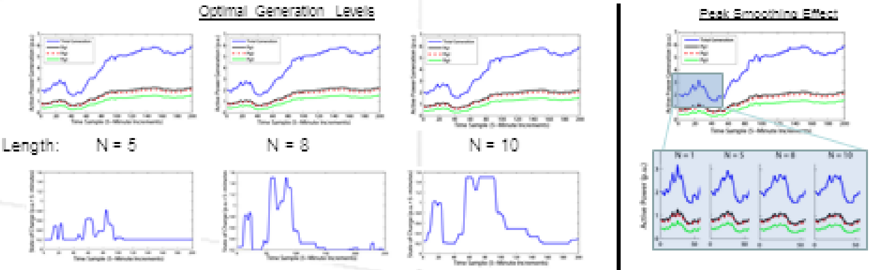
- Uses a model of the system to optimize over a time horizon [2]
- Helps answer when to use storage, backup generation, load control, etc. based on load forecasts and wind generation predictions

Simulation Results on IEEE-14 Bus System

Optimal Generation Levels

Peak Smoothing Effect

Horizon Length: N = 5, N = 8, N = 10



Optimal Energy in Storage

As horizon length N increases, storage use increases

References:
[1]: F. Nogales, F. Prieto, and A. Conejo, "A decomposition methodology applied to the multi-area optimal power flow problem," *Annals of Operations Research*, vol. 120, pp. 99–116, 2003.
[2]: J.M. Maciejowski. *Predictive Control*. Prentice Hall, 2002.