Decentralized Control of RES by Fast Market-based MAS

IRP 1.2

Hazem A. Abdelghany
Ph.D. Candidate, TU Delft

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Work in Progress

Optimal bidding with planning ahead of DERs in real-time market-based control under uncertainty

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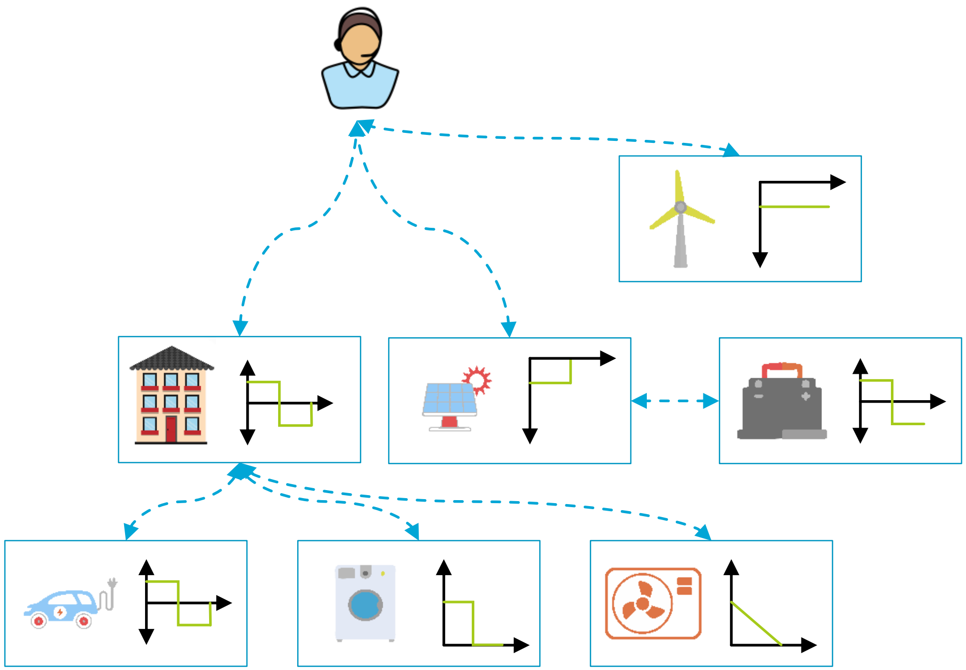
Introduction

- Flexibility utilization through real-time market-based control.
- Flexible/inflexible device agents in automated market.
- Agents bid subject to
  - Uncertainty.
  - Local constraints.
  - Local objective.
- Market is cleared, clearing price communicated.
- Local control actions are taken based on market price and bid.



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Introduction

Top-down Switching

- No privacy/ No autonomy.
- Highly scalable/ No openness.
- Response unknown.

Price-based Control

- Full privacy/ Full autonomy.
- Highly scalable/ Open.
- Response unknown.

Centralized Optimization

- No privacy/ No autonomy.
- Poor scalability/ No openness.
- Response known.

Market-based Control

- High privacy/ High autonomy.
- Highly Scalable/ Open.
- Response known.

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Challenges

Lack of planning ahead in real-time MBC

- Leads to Sub-optimal use of flexibility over time.
  - Multi-settlement markets:
    - Complex bidding, risk of gaming.
  - Iterative/negotiation mechanisms:
    - Long/uncertain clearing time, dependence on initial conditions.
  - Cooperative mechanisms:
    - Not suitable with self-interested agents.
  - Central scheduling:
    - Lack of privacy.

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Research Problem

Inefficient utilization of flexibility within distribution grids with high penetration of DERs.

- Optimal bidding with planning ahead
- Effect of regularly updated price predictions
- Decentralized network constraint management

