Hierarchical Probabilistic Coordination and Optimization of DERs and Smart Appliances

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Research Objectives

The objective of the research is to develop an hierarchical stochastic optimization method and a supporting infrastructure that coordinates the operation of non-dispatchable (renewables) and other resources including storage, smart appliances, and PHEVs that will enable:

a) Maximization of the value of renewables
b) Improved operation and economics resulting from peak load reduction and loss minimization
c) Improved environmental impact from using environmentally friendly sources with less greenhouse emissions
d) Improved operational security from ancillary services and controls provided by the power electronic interfaced devices.

Importance for the Future Grid

The proposed infrastructure and associated optimization procedures and control makes renewables economically and technically attractive and it will enable higher penetration of these technologies. The grid is transformed into an active and controllable resource with favorable attributes:

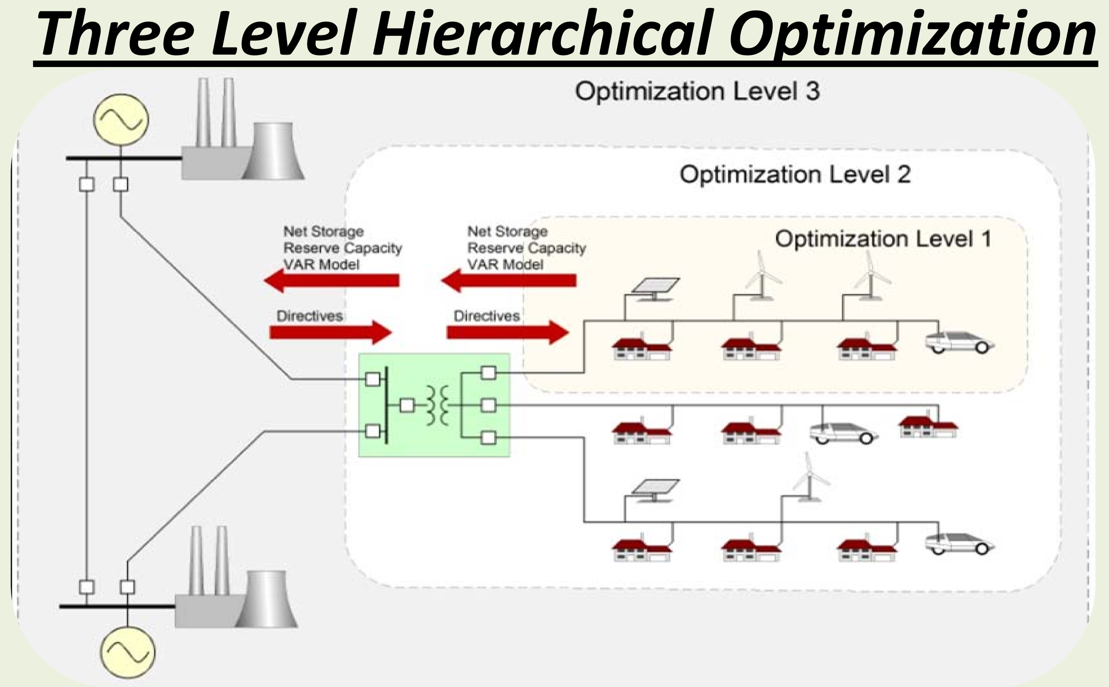
- Efficiency
- Minimal environmental impact
- Increased utilization of renewables

Research Deliverables

- An infrastructure and an hierarchical optimization algorithm (formulation and solution methods)
- A business case analysis that quantifies the benefits on system operation, economics and reliability resulting from the proposed optimization scheme.
- Comprehensive studies and application on utility scale systems.

Research Approach

Three Level Hierarchical Optimization



Optimization Level 1: Feeder optimization:

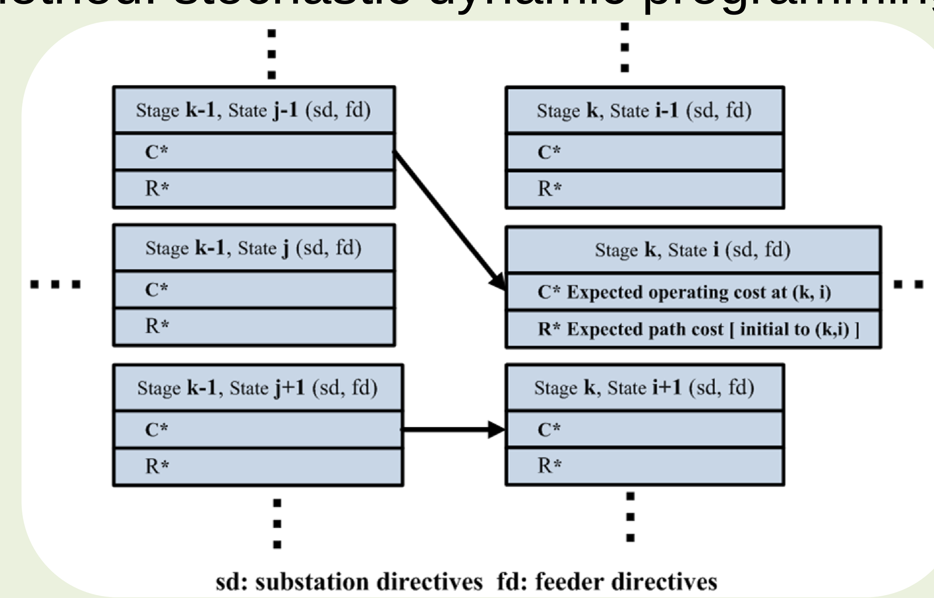
$$\text{Min } J = f(x, u, fd)$$
$$\text{s.t } g(x, u, fd) = 0$$
$$h(x, u, fd) \le 0 \qquad \underline{u} \le u \le \overline{u}$$

x: states, u: controls, fd: feeder directives

- Determines the optimal operating conditions for all DERs, customer resources, etc. subject to meeting the directives from the higher optimization level over the planning period .
- Solution approaches: (a) successive linear programming (b) barrier methods

Optimization Level 2: Substation optimization:

- Utilization of the aggregate model of each feeder of the substation, along with target values from the upper level
- Computes targets (directives) for each feeder.
- Solution method: stochastic dynamic programming



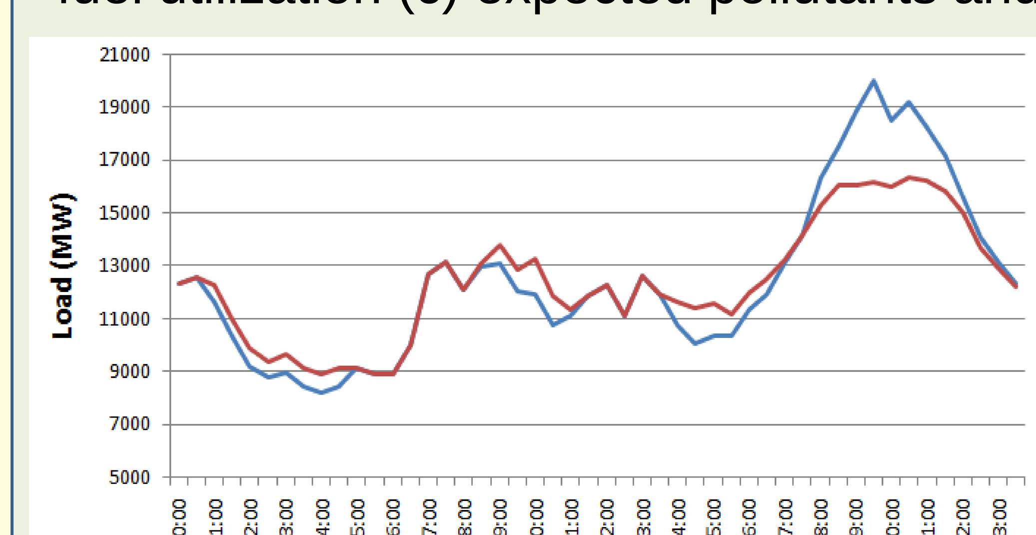
Optimization Level 3: System optimization

- Coordinates the operation of all substations and generates the target (directive) values for each substation
- Solution method: A dynamic programming approach is also used for this level.

Business Case Analysis

- Quantifies the benefits resulting from the proposed optimization scheme by comparing system operating costs with and without the proposed coordination and optimization.

