

Multiagent Coordination for Demand Management with Energy Generation and Storage

(Extended Abstract)

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ABSTRACT

This paper focuses on demand management of electricity in consumer groups that form a cooperative. We propose a novel multiagent coordination algorithm to shape the energy consumption of the cooperative in the presence of energy generation and storage. To coordinate individual consumers under incomplete information and optimize the energy storage decision, we decompose the problem to two subproblems: (a) optimizing demand profile of consumers given storage policy and (b) optimizing storage policy given demand profile of consumers. We prove that our algorithm converges to the optimal solution. Simulation results based on real world consumption data indicate scalability of our algorithm with respect to the number of agents and consumption slots.

Categories and Subject Descriptors

I.2.11 [Artificial Intelligence]: Distributed AI-MAS, Coordination

General Terms

Algorithms

Keywords

Multiagent Coordination, Energy, Convergence

1. INTRODUCTION

This paper studies an energy consumption cooperative, whose members' electricity demand is coordinated by a mediator agent with the purpose to reduce total energy consumption cost and avoidance of demand peaks. The paper is inspired by [1, 2]; but we consider the presence of generation and storage facilities within the cooperative, which has not been addressed in previous literature.

To solve the demand management problem of the cooperative, we design an iterative algorithm consisting of two primary steps (a), the coordinator assumes a profile for charging and discharging the battery and uses virtual price signals to coordinate the consumers to obtain an optimal demand profile for the consumers; (b) the coordinator uses the demand profile given by the consumers to compute an optimal storage profile. We prove that this iterative algorithm converges to an optimal demand profile for the agents.

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We also perform simulations based on real world data which show that the number of iterations taken for the agents to converge to the optimal solution is not sensitive to the size of the cooperative.

2. PROBLEM FORMULATION

Our model is based on a consumer cooperative with N members, who plan their electricity demands within a planning period with M discrete time slots. The cooperative owns a renewable energy generation facility and a storage facility. A central coordinator ("she") operates the storage facility and purchases electricity from the market on behalf of the cooperative.

Each agent chooses its own electricity demand profile. Let \mathbf{R} be an $N \times M$ matrix where each entry r_{ij} is the demand of agent i for time slot j and each row of the matrix, \mathbf{r}_i , is the *demand profile* of agent i , $i \in \{1, 2, \dots, N\}$. Define the total aggregated demand in time slot j as $\rho_j = \sum_{i=1}^N r_{ij}$. The demand profile of each agent \mathbf{r}_i must satisfy their *private* individual constraints set, which is represented by a convex polytope \mathcal{X}_i (see [2])

Agents' demands are satisfied by the market and the electricity generator. In each time slot j , the cooperative can buy as much as h_j amount of electricity from the market at a known price p_j , and receive green generation g_j for free. Let \mathbf{h} , \mathbf{p} and \mathbf{g} represent the $N \times 1$ vector formed by concatenating h_j , p_j and g_j , respectively.

The central coordinator operates the storage facility: in each time slot j , she decides the amount of energy, y_j to be charged ($y_j > 0$) or discharged ($y_j < 0$). The amounts are bounded by the maximum (dis)charging amount d during each time slot, and the capacity of the storage facility u : $0 \leq \mathbf{A}\mathbf{y} \leq \mathbf{u}$ and $-\mathbf{d} \leq \mathbf{y} \leq \mathbf{d}$, where \mathbf{A} is a lower triangular matrix with elements 1, and 0 , $\mathbf{y} = [y_1, \dots, y_j, \dots, y_M]^T$, $\mathbf{u} = [u, \dots, u, \dots, u]^T$ and $\mathbf{d} = [d, \dots, d, \dots, d]^T$.

3. COORDINATION ALGORITHM

3.1 Optimal Demand Profile without Storage

The iterative algorithm for the centralized problem without storage via *virtual price signals* is:

1. The central coordinator sends initial virtual price signals, denoted by s_{ij} , for each period j to each agent i .
2. After receiving s_{ij} , each agent individually calculates its optimal demand profile \mathbf{r}_i and reports it back to the coordinator.
3. Based on the reported demand profile \mathbf{R} , the central coordinator updates the virtual price signal and sends it to each agent.
4. Given new signal, each agent chooses new demand profile \mathbf{r}'_i .

