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Load Management for Price-based Demand Response Scheduling — a Block Scheduling Model

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***Abstract*—Demand Response (DR) plays an important role in electricity market design, in both reducing utility's investment on peak generation and improving electricity bill savings and incentive payments earned by customers. Improved resource-efficiency of electricity production is achieved by closer alignment of electricity pricing information with energy consumption behaviors. In this paper, a block scheduling model of load management for price-based *Demand Response* is presented under two different real-time pricing schemes: linear pricing scheme and threshold pricing scheme. For linear pricing, the problem is formulated as a convex optimization problem and the optimal demand response profile is given as a two-dimensional *water-filling solution* either with flat water levels or different water levels for different customers. From the perspectives of the customers as a whole or as selfish individuals, the demand-response computations lead to centralized or distributed optimizations, respectively. A trade-off strategy which attempts to balance these competing objectives is also provided. This trade-off strategy divides customers into local groups within which group-wise distributed optimization is performed to improve the overall performance so that the Price of Anarchy (PoA) is reduced. For threshold pricing, which might be more applicable in certain scenarios, detailed characterization of different optimal load profiles are given assuming a discrete load unit model. A search algorithm is also proposed to find the optimal load profiles for both constant and dynamic pricing threshold scenarios. The effect of dynamic pricing threshold on customers' electricity consumption behaviors is highlighted.**

***Index Terms*—Demand response (DR), real-time pricing, load management, two-dimensional water-filling, block scheduling.**

I. Introduction

In most current electricity markets, fixed pricing schemes with constant rates are being widely used. Customers face retail electricity prices that are flat over months or even years [1]. A problem with fixed pricing schemes is the disconnection between short-term marginal electricity production costs and retail rates paid by customers, which leads to inefficient overall resource usage. Due to lack of information on generation costs, electricity consumption behavior of customers may not adjust to supply-side conditions. Thus fixed constant pricing results in suboptimal customer behavior as well as higher electricity costs than they would otherwise be in an optimally efficient system [2].

There is a growing consensus that Demand Response (DR) can play an important role in market design [3]. Lack of DR has been shown to be a major contributing factor for energy-market meltdowns [4]. In [1], for example, DR is defined as *"Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."* DR not only reduces the capacity investments in peak generation units to serve occasional heightened demand, but also provides short-term reliability benefits as it can offer load relief to resolve system and local capacity constraints. There are two basic demand response options: Price-based demand response and incentive-based demand response. Price-based demand response includes real-time pricing (RTP), critical-peak pricing (CPP), and time-of-use (TOU) rates. Customers can respond to the price structure with changes in energy use, reducing their electricity bills if they adjust the timing of their electricity usage to take advantage of lower-priced periods and avoid consuming when prices are higher [1]. Incentive-based demand response schemes pay participants to reduce their loads at times requested by the program sponsor, triggered either by a grid reliability problem or high electricity prices. DR programs typically specify a method for establishing customers baseline energy consumption level below which demand reductions are not allowed. In power systems, the energy requests that customers send to utility consist of two parts: nonflexible load request and flexible load request [5]. The nonflexible part is the minimum amount of energy that utility needs to provide at a specific time. The flexible part can be reallocated over time according to a certain load management strategy. For any load management strategy there are two common primary goals: peak load shaving and load profile flattening. Under real-time pricing, the electricity price is determined by real time load information.

This paper presents a block scheduling model of load management for price-based demand response scheduling. In this model, the size of the time block is set to be small enough so that all load shifting within the time block can be considered as cost free and acceptable to customers. The solution to this block processing problem can then be the basis for implementations of arbitrarily long scheduling periods. Two types of real-time pricing schemes, linear pricing and threshold pricing, are discussed in this paper. We consider optimal demand-response when customers cooperate as a group as well as when each customer is only interested in minimizing its own cost. Naturally these two scenarios, as shown to lead to centralized and distributed optimizations.

The rest of this paper is organized as follows: In Section II, the system model and the problem formulation for block