A unified decision making framework for supply and demand management in microgrid networks

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The concept of 'Smart Grids'

- Solution concept aimed at improving traditional power grid operations.
- Distributed energy network composed of intelligent nodes (or agents) that can either operate autonomously or communicate and share energy.

Objectives that are considered

- Demand side management
  - Minimize the peak Demand : Dynamic Pricing and integrating the customers participation.
  - Minimize the cost of consumption of power.
- Supply side Management
  - Minimize the Demand-Supply power deficit.
  - Minimize the use of fossil fuels.

What are 'Microgrids'

- A microgrid encompasses a networked group consisting of renewable energy generation sources, battery storage with the aim of providing energy to small areas.
- An important alternative to the conventional scheme with large power stations transmitting energy over long distances.
- Can operate in Island Mode or Cooperative mode.

Introduction

- We consider two problems - one on the supply side and another on the demand-side.
- On supply-side : Energy sharing among microgrids with the goal of maximizing profit obtained from selling power while meeting the desired customer demand.
- On Demand-side : Optimally scheduling the time-adjustable demand - i.e., of loads with flexible time windows in which they can be scheduled.

Setup

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- At every time instant t, microgrid i gets a demand d_t^i from its customers.
- The time-adjustable demand is also known as 'Activities of Daily Life (ADL)'.
- Each microgrid i has a set of ADL jobs ($J_t^i = \{\gamma_1^i, \ldots, \gamma_n^i\}$), where the j^{th} ADL job $\gamma_j^i = (a_j^i, f_j^i)$.

Setup

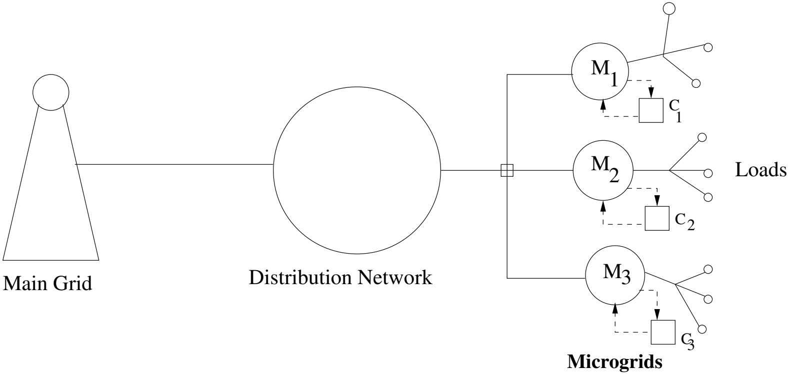

Figure: Cooperative Energy Exchange Model

Setup

Each microgrid i at every time instant t, has to decide on the following:
(a) Amount of energy it needs to buy (sell).
(b) The subset of ADL jobs it needs to schedule.

Model

- We formulate this problem in the framework of Markov Decision Process (MDP) [1].
- MDP is characterized by $< S, A, P, R >$.
- We divide a day into t decision time units.
- The state s_t^i at time instant t for the microgrid i is as follows:

$$s_t^i = (t, nd_t^i, p_t, J_t^i), \tag{1}$$

where the net demand $nd_t^i = r_t^i + b_t^i - d_t^i$. Here b_t^i is the battery level of microgrid i at time t, and p_t denotes the price per unit energy.

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  where the net demand $nd_t^i = r_t^i + b_t^i - d_t^i$. Here b_t^i is the battery level of microgrid i at time t, and p_t denotes the price per unit energy.
- If $nd_t^i > 0$, then there is excess of power after meeting the non-ADL demand and if $nd_t^i < 0$, there is a deficit in power even to meet the non-ADL demand.

[1] Sutton, Richard S., Andrew G. Barto, and Francis Bach. Reinforcement learning: An introduction. MIT press, 1998.

Model

- Actions : Each microgrid need to make two decisions : u_t^i and v_t^i.
- Goal: Maximize profit.
- Single-stage reward for microgrid i:

$$
\begin{aligned}
r^i(s_t^i, u_t^i) = p_t * u_t^i + c * min(0, nd_t^i - u_t^i) \\
- c * \sum_{k=1}^{n} I_{\{f_k^i = 0\}} a_k^i,
\end{aligned}
\tag{2}
$$

where c (≥ 0) is penalty per unit of unmet demand.

