A Multiple Criteria Utility-based Approach for the Wind-thermal Unit Commitment Problem

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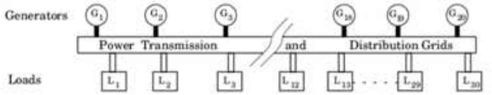
Thermal Unit Commitment Problem

Problem statement

Given a **set of thermal power generating units**:



- the UCP is **a scheduling problem** of determining which units must be **committed/decommitted** (ON/OFF) over a planning horizon.
- includes the **pre-dispatch problem** - determining the **production levels** at which the committed thermal units must operate in order to meet the forecasted **system demand and reserve at minimum costs**.

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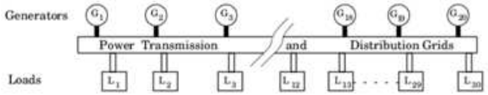

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Main decision variables and objective function

Decision variables:

- binary variables (y_{ut}) - 1 if thermal unit u is ON in period t, 0 otherwise;
- continuous variables (p_{ut}) - production level of thermal unit u, in period t;

Objective function:

- Minimize total operating costs:
  - **Production (fuel) costs** - quadratic function;
  - **Start-up costs** - stepwise cost function;
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- **System constraints**
  - Satisfaction of load requirements;
  - Satisfaction of spinning reserve requirements.
- **Technical constraints**
  - Minimum up and down times;
  - Minimum and maximum generation limits;
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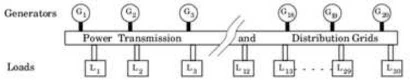
Some considerations

- Short-term UCP - Daily scheduling, discretized in **periods of (usually) 1 hour**;
- **Load and reserve** requirements are assumed to be known ***a priori***;
- Single bus representation (i.e. **network structure is not considered** in the problem);



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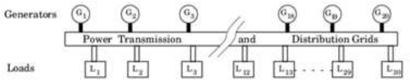

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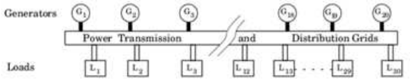

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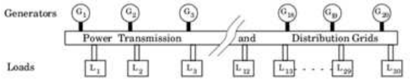

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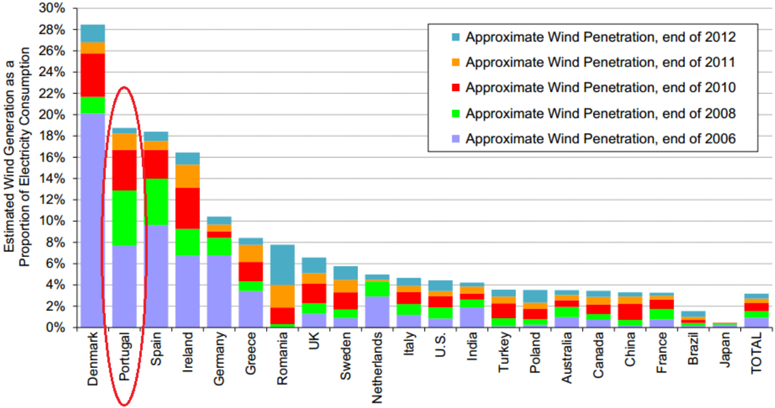
Wind Integration in the UCP

Worldwide Wind Penetration

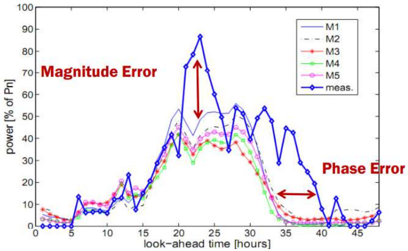


Source: Berkeley Lab estimates based on data from Navigant, EIA, and elsewhere

Wind Power Forecasting Uncertainty

Wind issues:

- Intermittent and variable
- Difficult to Predict
- May not be there when you need it...
- May have too much of it when you don't...



High wind power uncertainty

How to account for wind uncertainty in the day-ahead unit commitment?

