Integrating Small-Scale Distributed Energy Generation, Storage, and Demand-Side Management in the Unit Commitment Problem

Johan Hurink  
*University of Twente*

Maurice Bossman  
*University of Twente*

Albert Molderink  
*University of Twente*

Vincent Bakker  
*University of Twente*

Gerard Smit  
*University of Twente*

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INTEGRATING SMALL SCALE DISTRIBUTED ENERGY GENERATION, STORAGE AND DEMAND SIDE MANAGEMENT IN THE UNIT COMMITMENT PROBLEM

Johann Hurink,
Maurice Bosman, Albert Molderink, Vincent Bakker, Gerard Smit
CONTENT

- Motivation
- Unit Commitment Problems
- Solution Approach
- Examples
ELECTRICITY GRID YESTERDAY/TODAY

[Diagram of electricity grid with production and consumption points, and energy flow]
BASIC UNIT COMMITMENT PROBLEM

- Given
  - $N$ generators
  - $X_{i, \text{max}}$: maximum capacity generator
  - $(d_1, \ldots, d_{NT})$: demand vector for all periods
  - $(r_1, \ldots, r_{NT})$: spinning reserve vector for all periods
- Solution
  - $u^i = (u^i_1, \ldots u^i_{NT})$: unit commitment of generator $i$ for all periods
  - $x^i = (x^i_1, \ldots x^i_{NT})$: production level of generator $i$ for all periods
- Objective
  - Minimize cost $f(u, x) = \sum_{n=1}^{N} f^i(u^i, x^i)$
BASIC UNIT COMMITMENT PROBLEM

\[ \begin{align*}
\min & \quad f(u, x) \\
\text{s.t.} & \quad \sum_i x_{j}^i \geq d_j \quad \forall j \\
& \quad \sum_i (u_{j}^i x_{j}^{i,\max} - x_{j}^i) \geq r_j \quad \forall j \\
& \quad u_{j}^i x_{j}^{i,\min} \leq x_{j}^i \leq u_{j}^i x_{j}^{i,\max} \quad \forall i, j \\
& \quad g^i,\text{down} \leq x_{j}^i - x_{j-1}^i \leq g^i,\text{up} \quad \forall i, j \\
& \quad u_{j}^i \geq u_{j-k}^i - u_{j-k-1}^i \quad \forall i, j, k \\
& \quad 1 - u_{j}^i \geq u_{j-k-1}^i - u_{j-k}^i \quad \forall i, j, k \\
& \quad u_{j}^i \in \{0, 1\} \quad \forall i, j \\
& \quad x_{j}^i \in \mathbb{R}^+ \quad \forall i, j
\end{align*} \]

- minimize costs
- fulfill demand
- spinning reserve
- production boundaries
- ramp up/down rates
- minimum on/off times
ELECTRICITY GRID TOMORROW

Challenges

• Distributed production
• Small scale + uncontrollable production
• Large number of generators
• Intelligent consumers
• (Local) storage
• Bidirectional flows
GENERALIZED UNIT COMMITMENT PROBLEM

NEW ELEMENTS

• M ‘pool’ of decentralized appliances (e.g. heat pumps, MicroCHPs, batteries, controllable freezers, …)
  • M is of large size
  • For each \( m \in M \) it has to be decided:
    • \( u^m = (u_1^i, \ldots, u_{NT}^i) \): unit commitment
    • Note: \( u^m \) can change the demand

• Pool can act as VPP and produce electricity
• In practice M may be split up in sub-pools \( M_1, \ldots, M_k \)
GENERALIZED UNIT COMMITMENT PROBLEM

\[
\begin{align*}
\min & \quad f(u, x) - g(p, y) \\
\text{s.t.} & \quad \sum_i x_{ij}^i + \sum_m y_{jm}^m \geq d_j + \sum_m h_j(z^m) \quad \forall j \\
& \quad \sum_i (x_{ij}^{i,\text{max}} - x_{ij}^i) \geq r_j \quad \forall j \\
& \quad u_{ij}^{i,\text{min}} \leq x_{ij}^i \leq u_{ij}^{i,\text{max}} \quad \forall i, j \\
& \quad s_{ij}^{i,\text{down}} \leq x_{ij}^i - x_{ij-1}^i \leq s_{ij}^{i,\text{up}} \quad \forall i, j \\
& \quad u_{ij}^i \geq u_{ij-k}^i - u_{ij-k-1}^i \quad \forall i, j, k \\
& \quad 1 - u_{ij}^i \geq u_{ij-k}^i - u_{ij-k}^i \quad \forall i, j, k \\
& \quad u_{jm}^m \geq u_{jm-k}^m - u_{jm-k-1}^m \quad \forall m, j, k \\
& \quad 1 - u_{jm}^m \geq u_{jm-k}^m - u_{jm-k}^m \quad \forall m, j, k \\
& \quad u^m \in \mathcal{H} \\
& \quad y_{jm}^m = l(u^m) \quad \forall m, j
\end{align*}
\]