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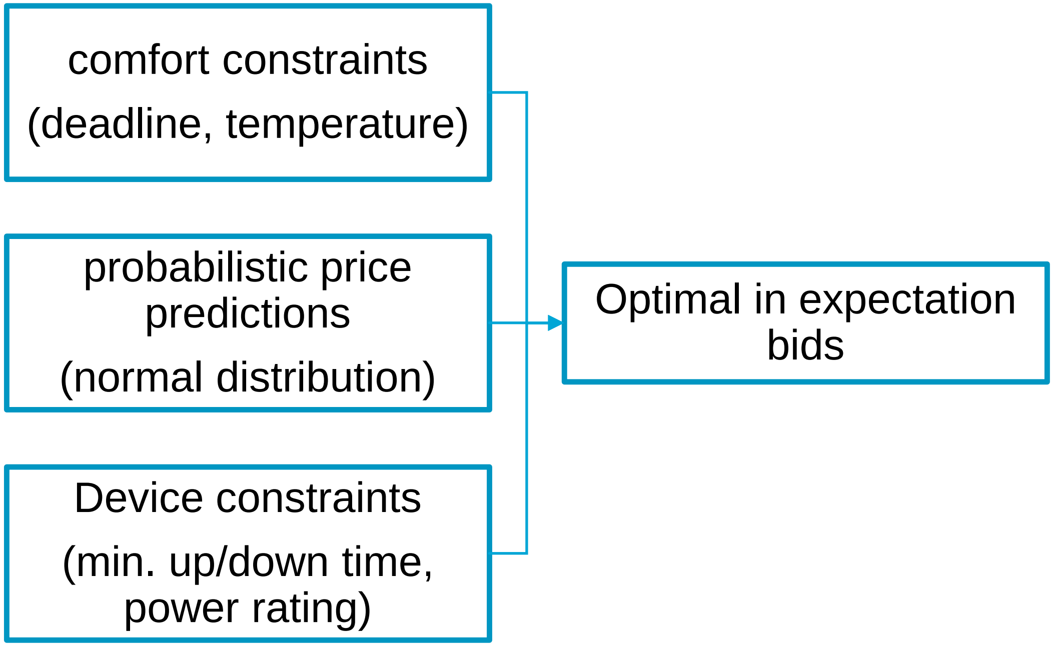
Overview

- Optimal-in-expectation bidding algorithms.
- Speed, scalability are required.
- Limitations
  - Small computational capability.
  - Heterogeneity.
- Challenges
  - Continuous state-space, action space.
  - Time dependency.



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Methodology

- In Literature,
  - Uncertainty in neglected (i.e. deterministic planning).
  - Simplified models/assumptions.
  - Complex, unscalable.

- MDP,
  → Planning over multiple time-steps with uncertainty.
- Threshold policies,
  → Scalability.
- Specialized algorithms,
  → Heterogeneity.

Complete information

Optimal in expectation

Deterministic

Naive

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MDP Model

- Discrete time steps indexed by t.
- First bid is formulated and submitted at $t = 0$.
- The last bid a device submits is formulated and submitted at $t = T - 1$.
- T is the deadline set by the device owner.
- Price Predictions $\overline{P}_t, \sigma_t$.
- A device's energy reserve/state-of-charge (SOC) has a minimum and maximum $Emin$, $Emax$ at any time.
- A device has a power rating of D.
- e is the required energy to fulfill a device's task.
- the state of a device at any time step is a vector of the required energy to fulfil the device's task e_t, and the real-time price $s_t = (e_t, P_t)$.
- Actions are represented by $a \in [-1, 1]$.

$$c(s_t, a) = aP_tD + c_\mathrm{i}(s_t, a)$$

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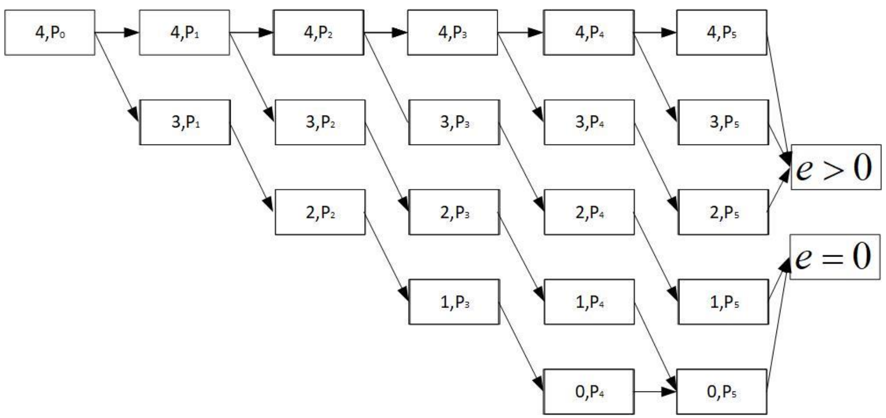
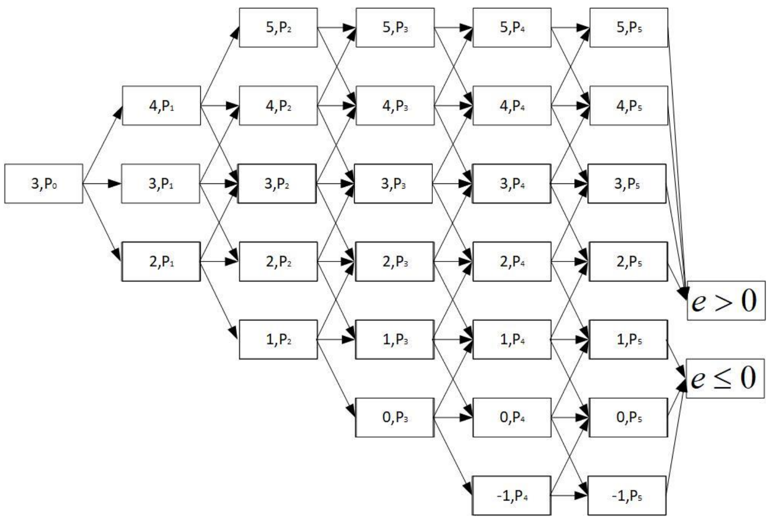
MDP Model



