Agent-based Coordination Mechanisms in Smart Electricity Markets

(Doctoral Consortium)

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ABSTRACT

Electric Vehicles (EVs) and their integration in the smart grid are challenges that sustainable societies have to tackle. Uncontrolled EV charging increases peak power demand, which needs extra grid infrastructure to be covered effectively and consequently this solution is costly. We propose coordination mechanisms using decentralized, centralized and hybrid principles in order to schedule EV charging in a beneficial way for EV owners, smart grid and the environment. We evaluate each mechanism under realistic conditions and show their benefits in different market environments.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems

General Terms

Algorithms, Management, Design, Economics

Keywords

Electric Vehicles; Smart Grid; Smart Markets; Coordination

1. INTRODUCTION

Electricity grids are undergoing fundamental changes that transform them from their traditional top-down structure to decentralized networks, where electricity customers are active participants. This new electricity grid structure, is known as *smart grid*. Smart grid's important components are renewable sources such as solar panels, wind turbines, electric vehicles, etc. Critical factor to maintain smart grid's stability and reliability is the grid operator's ability to match demand and supply in real time. However, that can be challenging when renewable sources are adopted by significant share of the energy customer population. These renewables are highly volatile since they depend (to a large extent) on the unpredictable weather conditions and individual human behavior. In this dissertation we put the focus on electric vehicle customers and the batteries they own.

Electric vehicles (EVs) require particular attention for two reasons. Firstly, they are significant electricity consumers since the amount of electricity needed to fill a battery of e.g. a Nissan leaf is 24KWh, which is multiple times higher than an average household electricity consumption. If EVs continue to gain popularity with the rates they are currently adopted by consumers, they are expected to put the smart grid under critical strain, since its infrastructure is not designed to handle so high and concurrent electricity demand. Secondly, EVs are means of individual commuting and hence tied to the periodicity shown by the human behavior. For example, most of EVs are charged during evening hours when their owners return home from work and want to be sure that their battery will be charged enough to allow them to drive the next day. Therefore, a significant peak on the demand is expected during evening hours, which coincides with the existing afternoon peak on the household electricity demand. Thus, it is challenging to manage EV charging in a way that the individual EV owner will be always able to drive and also the electricity grid will be protected from excessive peak demand and potential black outs.

1.1 Thesis Objective

Goal of this dissertation is to propose mechanisms that will coordinate EV charging with the double objective to satisfy individual customer preferences and to protect the smart grid from critical strains. Coordination mechanisms can be either decentralized (*bottom-up*) or centralized (*top-down*), both of them having advantages and disadvantages depending on the market they are applied to. On the one hand, decentralized approaches have as main benefit that they respect customers' preferences and the customers have the freedom to schedule their power consumption based on their individual behaviors. However, the main disadvantage is that since the same price signals are provided to all the customers, the power consumption schedules coincide leading to *herding* behavior. Specifically, since all agents are cost minimizers, they tend to shift power demand to the cheaper time instants, creating new peaks in the power demand. On the other hand, the benefits of the top-down coordination mechanisms are that they easily satisfy the constraints imposed by the coordinator (e.g. smart grid manager), leading to a reliably balanced system. The most important challenge is that the coordinator must intervene and exogenously con-

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trol the EV battery, violating the EV driver's comfort. One significant practical barrier is that EV owners are driving for considerable amount of time and thus are away from charging locations.

1.2 Research Design

We first propose a decentralized charging mechanism that takes the stand-point of the individual EV owner. We show how this mechanism can be beneficial for the individuals but also for the electricity grid, overcoming the main shortcoming, which is *herding* behavior in EV charging. Secondly, we propose a top-down auction based mechanism which, taking the stand-point of the grid operator, schedules EV charging with main objective not to overload the grid and service as many EV owners as possible. We show under which market conditions, this approach can be beneficial overcoming practical implementation barriers. Finally, we propose a hybrid coordination mechanism that combines the benefits of decentralized and centralized approaches, yielding both peak demand reduction and individual preference satisfaction, without having *herding* in EV charging. All the proposed mechanisms are going to be evaluated within the Power Trading Agent Competition [2] environment, which is a large scale smart grid simulation platform and allows for realistic evaluation of our algorithms.

2. THESIS STRUCTURE

Based on the research design described above, the thesis is structured as follows.

2.1 Decentralized EV Charging coordination

In the first study, we propose a decentralized EV charging algorithm [5, 3] which is implemented through a learning agent, representing the EV customer. Main task of this learning agent is to *learn* EV owner's past consumption behavior and *individual preferences*. Having these two inputs, the agent optimizes charging satisfying the individual benefit maximization objective. We observe that by satisfying each individual EV owner's preferences and under certain market conditions, we can achieve a bottom-up coordination without violating the customers' comfort. We extend this algorithm by coupling EV charging with household power consumption and changing the individual objective from benefit maximization to cost minimization [6]. We observe differences in the benefits for the energy customers and the electricity grid, leading to different market structure recommendations.

2.2 Centralized EV Charging coordination

In the second study, we take the stand-point of the smart grid manager (or grid operator) who is represented by an intelligent agent and schedules EV charging using an auction mechanism. Its main objective is to service as many EV owners as possible without overloading the grid. We allocate the payments using Vickrey-Clarke-Groves (VCG) pricing, uniform pricing mechanisms [1] and propose an efficient heuristic that will overcome the intractability of VCG payment allocation once the number of EV owners grows. This study is going to propose both a theoretical auction-based framework for EV charging scheduling and payment allocation and is going to be evaluated empirically using a mobile app real-world experiment.

2.3 Hybrid EV Charging coordination

In the third study of this dissertation we design a hybrid coordination mechanism that combines the bottom-up with the top-down nature [4]. We show that this mechanism is capable of reducing peak demand and satisfying individual preferences. What is more important, this mechanism can mitigate *herding* behavior that is present in bottom-up mechanisms and overcomes the practical implementation barriers of the top-down approaches. It worths mentioning that this mechanism is also fair, (unlike traditional VCG approaches) since it broadcasts the same price function to all customers in the market.

3. CONTRIBUTIONS & FUTURE WORK

This PhD dissertation aims to examine how various agent-based coordination mechanisms can be beneficial in the smart grid environment, specifically applied to EV charging context. The benefits of each mechanism are evaluated under the prism of benefits for individual EV owners, grid operators and the environment, reducing CO_2 emissions and increasing sustainability. Each study shows how each mechanism (decentralized, centralized and hybrid) influences the benefits for the aforementioned stakeholders. Furthermore, each mechanism is suitable for different market conditions and energy customer portfolios. Therefore, we create recommendations for energy policy makers depending on the coordination mechanism and market conditions they are facing. In future we are going to conduct real world experiments using a mobile application in order to enhance empirical validity of this thesis.

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