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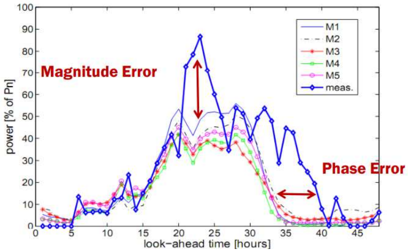

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Deterministic vs Stochastic Approaches

- **Deterministic** unit commitment:
  - Traditional approach used in industry
  - Wind uncertainty is not taken into account
  - More expensive schedules are obtained when compared to stochastic approaches
- **Stochastic** unit commitment:
  - Explicit representation of uncertainty in problem formulation
  - Minimization of expected costs (scenario-based approach)
  - May become computationally too intensive
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A Common Stochastic Wind-thermal UCP Model

- **Objective function**:

  Minimize probability_scenario * (Production cost + start-up cost + load curtailment cost).

- **Subject to**:
  - **For all scenarios:**
    - Minimum up and down times;
    - Start-up and shutdown constraints.
  - **For each scenario:**
    - Thermal+wind(+hydro) generation = load - load curtailment;
    - (Maximum feasible - dispatched) production $\geq$ reserve;
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Proposed Methodology

Criteria and objective function

Stochastic scenario-based MOCO model to be run at the day-ahead stage:

- Two criteria (**costs** and **energy not served**) to be **minimized**:

$$x_s^{cost} = \sum_{t \in \mathcal{T}} \sum_{u \in \mathcal{U}} (F(p_{uts}) + S(x_{ut}^{\text{off}}, y_{ut})), \quad \forall s \in \mathcal{S},$$

$$x_s^{ens} = \sum_{t \in \mathcal{T}} ens_{ts}, \quad \forall s \in \mathcal{S}.$$

- Objective function - **Additive utility function**:

$$\max U(x_s^{cost}, x_s^{ens}) = \sum_{s \in \mathcal{S}} \text{prob}_s (k^{cost}.U_s^{cost}(x_s^{cost}) + k^{ens}.U_s^{ens}(x_s^{ens})).$$

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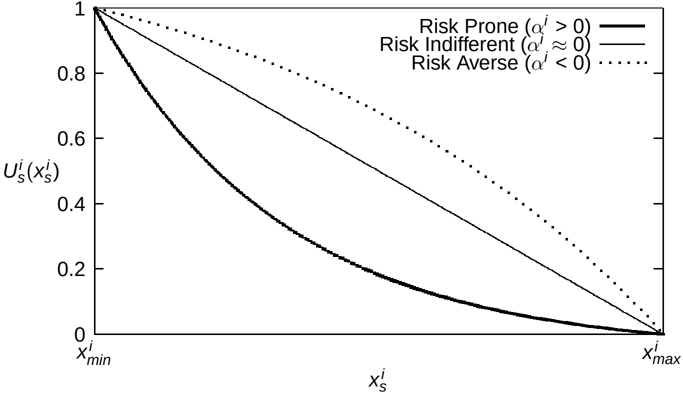
Individual Utility Functions

$$U_s^i(x_s^i) = \frac{e^{\alpha^i . y(x_s^i)} - 1}{e^{\alpha^i} - 1} \quad \text{with} \quad y(x_s^i) = \frac{(x_{max}^i - x_s^i)}{(x_{max}^i - x_{min}^i)}$$



Assess the scaling constants k^{cost} and k^{ens}

- Estimated through some **interactive questions** between an analyst and the DM[2]:
  1. Build "extreme" alternatives and ask for a judgement;
  2. Search for an **indifference judgement** from the DM;
  3. Use the information from 2. (**U(A) = U(B)**) and, in conjunction with $\mathbf{k^{cost} + k^{ens} = 1}$, compute the constants.

Common mistake when using Utility Theory

Scaling constants are not weights directly defined by the decision maker !

[2] R. L. Keeney and H. Raifa. *Decisions with Multiple Objectives: Preference and Value Tradeoffs*. Cambridge University Press, 1993.