- Gain from VPP
- Production + demand change
- Technical constraints
CHALLENGES OF GENERALIZED PROBLEM

- Already restricted versions are NP-hard
- The instances get extremely large (large set $M$)
- Several independent ‘pools’ $M$ may exist
- Decisions are taken on different ‘levels’
HEURISTIC APPROACH FOR GENERALIZED PROBLEM

- Leveled approach
  - based on a general energy model
  - Cooperation between master- and subproblems
  - ‘Divide and Conquer’
- Patterns form ‘building blocks’
  - Represents sequence of decisions for the complete time horizon for a single device or a group of devices
  - Local constraints are taken into account
  - Leads to ‘electricity flow’-values per time period
HEURISTIC PATTERNS

devices                                     electricity flow

\[ N_H \]

pattern

\[ \text{time} \]

1

1

\[ N_T \]

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LEVELLED APPROACH

- Patterns are communicated between levels

level 1: large power plants

level 2: small power plants/villages

level 3: houses

level 4: appliances
LEVELLED APPROACH

ORIGINAL PROBLEM

- Black nodes: devices for which a planning is needed
- White nodes: aggregation nodes
LEVELLED APPROACH
MASTER- AND SUBPROBLEMS

- Master problem

• pattern have to be found
• serve as input
LEVELLED APPROACH
MASTER- AND SUBPROBLEMS

- Pattern have to be found
- Serve as input

- Sub problem for villages
LEVELLED APPROACH
MASTER- AND SUBPROBLEMS

- Sub problem for small generators

- pattern have to be found
- serve as input
LEVELLED APPROACH
MASTER- AND SUBPROBLEMS

- Sub problem for houses

- pattern have to be found
- serve as input
LEVELLED APPROACH
MASTER- AND SUBPROBLEMS

- Sub problem for house with only one devise

• pattern have to be found
• serve as input
LEVELLED APPROACH
MASTER- AND SUBPROBLEMS

- Sub problem for devises

- pattern have to be found
- serve as input

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LEVELLED APPROACH

INITIAL PHASE

- pattern have to be found
- serve as input

- Solve master problem
  - model real devices ‘in detail’
  - use ‘rough’ estimation for local entities represented by aggregation nodes
- Result:
  - Schedule for real devices
  - ‘goal’-pattern for aggregation nodes
LEVELLED APPROACH
ITERATIVE PHASE

- pattern have to be found
- serve as input

- Solve sub problem for aggregation node
  - use ‘goal’-pattern of master problem as objective
  - model real devices of this sub problem
  - use ‘rough’ estimation for aggregation nodes of this sub problem

- Result:
  - schedule for real devices
  - ‘goal’-pattern for local aggregation nodes
  - update rough estimate at master problem
LEVELLED APPROACH
ITERATIVE PHASE

- Iterative process is repeated taking into account
  - new information from subproblem or
  - new goals from master problems

- Have to decide for a given problem at some level whether
  - to ask for new pattern from sub problems or
  - to update information to master problem

- Concrete optimization problems resulting for specific aggregation nodes may vary
EXAMPLE 1
POWER PLANTS AND MICRO-CHP’S

- 10 small power plants
  - total capacity 15 MW
- 5000 houses equipped with a micro-CHP forming a VPP
  - total capacity 5 MW
  - production capacity one day around 37 MWh
- Total demand 114 MWh

- Rough planning:
  - aggregate all micro-CHP’s by calculating minimum and maximum production up to time t based on heat demands of the houses
EXAMPLE 1
POWER PLANTS AND MICRO-CHP’S

Fulfilling demand only by power plants
EXAMPLE 1
POWER PLANTS AND MICRO-CHP'S

Rough planning Master Problem including micro-CHP's
EXAMPLE 1
POWER PLANTS AND MICRO-CHP’S

Final detailed planning including micro-CHP’s
EXAMPLE 1
POWER PLANTS AND MICRO-CHP'S

Difference rough and detailed micro-CHP planning
EXAMPLE 2
POWER PLANTS, MICRO-CHP’S, HEAT PUMPS, EL. CARS, FREEZERS, BATTERIES
QUESTIONS

Webpage on Energy Research University of Twente

et.utwente.nl