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Algorithms for the Implementation of a Dynamic Electrical Energy Pricing Policy

Manek Biswas and Chilukuri K. Mohan*

Department of Electrical Engineering and Computer Science, Syracuse University, NY 13244, USA

Abstract

This paper addresses the implementation of electrical power load scheduling, given a model for predicting energy price fluctuations during a single day. We present a realistic model that utilities may use for implementing dynamic pricing, and discuss how this can be profitable for the utilities and their customers. We provide a dynamic programming algorithm and a greedy algorithm to partition the total demand over a 24-hour period into intervals, minimizing the total cost. The outputs of these algorithms provide ideal load distribution curves for the utility. Using these, each subunit of the grid, e.g., an individual consumer, can create its own ideal load curve which would be a scaled version of the global load curve. Each grid subunit can then find a schedule for its flexible loads so that its load profile is as similar to its ideal load curve as possible. The optimization problem is NP-hard, hence we have explored several algorithms to traverse through the search space of possible schedules, including a greedy algorithm, a randomized greedy algorithm with restarts, the Metropolis algorithm, Tabu search, and finally, a randomized Tabu search with random restarts. Best performance in simulations was obtained with the randomized algorithms.

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Keywords: smart grid; load scheduling; dynamic pricing

* Chilukuri K. Mohan. Tel.: +1-315-443-2322; fax: +1-315-443-4936.
E-mail address: mohan@syr.edu

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1. Introduction

Many researchers have advocated the use of economic principles to determine electricity prices, e.g., Kahn[1] discusses the possibility of applying marginal cost pricing. Recent developments in this area, and obstacles to progress, are surveyed by Joskow and Wolfram[2]. This paper presents algorithms that may be applied to implement sound pricing policies, with the active involvement of consumers as well as utilities, i.e., organizations involved in the generation, transmission, and distribution of electrical power to consumers.

The principal problem we address is that typical electrical energy usage by utility customers varies very predictably and sharply over a day. But changing energy production according to the day's fluctuations in demand raises challenges for the utility. Additionally, utilities also need to invest in building and maintaining "peaker" power plants which supply energy when usage is abnormally high; these are rarely used, and their chances of failure are relatively high, increasing the probability of blackouts when energy demand is very high.

A natural solution to the problem is to have an almost flat, averaged-out demand distribution over time, which can be supported by base-load power plants with minimal intervention for generating excess power or for removing energy sources (when demand is low). Load shedding is an inconvenience to consumers, but load balancing offers a viable alternative. Since battery storage requires huge investments and frequent replacements, load balancing is best achieved using a *Demand Response (DR)* approach, using smart meters that provide two-way communication, informing customers in real-time about current electricity demand and price data. Any customer with a smart meter, a controller, and smart appliances may then schedule some loads in order to reduce energy consumption and cost. DR programs encourage users to shift their loads away from peak times, lowering overall costs of production and reducing customers' electricity bills; in addition, equipment and maintenance costs for the utility are reduced, as is the probability of blackouts[3]. To accomplish these goals, energy costs must vary with time (as functions of demand), and relevant data must be provided to the consumers. Algorithms must enable individual consumers to perform localized load balancing, subject to their personal constraints and preferences.

This paper studies three aspects of the problem. In Section 2, we formulate a pricing model based on marginal cost computation. Section 3 presents algorithms for each individual customer to determine how its load may be distributed over a 24-hour period. This distribution is achieved using scheduling algorithms presented in Section 4. Section 5 summarizes and presents concluding remarks.

2. Pricing Model

Demand Response programs need to provide appropriate economic incentives to encourage users to shift their demand away from the peak periods. However, a simple approach of introducing a substantial difference in tariff between peak periods and low-demand periods will not solve the problem, as it will merely shift the peak rather than ensuring relatively uniform demand over a twenty-four hour period. This has been established in a simulation study by the U.K. Department of Energy and Climate Change[4]. Instead, as economists have argued, appropriate *real time pricing* (RTP) tariffs are needed[5].

Conventional electricity tariffs reflect average supply cost over a long period of time and are fixed for months. In contrast, in RTP as practiced now, customers are charged prices that can vary over very short time intervals to reflect marginal supply costs. The supplier is not required to quote the price for such short intervals even at the start of the intervals, but it may simply provide the users with recent past tariffs data. RTP achieves twin benefits: it will result in a relatively flat demand curve, and will also provide the customers with substantial reduction in their electricity costs. For these reasons, policymakers have identified RTP as a strategy for developing demand response.

RTP tariffs were first introduced in the mid-1980s. In 2004, more than seventy utilities in the U.S. offered voluntary RTP tariffs. However, in spite of the potential benefits, RTPs have not been popular. There are two reasons; the first is that on the demand side what was expected often was manual response to dynamically changing tariffs. It is