Impact of Uncertainty from Load-based Reserves and Renewables on Dispatch Costs and Emissions

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Motivation

Previous work

- Load-based reserves are inexpensive, fast-responding and environmental-friendly
- Their capacities are highly affected by ambient conditions and load usage patterns
- Chance-constrained optimization and thermal battery model are used to model the load and renewable uncertainties in a multi-period optimal power flow problem

This work

- Qualitatively explore the impacts of renewable and load control uncertainty, cost parameters, methods for solving the problem and types of controllable loads on optimal dispatch solutions and CO₂ emissions.
Aggregation of residential loads

- Thermostatically controlled loads (i.e. electric heaters) with temperature setting and deadband
- On/Off signals from aggregator to individual loads (Non-disruptive control)

**Thermal battery model** (Mathieu, et al. 2015)

- Baseline power consumption $P_T$
- Aggregated power consumption (set point) $P_{C,t}$
- Real time energy state $S_t$
- Energy Storage: Charging/Discharging

$$S_{t+\Delta t} = S_t + (P_{C,t} - P_T(T_t))\Delta t$$

$$P_C(T_t) \leq P_{C,t} \leq \bar{P}_C(T_t)$$

$$S(T_t) \leq S_t \leq \bar{S}(T_t)$$
Optimization for day-ahead planning

Objective: To determine the optimal dispatch with uncertain load control and renewable resources by co-optimizing reserves and energy.

Uncertainties: wind power production and outdoor temperature

Design variables

- Generation schedule and load set points
- Generation and load reserve capacity
- Percent contribution of each reserve provider

Constraints

- Deterministic/Probabilistic
- Generation limits/Load limits/Line limits/Reserve limits

Solving methodologies

- Probabilistic robust method (Margellos, et al. 2014)
- Analytical reformulation (Bienstock, et al. 2014)
Modified IEEE 9-bus system

- Features: renewable energy producers, controllable load, congestion, different types of generators for CO₂ emissions analysis.
- A base case is defined as comparison reference using empirical wind/temperature data.

We vary the following factors that influence the dispatch:

- Wind forecast error
- Temperature forecast error
- Temperature forecast
- Load energy capacity
- Generation secondary reserve cost
- Methods to solve the problem

15% of each load is controllable but uncertain.
Results: wind forecast error

- Generation Cost
- Emissions

- CO₂ (lbs)

- Reserve Cost

- Wind Error Scaling

North America Power Symposium 2016, Sep. 18-20, 2016, Denver, USA
Results: temperature forecast error
Results: temperature forecast

![Graph showing temperature forecast results.]

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Results: load energy capacity

- Generation Cost
- Emissions
- Gen Secondary
- Gen Re-dispatch
- Load Secondary

Energy Capacity Scaling:
- Reserve Cost ($)
- Generation Cost ($)
- Δ CO₂ (lbs)
Results: generator secondary reserve cost

![Graph showing generation cost and emissions relationship](image)

- Generation Cost
- Emissions

![Graph showing reserve cost and cost scaling relationship](image)

- Gen Secondary Frequency
- Gen Re-dispatch
- Load Secondary

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Conclusions

- Wind uncertainty has larger impact on dispatch and emissions
- Controllable loads are used to provide reserve first until the capacity is reached
- Changes on generation dispatch has larger effect on emissions
- Higher load capacity results in more load reserve provision, more load shifting and reduced emissions
- Analytical reformulation gives less conservative results.

Future Work

- Improve the aggregated load model
- Impact of forecast profiles on results
- Quantify the results
Thanks!

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### TABLE I. BASE CASE COSTS & EMISSIONS RESULTS

<table>
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<tr>
<th></th>
<th>Dispatch ($)</th>
<th>Gen. Sec. ($)</th>
<th>Re-dispatch ($)</th>
<th>Load Sec. ($)</th>
<th>Emissions (lbs)</th>
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