Probabilistic Production Cost (PPC) Analysis:
It is used to compute (a) expected operating cost, (b) expected fuel utilization (c) expected pollutants and d) reliability indexes



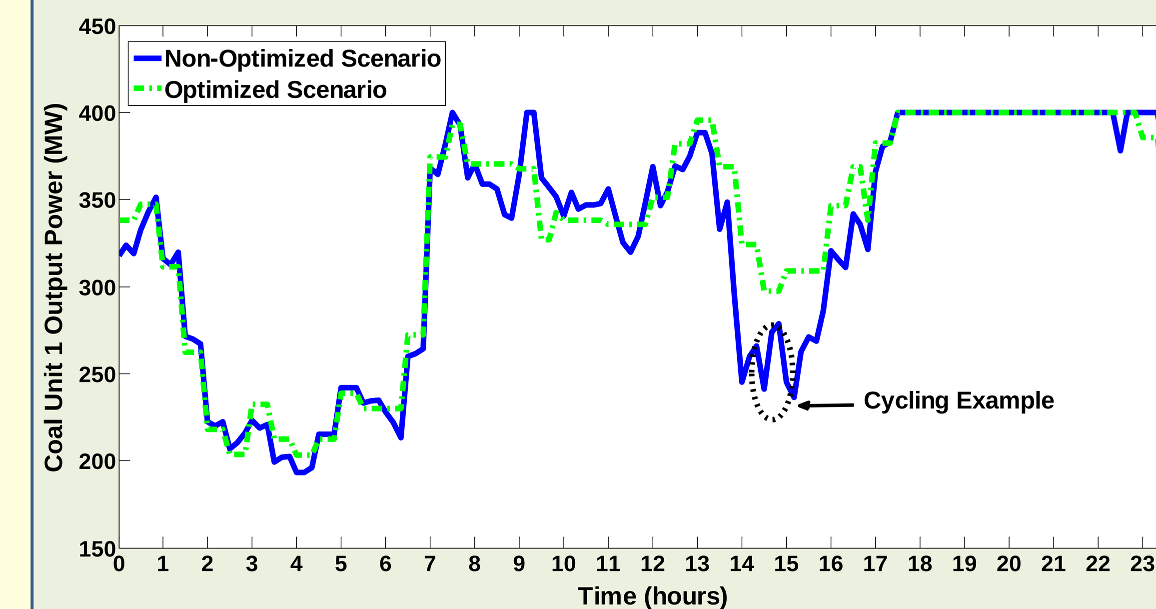
Utility scale test system:

- Capacity 22 GW, 40 generator units (coal, nuclear, oil, natural gas).
- Assumed 6.6% of penetration of DERs and storage devices.

	Non-Optimized Scenario	*Optimized Scenario*
Loss of load probability	0.04173	0.00227
Generated energy (MWh)	297,841.7	297,018.6
Unserviced energy (MWh)	1,103.7	32.9
Total production cost (k$)	8,234.7	7,945.5
Average production cost (cents/KWh)	2.7648	2.6751
Total CO2 emissions (kg)	125,671,208	124,906,337
Total NOx emissions (kg)	381,722	379,289

Effects on Conventional Generation Cycling

- Increased penetration of intermittent non-dispatchable renewable resources to the power grid could result in increased cycling of conventional units.
- Thermal Unit Cycling results in increased operational and maintenance cost and reduced reliability.
- The proposed optimization scheme reduces cycling of dispatchable thermal generating units (as a by-product).



- Dispatch of a coal unit in the test system with 10% wind integration for optimized and non-optimized scenarios.

Cycling indexes:

1) **Number of Cycles**: the number of cycles which have a duration less than 1 hour, that a unit experiences within one day
2) **Average MW per cycling**: The sum of MW variation of all the cycles during a day over the number of the cycles within one day

Coal Unit	Number of Cycles	Average MW Variation per cycle
Non-Optimized Scenario	22	56.23
Optimized Scenario	0	0

Capacity credit of non-dispatchable generation

- **Wind Farm Capacity Credit** is the capacity of a dispatchable unit with a specific forced outage rate (FOR) that will provide exactly the same reliability improvement as the wind farm capacity.
- **Computational Approach**: The PPC tool is used to evaluate the capacity credit of wind farms using the Loss of Load Probability (LOLP). Example results are given below.

FOR	*Capacity Credit (MW) (Case: Wind Capacity 2000 MW, 10% of total load)*	*Capacity Credit (MW) (Case: Wind Capacity 4000 MW, 20% of total load)*
0.81	500	915
0.85	435	830
0.88	411	796
0.92	397	767
0.94	385	752

Potential Uses of the Research

The grid of the future will have distributed resources, utility and customer owned with significant variability. Coordination of all resources is computationally and physically a challenging problem. This research will result in a feasible and effective solution.