Multi-Agent Mechanism for Efficient Cooperative Use of Energy

(Extended Abstract)

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ABSTRACT

Promoting the development of renewable energies and the efficient and intelligent use of energy could be achieved through making adaptive consumer demands to energy supply. In this paper, we propose a mechanism based on three time scales, year, day and hour and three sets of agents, consumers, aggregators and providers to adapt consumption to production. We propose to use in this model the breakthroughs in energy : grouping consumers to reduce deviation in aggregated demand, *Time-of-Use* and *Prediction-of-Use* tariff schemes, storage capacities, shifting and the possibility for consumers to produce energy.

CCS Concepts

•**Computing methodologies** → **Multi-agent systems;** *Multi-agent planning;*

Keywords

Negotiation; Multiagent; Protocol; Energy Management

1. INTRODUCTION

Today, research on energy focuses on energy supply and mix, whereas consumption should be raised first. Indeed, the technological progress allows buildings to be equipped with generator units, as well as optimization and monitoring tools of their consumption. The use of the new storage capacities (Electric vehicles, household batteries) in the home looks promising to manage this complexity. The new meters allow sending and receiving data, allowing to balance supply and demand given new tariff scheme. Indeed, the current tariff schemes are insufficiently flexible to adapt the supply and demand on a continuous way. Lots of tariff schemes have been created [2] to address this issue. One of the most studied, *Time-of-Use* (TOU) is founded on slot of energy demand and gives different prices according to the slot. The tarification *Prediction-of-Use* (POU) [7] is based on a forecast base demand that the consumer gives to his provider. Every deviation from this base demand involves the payment of a penalty. On one side, the TOU scheme allows proposing a tariff according to the demand but doesn't take into account the forecast aspects. On the other side, the POU scheme incites consumers to forecast exactly their demand but doesn't propose a tariff which depends on the supply and the demand. Moreover, other works study the coalition formation or agent cooperatives with the aim to reduce energy costs [6, 1, 5, 4]. This reduction is often reached by the transmission of a price signal which incites consumers to buy energy when prices are low and shift consumptions when prices are high. In this paper, we propose a multi-agent architecture which allows combining both tariff schemes. In this architecture three kinds of agents are modeled, consumers, providers and aggregators and three time scales are considered. We consider that consumers can produce their energy, have storage capacities and group into cooperatives. The aggregator agent role is to locally match the production and the consumption of the cooperative by pooling local information and productions. We propose a negotiation model which relies on three interaction levels according to three time scales : the first level supports interactions between providers and aggregators for the annual contract negotiation. The second level supports interactions between aggregators and consumers for the daily contract, allowing coordination between agents. Last level is dedicated to the hourly contracts including an amount of energy and a tariff. The POU properties should be preserved : not be incited to consume to avoid penalties and not consuming should be viewed as the best option. The respective commitments for consumers (to respect some consumption limits) and providers (the tariffs never exceed a maximum price) guarantee a band of price for the consumers and a band of demand for the providers. The model based on cooperatives should incite the agents to join a cooperative with regard to views on final profit they will earn.

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2. MODEL OF THE AGENTS

We consider three sets $\mathcal{A}_U, \mathcal{A}_A, \mathcal{A}_F \in \mathcal{A}$ of agents where $\mathcal{A}_U$ represents the set of consumers, $\mathcal{A}_P$ the set of providers and $\mathcal{A}_A$ the set of aggregators which manage interactions between providers and cooperatives of consumers.

The behaviour of an aggregator agent: an aggregator agent manages the energy stream within a cooperative. This agent contracts with providers to meet internal demand of the cooperative. We differentiate three kinds of contracts: (i)-the annual contract sets the maximum tariff applicable by a provider and the maximal and minimal demand requested by the cooperative at each slot. (ii)-

The daily contract concerns a set of hourly contracts and applies the TOU tariff scheme. (iii)-The hourly contract is composed of a tariff, an amount of energy and the number of slots. POU tariff scheme is applied on hourly contracts taking as baseline what have been negotiated in the daily contract.

Optimization model of a consumer agent : let a_u be an agent representing consumer u and $\mathcal{T}$ the set of slots. We assume that a_u is represented by a tuple <$\mathcal{Q}^{min}$, $\mathcal{Q}^{max}$, b, q, s, soc, α, p^{max}, p, σ^b, σ^p>, with : $\mathcal{Q}^{min}$ (resp. $\mathcal{Q}^{max}$), the minimum (resp. maximum) amount of energy requested by a_u whatever the slot t. b, is the energy amount a_u needs at slot t, $q \in [\mathcal{Q}^{min}, \mathcal{Q}^{max}]$, is the energy amount requested by a_u at slot t. q may differ from b since the needs may partially be compensated by the stored energy and the produced energy, etc. s is the storage capacity of a_u. soc_- represents the state of charge and soc_+ represents the remaining storage capacity, $soc_- + soc_+ = s$. p represents the energy produced by a_u renewable generator, $p \leq p^{max}$. σ^b is the forecast mean error of the consumer consumption. The deviation between the forecast of consumer's needs and the real needs follows a normal law $\mathcal{N}(b, \sigma^b)$ (see [3]). σ^p is the forecast mean error of the consumer production. The deviation between the forecast of consumer's production and the real production follows the normal law $\mathcal{N}(p, \sigma^p)$. Every day, consumer agent minimizes formula (1) (under some constraints, not detailed here) :

