Increasing the level of operational detail in LT energy-system planning models

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Who am I?

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Supervisors: Dr. Erik Delarue, Prof. Dr. William D’haeseleer
‘Long-term optimization of electricity systems – addressing flexibility and market design issues’
Who are we?

The electricity generation systems modeling group
- Part of Mechanical Engineering department
- Main focus on the development and application of electricity generation models
- Involved in several research projects (e.g., E-highways)
- Teaching master courses on energy systems

Prof. Dr. William D’haeseleer
Dr. Erik Delarue
Kenneth Bruninx
Kenneth Van den Bergh
Kris Poncelet
Andreas Belderbos
Operational models (Unit commitment)
- Model formulation for large-scale problems
  - Mixed-integer programming
    - Tightness
    - Compactness
  - Heuristic approach
- Integration of intermittent renewables
  - Unpredictability: stochastic models
  - Variability: flexibility options
- New technologies
  - P2G, CCS, active grid elements

Expansion planning models
- TIMES framework
- Operational aspects
  - Temporal
  - Techno-economic
  - Portfolio theory approach

Impact of energy policies
- Renewables deployment
- Nuclear phase out

Impact of EU Emission Trading System
- Coal-to-gas fuel switching
- Marginal abatement cost curve for power sector

Interacting policies
- Renewable targets and EU ETS
Content

Context – Problem statement

Impact of the operational detail in LT planning models

Increasing the level of operational detail in LT planning models

Future work & conclusions
**Intermittent Renewables:**
- Variable generation
- Limited predictability (forecast errors)
- Location specific
- Capital intensive (low OPEX, high CAPEX)

**Impact on the power system:**

**Technical (Supply = Demand):**
- Limited load-following capabilities dispatchable power plants
- Need for sufficient back-up capacity
- Increased need for operating reserves
- Increased need for transmission capacity

**Economic (Profitability):**
- Lower, more volatile electricity prices
- Reduced number of operating hours
1) Context

Peak demand: 14GW

Wind turbines: 24GW
Energy system planning models - Problem statement

- Computationally Demanding:
  - Technology rich
  - Large geographical area
  - Long time horizon

=> Model simplifications:

- Temporal representation:
  - Limited number of time slices (1-12)
  - Deterministic (Short-term)

- Spatial representation:
  - Nationally aggregated regions

- Operational representation:
  - Technology-type level (no single units)
  - Limited techno-economic operational detail (E.g. no Ramping rates, start-up costs)
Impact of the level of operational detail

**Research Question:** What is the impact of the limited techno-economic operational detail in planning models?

**Methodology:**
- Island Operation (no cross-border trade)
- No grids (single node)
- No operating reserve requirements
- Imposed target share of VRES (TIMES)
The techno-economic operational detail matters

No operational constraints

Detailed operational constraints
The techno-economic operational detail matters

**Generation mix:**

- **Overestimation uptake of VRES**

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Imposed target for the share of intermittent renewables in the electric energy mix
The techno-economic operational detail matters

**Generation mix:**

- Overestimation uptake of VRES
- Overestimation inflexible baseload generation
- Underestimation flexible plants

![Generation Share Graph](image-url)
The techno-economic operational detail matters

- **Generation mix:**
  - Overestimation uptake of VRES
  - Overestimation inflexible baseload generation
  - Underestimation flexible plants

- **Underestimation Operational cost**
The techno-economic operational detail matters

- **Generation mix:**
  - Overestimation uptake of VRES
  - Overestimation inflexible baseload generation
  - Underestimation flexible plants

- **Underestimation Operational cost**

- **Security of supply**
  - Dependent on peaking equation

  ⇒ Inaccurate projections of primary fuel consumption, GHG emissions and operational costs
  ⇒ Sub-optimal investments
  ⇒ Importance increases with share of VRES
Increasing the techno-economic detail

**Detailed UC & ED**
- Chronological data (load, VRES) @ hourly (or smaller) time step
- Integer variable to track commitment status (per plant, per time step)
- => Computationally demanding

**Flexibility constraints for system planning**
- 2 approaches:
  - Direct Integration
  - Soft-link planning model to operational model
Increasing the techno-economic detail