Model

- We formulate this problem in the Average-cost MDP setting, where the objective is to maximize the expected average profit of the microgrids
- The long-run average reward objective function $J(\pi)$ of the microgrid i for a given policy π is given as follows:

$$J(\pi) := \lim\sup_{n \to \infty} \frac{1}{n} E\left(\sum_{t=0}^{n-1} r^i(s_t, u_t) \middle| \pi \right), \tag{3}$$

where $E(.)$ denotes the expected value. Here we view a policy π as the map $\pi : S \to A$ which assigns for any state s, a feasible action a.

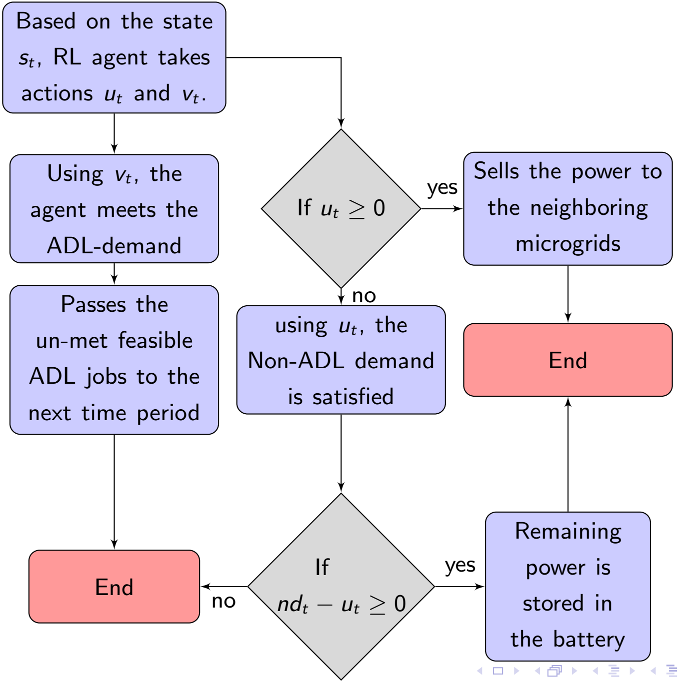
Algorithm

- We do not assume any model of the system (i.e., probability transition model of the demand, prices).
- We apply the Relative Value Iteration (RVI) based Q-Learning algorithm [2]. The Q-values $Q^n(s, u)$

$$Q^{n+1}(s,u) = Q^n(s,u) + \alpha(n)(r(s,u,s^{'})+ max_u Q^n(s^{'},u) - max_u Q^n(s_0,u) - Q^n(s,u)), \quad (4)$$

where α is the learning rate and s_0 is any prescribed state.

[2] Abounadi, Jinane, D. Bertsekas, and Vivek S. Borkar. "Learning algorithms for Markov decision processes with average cost." SIAM Journal on Control and Optimization 40.3 (2001): 681-698.


Based on the state s_t, RL agent takes actions u_t and v_t.
Using v_t, the agent meets the ADL-demand
Passes the un-met feasible ADL jobs to the next time period
End
If $u_t \geq 0$
yes
no
Sells the power to the neighboring microgrids
End
using u_t, the Non-ADL demand is satisfied
If $nd_t - u_t \geq 0$
yes
no
Remaining power is stored in the battery

Experimental setup

- We used the RAPSim [3] simulator for estimation of the renewable energy.
- We implement our models on a network with three microgrids and five microgrids respectively.

[3] Pochacker, Manfred, Tamer Khatib, and Wilfried Elmenreich. "The microgrid simulation tool RAPSim: Description and case study." In Innovative Smart Grid Technologies-Asia (ISGT Asia), 2014 IEEE, pp. 278-283. IEEE, 2014.

Implementation

For comparison purposes, we also implement the following models.

- **Greedy-ADL model**: Here, microgrids exhibit greedy behavior, share power only after filling their respective batteries completely.
- **Non-ADL model**: Here, ADL demand is treated as normal demand. Penalty is levied immediately if the demand is not met in the current time slot.

Simulation setup

- The number of decision time periods (t) in a day is taken to be 4.
- The maximum size of the battery (B_t^i) and maximum power that a microgrid can obtain from the main grid (M_t^i) are considered to be 8 and 10 energy units respectively.

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- At each microgrid, we consider 3 ADL jobs, $\{\gamma_1^i = (1,2), \gamma_2^i = (1,3), \gamma_3^i = (2,4)\}$ at the start of the day, where ADL job $\gamma_j^i = (a, b)$ requires a units of energy within b time slots.

