Intelligent Bidding in Smart Electricity Markets

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ABSTRACT

This paper has two aims. Firstly, to briefly present overall objectives and expected outcome of an on-going effort concerning design, implementation and the analysis of next generation energy systems based on anticipatory control and a set of ICT emerging technologies and innovations. Secondly, to describe an early proof-of-concept implementation and the associated experimentation of a simulation platform focused on holistic detailed studies of electric energy markets. The proposed platform allows us to elucidate issues related to the open and smart participation of producers and consumers on large-scale e-markets. Based on an existing simulation system, the authors present the required theoretical studies, the enabling technologies, and the practical tools that contribute to the development of such a platform capable of truly large scale simulations. Elements of game theory are utilized to solve the optimization problem related to the maximization of the social welfare of producers and consumers. Selected simulation results associated with the basic required characteristics are presented.

Keywords: Demand Elasticity, e-Market, Game Theory, Intelligent Energy, Nash Equilibrium, Power Flow, Price Elasticity, Smart Grid

1. INTRODUCTION

The smart power grid ought to involve smart consuming appliances and intelligent energy producers that strategically place bids in a short-term energy market. It is widely accepted that such smartness cannot be easily incorporated solely as hardware in the consuming and producing devices during the manufacturing time. Therefore, the recent research efforts that focus on software solutions to add intelligence to the smart grid are both scientifically interesting and technically well justified. Such task is surely not trivial as in the stochasticity traditional involved in the energy consumption, next generation power grids added stochasticity from the producers site through the integration of the distributed producers (renewable energy sources). This double stochasticity together with emerging market mechanisms and other more traditional issues make the task of adding intelligence to the grid in general a challenging issue and adding strategies on producing and consuming energy even more difficult.

We contribute to the efforts of smartening the smart grid by developing micro-learning (see section 2.2 for details) procedures that utilize weather data to train producing and/or consuming

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devices to strategically place bits. Our methodology, although simple, has the potential to be rather effective, in terms of the economic benefits for the energy market participants. Our learning algorithms reside in every device consuming or producing power and turn it in a strategic consumer and/or producer. This leads to what is known as distributed artificial intelligence in the smart grid.

Before we put any trust in our machine-learning procedures and before even testing them in a real environment, we must first study them in a (as realistic as possible) simulation environment. For this we have developed algorithms that lead to a machine learning layer, which we have integrated in a very comprehensive, detailed and widely used simulation power grid distribution network framework. This enables us to perform a series of experiments that involve very detailed energy producing and consuming configurations on a distribution network with more than 600 houses and several local energy renewable sources.

The rest of this paper can be divided in two parts. In the first we briefly give the basic concepts and issues on energy markets and learning methods that consist our background for the material presented in the sections 3 to 5 that will follow and describe our approach and present the experimental results. In the second part we study the use of game theory in energy grids. In section 6 we briefly present the basic concepts of game theory and in section 7 we give an overview of previous works that use game theory to implement strategic consumers and producers. In sections 8 and 9 we describe our approach in integrating game theory in our implementation and the experimental results. Our synopsis and future prospects can be found in Section 10.

2. ENERGY GRIDS AND LEARNING METHODS

2.1. Next Generation Energy Grids and Markets

Smart grids have been a widely known concept that motivated several research, development and entrepreneurship efforts worldwide. It is foreseen that smart markets will follow the same routes. Smart price making in the consumption of electricity is important for the acceptance and the future of smart grids. Open and fair participation in the price making procedures could be established through learning procedures.

Figure 1 clearly exhibits the price volatility as recently measured by PJM (http://www.pjm.com), the regional transmission organization that coordinates the movement of wholesale electricity in most states in the eastern coast of USA. It graphically depicts the difficulty of defining in advance any model of prices that will provide a good approximation of real-time prices. This leads to rapid economic transactions that require appropriate smartness.

Auction design is at the heart of the evolving energy markets. Based on theoretical models and practical considerations several efforts have been devoted to effectively predict the bid prices and quantities. These efforts utilize results from diverse thematic areas ranging from optimal power flow formulation, to economic models, to game theory, to artificial intelligence etc.

In addition to the design of several associated theoretical models, energy markets lead to the development of simulation systems that integrate the physics expressed in the form of power flow equations with financial mechanisms. These systems allow us to elucidate several issues associated with both system and market stability in the emerging next generation grids where electricity flows along with measured data of various kinds. GridLAB-D (Chassin, Fuller, & Djilali, 2014) is such a system. It is an open source, detailed and comprehensive agent-based system that has been recently developed mainly in C++ and is widely used. For a recent study that utilizes GridLAB-D for large-scale experimentations without learning in a way similar to the one we follow in the present paper, the reader is referred to (Fainti, Nasiakou, Tsoukalas, & Vavalis, 2014).
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