**Direct Integration**

- Single Model
- Requires chronological data
- Computational Cost => highly stylized representation of operating constraints

**Soft-link**

- Computational cost
- Manage planning and operational model
- Feedback-loop?
- Convergence?
Direct Integration of operational constraints

- Often highly stylized
  - ‘technological ramp rates’ representing all dynamic constraints
  - ‘Flexibility constraint’:
    - assigning a positive flexibility parameter to technologies that can provide flexibility, negative flexibility to VRES, load
    - Overall flexibility $\geq 0$
  - Aim to mimic impact of detailed operational constraints
  - $\Rightarrow$ Do not directly reflect system needs or technological constraints

- Validation issues
  - Validation often lacking
  - Extrapolating calibration to historical (low VRES) to future (high VRES)
  - Method generally applicable? System-dependent calibration?
Direct Integration of operational constraints

Objective: Determine a computationally efficient, validated set of operational constraints that reflect system needs and technological flexibility constraints and associated costs

Research questions:

- Which constraints impact results most?
- Which constraints can be omitted?
- Interaction between different constraints?
- What is the impact of relaxing integer variables?
- Can we identify simplified formulations of critical constraints?
- Influence of share of VRES?
Methodology

**Clustered UC&ED Model**

**Input:**
- Technology description
- Hourly load and VRES profiles
- Fuel Prices
- Installed capacities (#plants for each technology)

**Output:**
- UC&ED
- Detailed operational constraints (each can be turned on/off)
- MILP CUC model

**System:**
- Operating reserves
- Minimum rotating units (synchronous)

**Plant:**
- Maintenance
- Minimum up and downtime
- Minimum operating point
- Ramp rates
- Part load efficiency
- Start-up costs

**Static Investment Model**

**Input:**
- Technology description
- Hourly load and VRES profiles
- Fuel Prices
- Target share VRES (0,25,50)

**Model:**
- No operational constraints
- LP Investment model

**Output:**
- Installed capacities
Methodology

- Turn different constraints on/off
- Compare to the reference case = MILP Clustered UC with all constraints

Metrics for evaluation:

- Relative Operational cost error
- Generation Mix error
  \[ \text{Gen mix error} = \sum_i |\text{share}_i - \text{share}_i^{\text{ref}}| \]
- Relative curtailment error
- (Relative) load shedding error
Intermezzo: Clustered Unit Commitment (CUC)

**General MILP UC**
- Each individual unit
- Commitment status: 1 binary variable (on/off) per plant, per time step

**Clustered MILP UC**
- Groups similar plants into clusters
  - Here: grouping based on technology
  - Lose plant-specific information (all plants within one cluster are identical)
- Commitment status: 1 integer variable per cluster, per time step
  - Reduction of number of variables
  - Reduction of the state space
  - => Reduction of computational cost

8/12/2014
Results

Which constraints matter?
Which don’t?

Chronological data needed.
Results - Pitfalls

- Impact reserve requirements strongly dependent on assumptions:
  - Technological: ramp rates, minimum operating point
  - Reserve sizing, market design

- System dependency?
  - Ratio dispatchable capacity/Peak demand
  - Amount of baseload generating units

- Linkage between different constraints need to be investigated
  - E.g., Part-load efficiency ↔ Reserves
Results

What is the impact of relaxing integer (commitment) variables?

Speed-up: 11-50
But: Strongly dependent on set-up
Future Work

- In depth analysis:
  - Operating reserves
  - Modeling of maintenance
- Interaction different constraints
- Sensitivities to technical parameters
- Integrate relaxed clustered UC in LT planning model/TIMES
- Interaction temporal and operational aspects
Conclusions

Operational detail matters:

- Over-estimation uptake RES, over-estimation inflexible baseload, underestimation flexible technologies
- Sincere underestimation operational cost
- Reserve requirements and maintenance cannot be neglected
- Importance of "dynamic constraints" (ramping, minimum up times) seems to be limited
- Some constraints are more important than others
- Relaxing integer variables has limited effect on results, large impact on computational cost
Questions?

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