MDP model for uninterruptible time-shiftable device



MDP model for electric vehicle

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Uninterruptible time-shiftable devices

$$A_t = \begin{cases} \{1,0\} & e_t = e_0 \\ \{1\} & 0 < e_t < e_0 \\ \{0\} & e_t = 0 \end{cases}$$

$$e_t \in \{\max(0, e_0 - Dt), ...e_0\} \; \forall t$$

$$\Pr\left(s_{t+1} = (j, P) | s_t = (e, P_t), a_t = a\right) = \begin{cases} \Pr(P_{t+1} = P) & j = e - aD \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

$$V(s_T) = \begin{cases} 0 & e_T = 0 \\ \infty & \text{otherwise} \end{cases}$$

$$V(s_t, a) = c(s_t, a) + \mathbb{E}V(s_{t+1})$$

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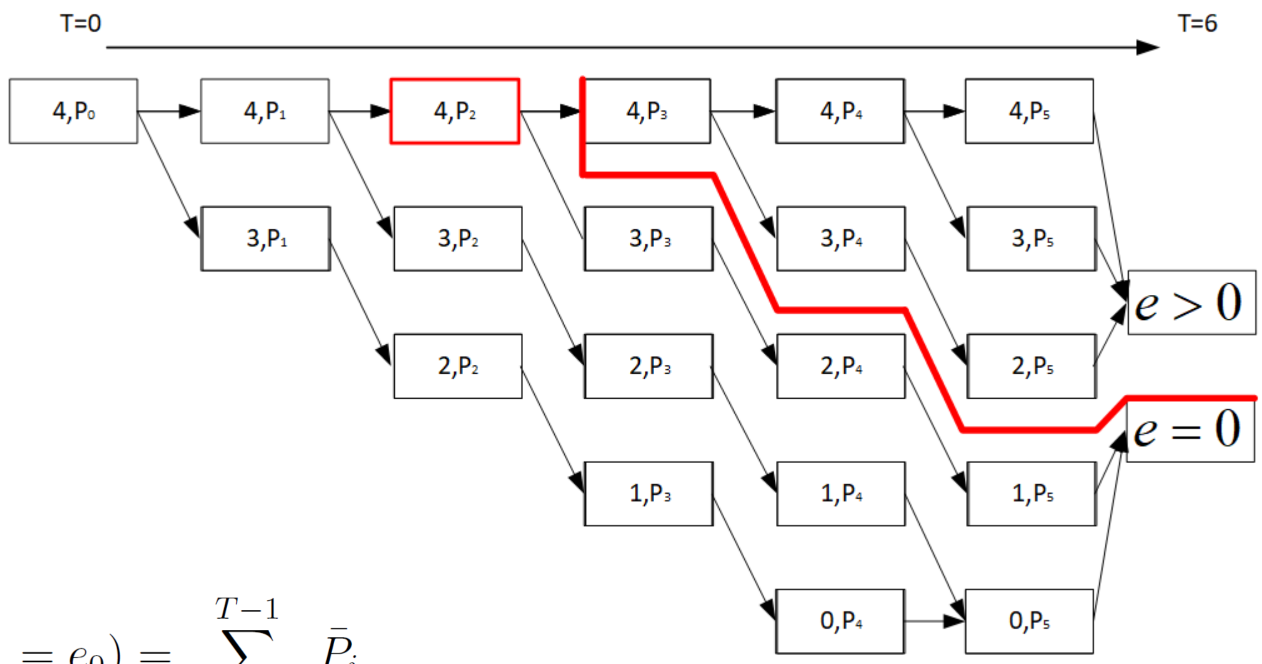