- We use the average profit obtained by each microgrid as a performance metric to evaluate the models.

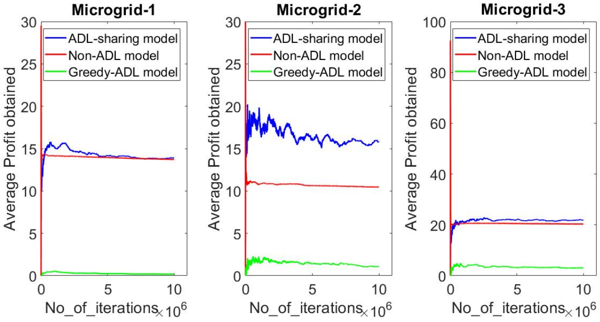


Figure: Convergence of algorithms when $c = 0$ for a three microgrid network.

Results

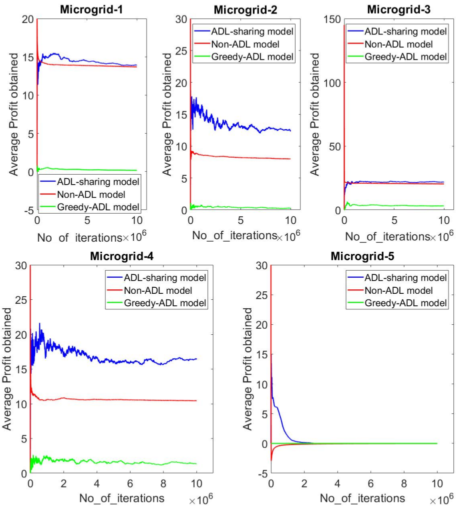


Figure: Convergence of algorithms when $c = 0$ for the five microgrid network.

Results

We run the trained models for 1000 runs to obtain the average reward in each case.

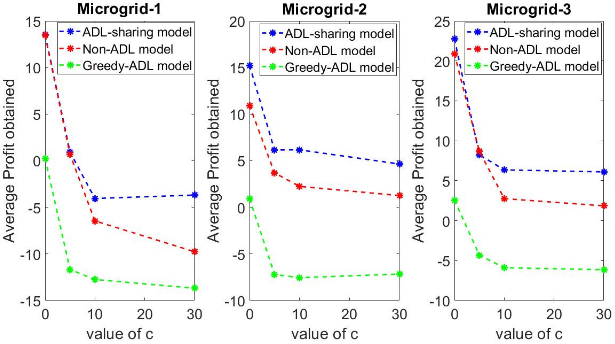
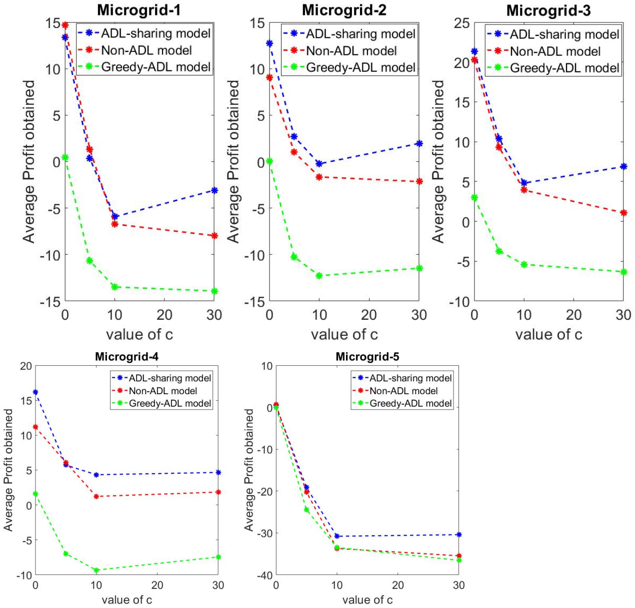


Figure: Comparison of algorithms on the three microgrid network



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Discussion

- ADL-Sharing model provides more profits to the microgrids by:
  - Intelligently sharing the power with the neighboring microgrids.
  - Making optimal use of flexible ADL jobs.

Future Work

- We would like to consider the pricing mechanism for microgrids.
- Asynchronous multiagent RL algorithms will play a role here.
- We would like to use efficient RL algorithms with function approximation to scale the proposed algorithms.

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Thank You