Stopping criterion: If no agent changes its demand profile \mathbf{r}_i during one iteration, end; Otherwise, set $\mathbf{R} = \mathbf{R}'$ and go back to step (3).

3.2 Solution Approach with Storage

One possible approach for the general problem with storage would be to decompose the problem to two subproblems, i.e., optimizing the demand profile given the storage policy and optimizing the storage policy given the demand profile. We design the overall coordination algorithm as shown in Figure 1. The basic intuition is that after either step 2 or step 3, the aggregate energy cost is reduced.

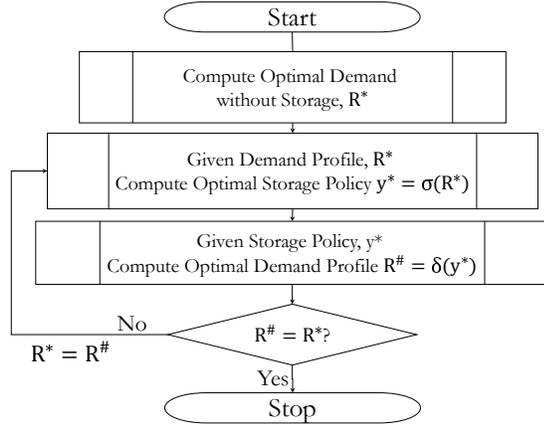


Figure 1: Algorithm Overview

Optimal Storage Policy: The storage policy given the demand profile can be solved by linear programming.

Optimal Demand Profile: The problem for centralized optimal demand profile given a storage policy is coupled with the storage policy y_j^* . Similar to §3.1, we can design virtual price signals and iterative algorithms to induce the centralized optimal consumption profiles. However in the current problem, the marginal cost associated with unit demand shifting also depends on the storage profile. Thus we use first in first out (FIFO) policy to calculate the marginal unit cost of the energy discharged.

THEOREM 1. \mathbf{R}^* is optimal demand profile with storage, if $\mathbf{y}^* = \sigma(\mathbf{R}^*)$ and $0 < \rho^* + \mathbf{y}^* - g < h$.

4. SIMULATION

In this section, we aim to evaluate the performance of our algorithm and quantify the impact of energy generation capacity and storage capacity on the energy cost. For consumers, we used the Irish Commission for Energy Regulation (CER) electricity consumption data set¹ to identify two important classes of consumers with shared characteristics.

Table 1 shows that the number of rounds does not increase significantly as the number of agents increase. The results indicate the scalability of our algorithm with respect to the number of agents.

Figure 2a shows the percent of cost reduction is almost linearly increasing with the capacity of the energy generation. Figure 2b shows that the percent of cost reduction is increasing with the storage capacity with a diminishing return.

5. CONCLUDING REMARKS

¹The data set is available at <http://www.ucd.ie/issda/data/commissionforenergyregulation/>.

Table 1: Performance of the Overall Coordination Algorithm

Number of agents	Number of rounds	
	Mean	SD
20	7.2	3.7
40	8.2	2.7
60	8.4	1.3
80	8.2	0.2
100	8.6	1.8

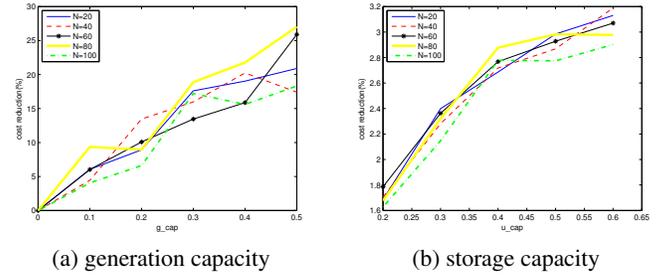


Figure 2: Impact of generation/storage capacity on cost reduction

In this paper we propose a novel multiagent coordination algorithm to shape the energy consumption of a consumer cooperative in the presence of energy generation and storage. To coordinate individual consumers under incomplete information with the presence of storage we decompose the problem into two sub-problems: (a) optimizing demand profile of consumers given storage policy and (b) optimizing storage policy given demand profile of consumers. We have proven that our algorithm converges to the optimal solution. We have also presented simulation results based on real world consumption data to show the performance of our algorithm.

6. REFERENCES

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