$$C_0(T-\frac{e_0}{D}) = \mathbb{E}V^*(s_{T-\frac{e_0}{D}} = e_0) = \sum_{i=T-\frac{e_0}{D}}^{T-1} \bar{P}_i$$

$$P_t^{th} = \max\left\{\min\left\{\left(C_o(t+1) - \sum_{i=1}^{D-1} \bar{P}_{t+i}\right), P_{t,max}\right\}, P_{t,min}\right\}$$

$$C_o(t) = \phi_h(t).C_o(t+1) + \phi_l(t).\left[average\left(P_{t,min}, P_t^{th}\right) + \sum_{j=1}^{D-1} \bar{P}_{t+j}\right]$$

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Optimal bidding policy

$$b^*(t) = \begin{cases} 1 & 0 < e_t < e_0 \\ 0 & e_t = 0 \\ 1 & e_t = e_0,\, t \geq T - \frac{e_0}{D} \\ 1 & e_t = e_0,\, t < T - \frac{e_0}{D},\, P_t \leq P_t^{\mathrm{th}} \\ 0 & e_t = e_0,\, t < T - \frac{e_0}{D},\, P_t > P_t^{\mathrm{th}} \end{cases}$$

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Electric Vehicles

$$e_0 = E_{T,\mathrm{req}} - E_0$$

$$E_t = E_{T,\mathrm{req}} - e_t.$$

$$A_t = \begin{cases} \{0, -1\} & E_t = E_{\max} \\ \{1, 0, -1\} & E_{\min} < E_t < E_{\max} \\ \{0, 1\} & E_t = E_{\min} \end{cases}$$

$$e_t \in \{\max\left(e_{\min},\, e_0 - Dt\right), \ldots, e_0, \ldots, \min(e_{\max},\, e_0 + Dt)\}$$

$$c_{\mathrm{i}}(s_t, a) = \begin{cases} (1-\eta) D P_t & a = -1 \\ 0 & \text{otherwise} \end{cases}$$

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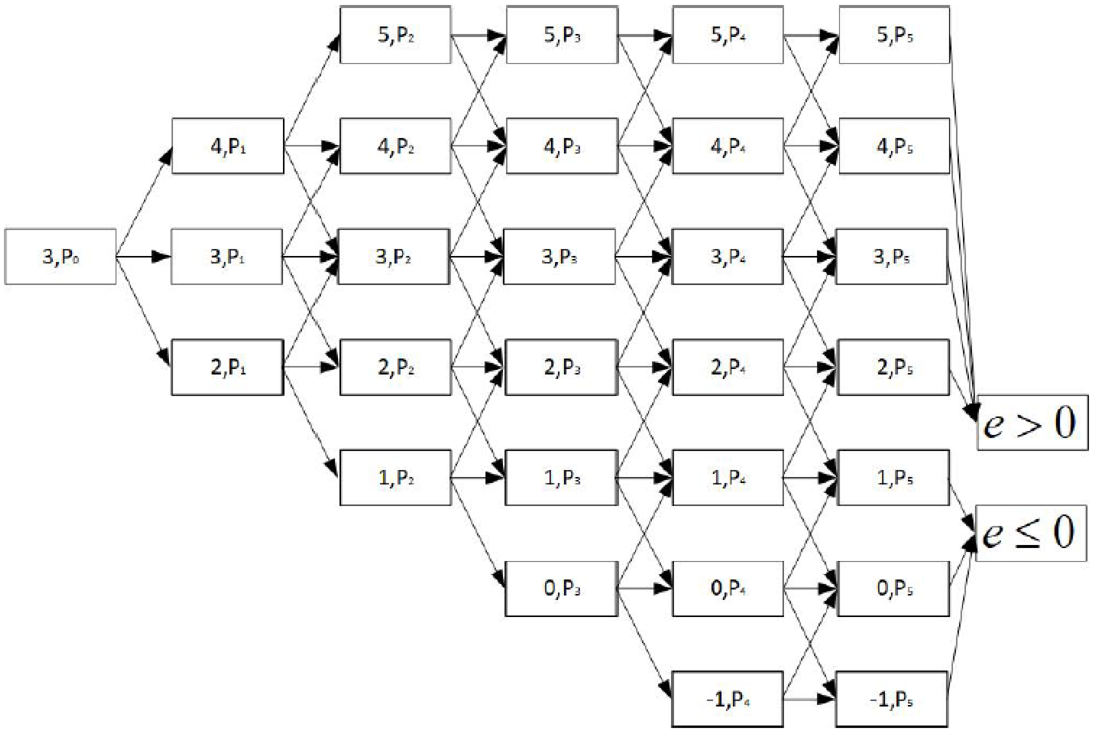
Electric Vehicles