Multi-attribute Utility Theory for the MOCO model

- **Requires:**
  - Verifying assumptions[3]:
    - Utility independence;
    - Additive independence.
  - Construction of the individual utility functions (definition of parameter α_i);
  - Indifference judgements to build the multi-attribute utility function;
  - Linearization on non-linear functions (4 segments each).
- **Difficulties:**
  - Building individual utility functions (α_i and ranges);
  - Validate required assumptions.

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Computational Experiments

Data-set

- 24 periods;
- 10 thermal units:
  - 3 peak (fast-start) units;
  - Total capacity: 1662 MW.
- 1 wind power plant: 500 MW;
- Spinning reserve: 10 % of load demand;
- Simulations for 30 unrelated days (Wind data from [3]):

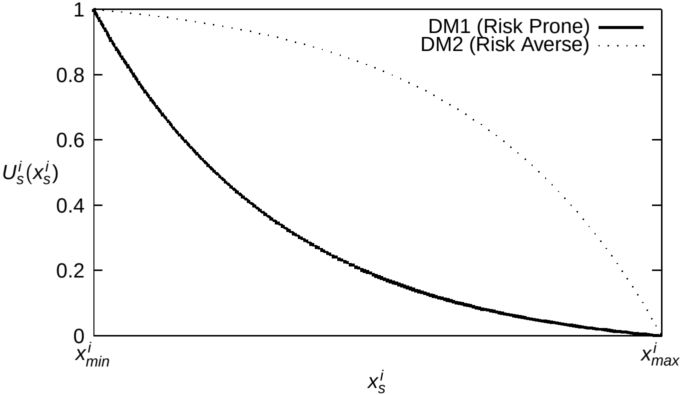
- Fixed load demand;
- 10 scenarios per day with a probability of 10 % each;
- Day-ahead unit commitment with wind power scenarios;
- Real-time dispatch with realized wind power.

[3] J. Wang, A. Botterud, R. Bessa, H. Keko, L. Carvalho, D. Issicaba, J. Sumaili and V. Miranda. Wind power forecasting uncertainty and unit commitment. *Applied Energy*, 88:4014-4023, 2010.

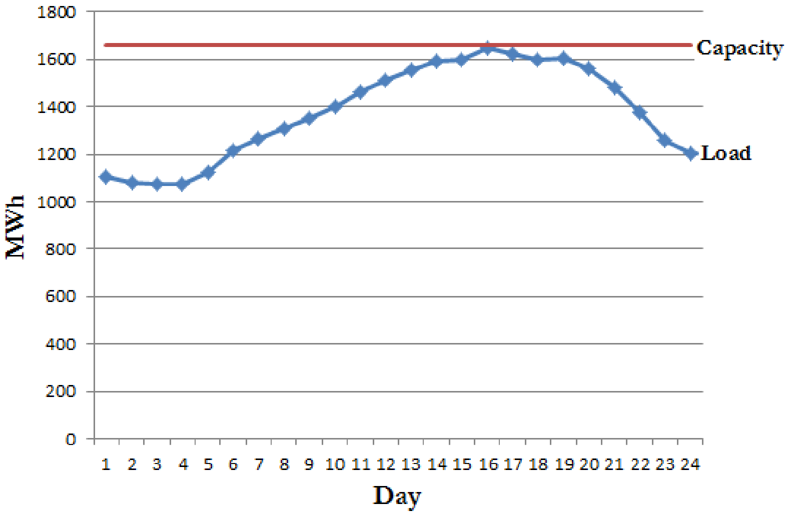
Simulated Risk Profiles

- Simulation for 2 risk profiles (DM1 and DM2);
  - **Parameter α^i for the individual UF's**:

Profile	Cost	ENS
DM1 (Risk prone)	≈0	3
DM2 (Risk averse)	≈0	-3



Case 1 - High load demand



Case 1 - High load demand

- **Ranges for daily feasible values (DM1 and DM2)**:

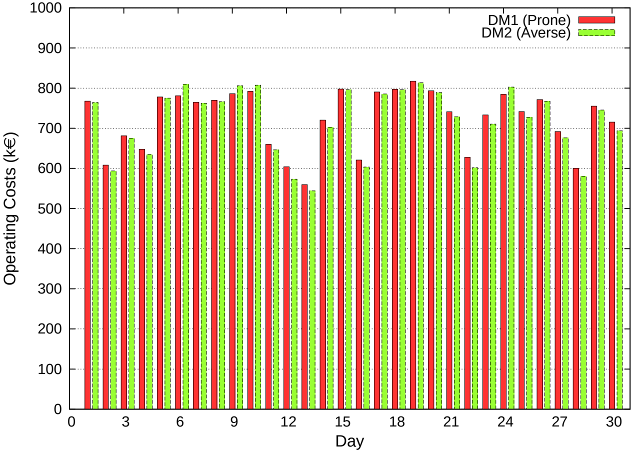
	Cost (€)	ENS (MWh)
x_{max}	1000 k	1000
x_{min}	0	0

- **Scaling constants**:

Profile	k^{cost}	k^{ens}
DM1	0.899	0.101
DM2	0.638	0.362

Case 1 - High load demand

- Daily operating costs for each of the 30 days:



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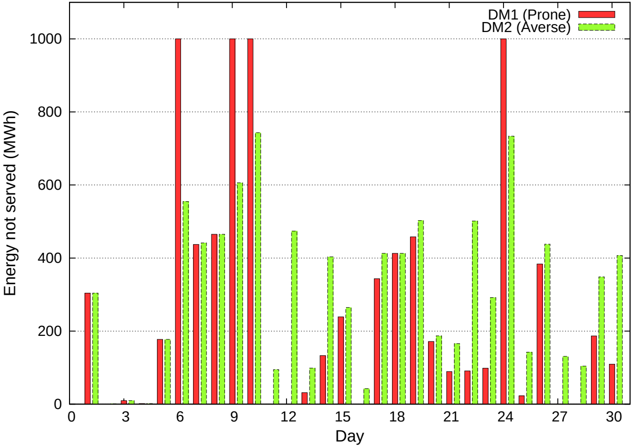
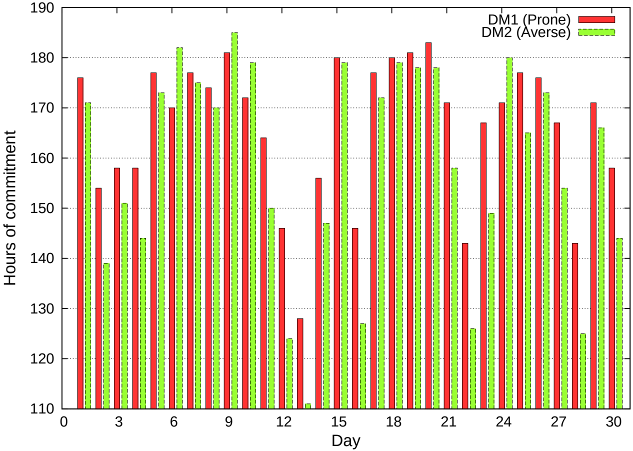
- Daily energy not served for each of the 30 days:

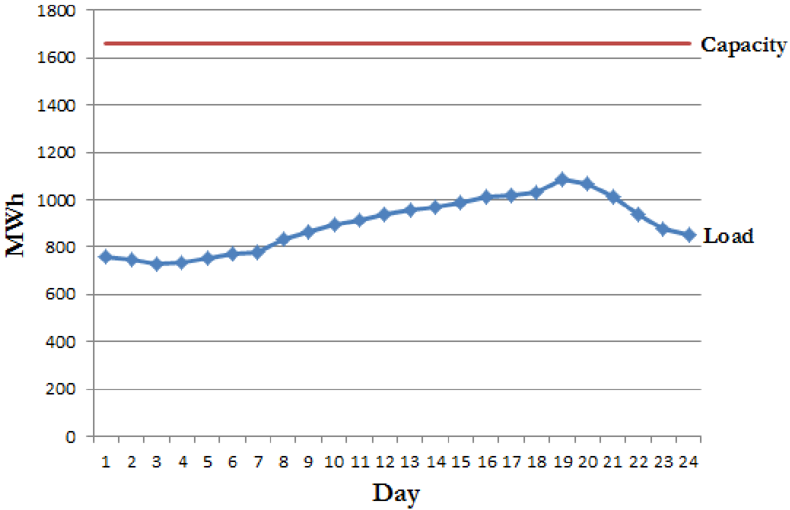


Case 1 - High load demand

- Daily hours of commitment for each of the 30 days:



Case 2 - Low load demand



Case 2 - Low load demand

- **Ranges for daily feasible values (DM1 and DM2)**:

	Cost (€)	ENS (MWh)
x_{max}	600 k	500
x_{min}	0	0

- **Scaling constants**:

Profile	k^{cost}	k^{ens}
DM1	0.846	0.154
DM2	0.812	0.188

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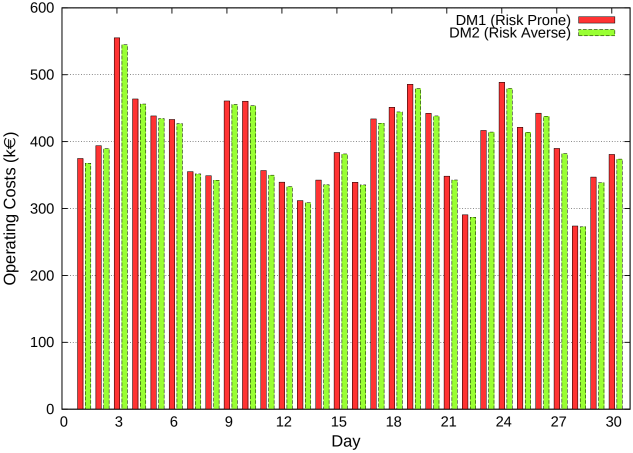

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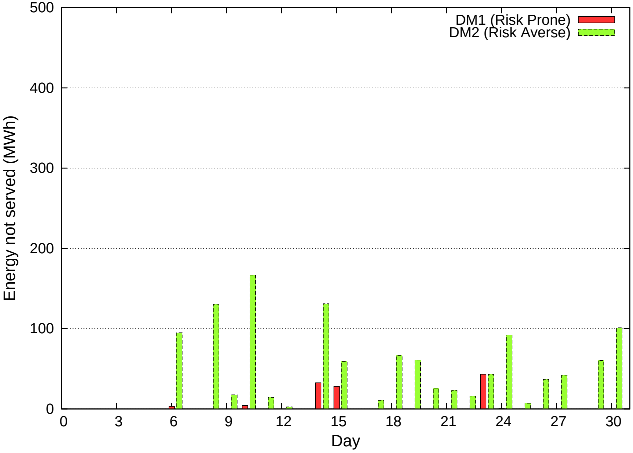

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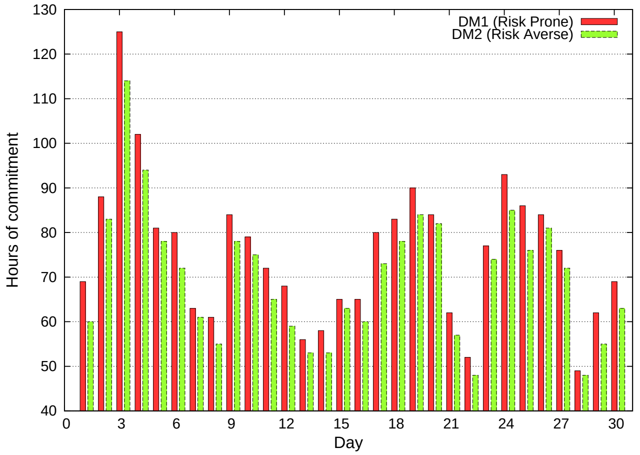

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- Main contributions:
  - The proposed MOCO model allows to **represent complex preference structures** of decision makers, whose risk attitudes towards costs and load curtailment **may vary over time**;
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