$$\min \sum_{t=1}^{24} tr_t.q_t \quad (1)$$

With tr_t, the tariff at slot t and q_t the energy requested at slot t.

Decision model of provider agents: Each provider agent $a_f \in \mathcal{A}_F$ has a production capacity $p_f^t \in [0; p_i^{MAX}]$ where p_f^{MAX} is the maximum production capacity of the agent. We also suppose that each agent has an optimal production capacity p_f^{OPT} which allows him to maximize profit, with $0 < p_f^{OPT} < p_f^{MAX}$. The tariffs proposed by the provider tend to be low when the energy demand is close to his optimal production p_f^{OPT}. The tariffs become higher as the demand moves away from the optimal production. Providers make consumers pay a subscription. The coefficients A_f and pen_f represent the subscription and the penalty costs of provider f. Moreover, each provider has a maximal tariff tr_{MAX} above which nobody is willing to buy his energy. The provider agent uses a function $\mathcal{F}$ which returns a tariff according to an amount of energy, $\mathcal{F} : \mathcal{Q} \rightarrow \mathcal{T}r$ where $\mathcal{Q}$ is an amount of energy and $\mathcal{T}r$ a tariff.

$$\mathcal{F}_f(q_a^{tot}) = tr_f^{OPT} + tr_a^{max}(1 - e^{(\frac{-|p_f^{OPT} - q_a^{tot}|}{tr_a^{max}})}) \quad (2)$$

tr_f^{OPT} is the minimal tariff proposed by the provider when $p_f^{OPT} = q_f^{tot}$ and $tr_f^{max} \in [0, tr_{MAX}]$ is the coefficient negotiated in the annual contract.

Optimization model of aggregator agents Aggregator agents have to manage the negotiations of the different contracts with providers, which can be formulated as a linear program (3). The goal is to get the lower energy price.

$$\min \sum_{f \in \mathcal{F}} A_f.x_a + pen_f.\sigma_{coop}.\mathcal{H}.y_a \quad (3)$$

With x_a the maximal amount of energy requested by the aggregator agent to provider f, $y_a = \mathcal{Q}^{max} - \mathcal{Q}^{min}$, $\mathcal{H}$ is the number of hours in a year and σ_{coop} the mean deviation consumption of the cooperative. x_a affects the subscription costs and y_a affects the penalty cost.

3. NEGOTIATION MECHANISM

The multilevel mechanism we propose takes into account information feedback from one level to another. The first level, Annual, interacts with the two other levels, Daily and Hourly levels.

Negotiation of the annual contract : the distribution of the demand according to the different offers of the providers results from (3). We choose to apply the MCP but our model allows to use other protocols: (i)-Each consumer agent sends his consumption profile to the aggregator. (ii)-The aggregator computes the cooperative profile and the distribution of the demands between the providers. He submits the annual contract proposals. (iii)- The provider accepts or counters proposals. (iv)- The negotiation between the agents continues following the MCP protocol.

Negotiation of the daily contract : (i) each consumer agent sends its profile of the day <q_{ps}^t,...,q_{ps}^{t+n}>, (ii) the aggregator computes the profile of the cooperative <$\sum_{ps \in Coop} q_{ps}^t, \ldots, \sum_{ps \in Coop} q_{ps}^{t+n}$> and requests providers, (iii) Providers send their tariff profile <tr_{pv}^t,tr_{pv}^{t+1},...,tr_{pv}^{t+n}>, (iv) Aggregators transfer pricing signal (consumers can reschedule their planning to reduce their bill), (v) Go to step (ii) if there are reschedules.

The hourly contract: There are no negotiations for the hourly contract. Agents pay for their consumption with penalties according to their deviation.

4. CONCLUSION

In this paper, we combine progresses in energy and multi-agent systems to attack the problem of designing a sustainable mechanism for energy management in smart grids. The mechanism we present allows grouping consumers into cooperatives to reduce uncertainty in aggregated deviation, taking into account a new tariff scheme, storage capacities and shifting in consumers model. Our experiments show that consumers take advantage being in a cooperative and adapt their demand to dynamic tariffs.

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