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Optimal Bidding Policy

$$
b^*(t) = \begin{cases}
1 & e_t \geq (T-t)D \\
-1 & e_t \leq (T-t)D \\
1 & e_t = (T-t-1)D \vee e_t = e_{\max},\ P_t \leq P_t^{\mathrm{th}} \\
0 & e_t = (T-t-1)D \vee e_t = e_{\max},\ P_t > P_t^{\mathrm{th}} \\
0 & e_t = -(T-t-1)D \vee e_t = e_{\min},\ P_t \leq P_t^{\mathrm{th}} \\
-1 & e_t = -(T-t-1)D \vee e_t = e_{\min},\ P_t > P_t^{\mathrm{th}} \\
1 & \text{otherwise},\ P_t \leq P_t^{\mathrm{th,\,low}} \\
0 & \text{otherwise},\ P_t^{\mathrm{th,\,low}} < P_t \leq P_t^{\mathrm{th,\,high}} \\
-1 & \text{otherwise},\ P_t > P_t^{\mathrm{th,\,high}}
\end{cases}
$$

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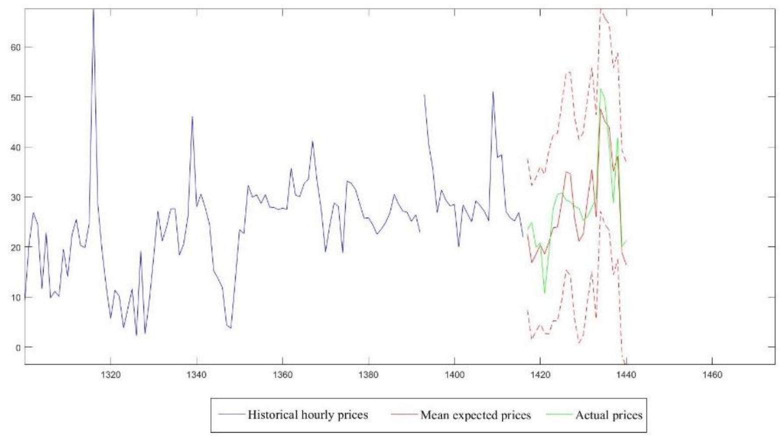
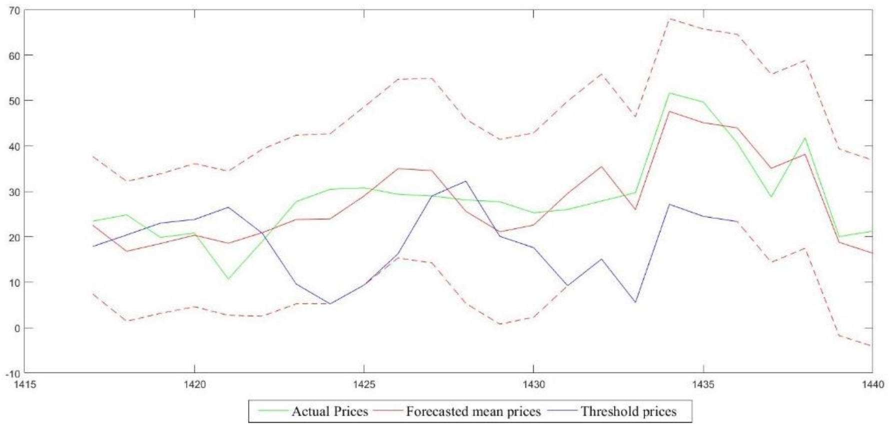
Preliminary Result

Price forecasts for one day



Threshold prices vs. actual prices



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