Applied Energy 175 (2016) 40–53

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Critical peak electricity pricing for sustainable manufacturing: Modeling and case studies

Yong Wang [a], Lin Li [b,*]

[a] Department of Systems Science and Industrial Engineering, Binghamton University, Binghamton, NY 13902, USA
[b] Department of Mechanical and Industrial Engineering, University of Illinois at Chicago, Chicago, IL 60607, USA

HIGHLIGHTS

- We analyze critical peak pricing (CPP) in California for manufacturing applications.
- We summarize CPP events characteristics based on historical data of major utilities.
- We study how to choose between CPP and the time-of-use rate when both are offered.
- Over 30% savings on electric bill can be achieved for most cases examined.
- 5.63% of GHG emissions can also be reduced with proper production rescheduling.

ARTICLE INFO

Article history:
Received 29 January 2016
Received in revised form 10 April 2016
Accepted 24 April 2016

Keywords:
Manufacturing
Sustainability
Critical peak pricing
Time-of-use
Demand response

ABSTRACT

Critical peak pricing (CPP) is an electricity demand response technology that has great potential to lower the electricity cost and eliminate the need for more GHG emitting power plants. Many utilities start to offer CPP as the default electric service for industrial customers in their market design. When a manufacturing customer defaults to CPP, it is vital to understand what it is and how it will influence their energy budget and facility operations. In addition, given the option to opt-out to a time-of-use (TOU) rate, it is not always easy to tell whether the switch will result in higher bills or more GHG emissions. These questions will be answered in this paper. Specifically, we will model and compare both CPP and TOU rates to gain more accurate knowledge regarding annual electric costs and GHG emissions. With these results, manufacturing enterprises will be able to make more informed decisions on which service to choose and how to use electricity while fulfilling their role for sustainability by enrolling. The case study results show that for industrial customers with production flexibility, with proper rescheduling of electric use, they can save money by adopting CPP, while contributing to reducing GHG emissions. The savings on the annual electric bill can be 30.45% with a simultaneous GHG emissions reduction of 5.63% for an average industrial customer.

1. Introduction

Climate change is a global threat facing the human race. It has caused serious impacts that harm economies around the world [1,2]. Reducing greenhouse gas (GHG) emissions is the key to tackling the challenge [3–5]. Combating climate change has become an indispensable main topic of the high-level international and intergovernmental events such as Asia–Pacific Economic Cooperation (APEC) Summit [6], the G-20 Summit [7], and the United Nations Climate Summit [8]. The seriousness of the challenge has urged both developed and developing countries to take solid actions to curb GHG emissions. For example, among a series of recent plans revealed to fight climate change, European Union has set a target of 20% cut in GHG emissions by 2020 compared with 1990 [9]. The U.S. pledged to cut total GHG emissions by 26–28% below its 2005 level in 2025 [10]. China pledged to reach its emission peak by 2030. These three economies jointly contribute about 50% of the world's total GHG emissions [11].

Electricity generation is a major source of GHG emissions worldwide. For example, in the U.S, it is responsible for 38% of total energy-related emissions in 2013 [12]. Electric demand oscillates vastly from season to season in a year and from hour to hour in a day [13]. The demand typically peaks from late afternoon to early evening during summer months, when extremely hot weather

* Corresponding author at: ERF 3057, 842W Taylor St, Chicago, IL 60607-7022, USA.
E-mail address: linli@uic.edu (L. Li).

http://dx.doi.org/10.1016/j.apenergy.2016.04.100
0306-2619/

prompts high air-conditioning use that strains the electric grid. As an example, the total electric load of California Independent System Operator (CAISO) in the U.S. during year 2012 [14] is shown in Fig. 1. The capacity reserved for the peak load is used only occasionally and then idled for the rest of the year. In the case of CAISO, the top 10% of the electric capacity is only needed for 67 h, which is only 0.76% of the time in the year. The electric price during peak hours can be extremely high. In some cases, the electric charges of the top 12 peak hours during a year can account for as high as 23% of a customer's annual electric bill [15].

New technologies that can constructively reduce GHG emissions start to emerge in the electric power industry. One such technology is demand response [16–18]. Demand response emerges as a smart grid technology to better balance electricity supply and demand. It encourages electric customers to reduce or shift electricity usage during peak hours in exchange for various economic benefits [19,20]. By doing so, the need for more expensive and more GHG-intensive peaking power plants can be avoided. According to a staff report of the U.S. Federal Energy Regulatory Commission (FERC) [21], as much as 150 GW of the peak load could be reduced by 2019 through demand response in the U.S., which is equivalent to the capacity of 2000 peaking power plants! Demand response also provides a viable way to integrate intermittent renewable sources as their market penetrations continue to increase [22]. This in turn helps decrease GHG emissions.

The introduction of demand response has been boosted in the past few years by the advancement of enabling technology. Both U.S. and EU have invested heavily to promote the deployment of smart meters [23,24]. The adoption of smart meters in developing countries such as China is also catching up [25]. Demand response has many different forms of implementation [16,26,27]. Two such forms are time-of-use (TOU) pricing and critical peak pricing (CPP).

Unlike the flat rates where the price of electricity stays constant throughout the day, dynamic pricing is more commonly adopted in demand response programs to represent the dynamic cost of power generation [28–30]. For example, the electric charges in TOU pricing are differentiated by on-, mid-, and off-peak periods, with the on-peak price being the highest and the off-peak price being the lowest [31]. The time and pricing blocks are kept unchanged every workday for a season or a year. CPP is an overlay on the TOU pricing. It imposes a much higher rate during a period called the critical peak in an event day, when the electricity use is significantly high. With CPP, the time and duration of the critical peak period within an event day are predetermined, so is the maximum number of event days per year, but the specific dates when the events will occur are not. The customers will be informed one day ahead of the event. Although the electric price is much higher during the critical-peak period in event days, the customers are offered discounted prices during other days in the rest of the year. Therefore, it enables the customers to significantly reduce their total electric bill by restraining electric use during CPP events. Many customers embracing sustainability leadership are at the vanguard of CPP applications [32–35].

Utility companies usually create different tariffs for residential and business customers, highlighting the different characteristics specific to each of these two sectors [36,37]. This paper studies CPP for business applications, with a special focus on industrial manufacturing customers. More specifically, we start with a literature review of CPP for industrial demand response. Then, we collect typical CPP tariffs from several utility companies that represent a wide range of tariff design. We also analyze the common components presented in the CPP tariffs and their differences from TOU tariffs. The detailed rate schedule information is tabulated for future reference. After that, we conduct a survey of CPP events and characterize their patterns. Case studies using a series of manufacturing systems have been conducted to illustrate how to choose between CPP and TOU rates when both options are provided to industrial customers. Finally, the economic and environmental benefits from adopting CPP have been quantified.

2. Brief literature review of CPP research

Related research on CPP demand response programs in the U.S. has been previously conducted by some researchers and organizations. For example, Herter et al. [38–40] studied customer response during CPP events in California. Aghaei and Alizadeh [41] investigated the application of a new form of CPP demand response program announced by U.S. FERC in the cost-emission-based unit commitment problem. Faruqui et al. [42] analyzed two dynamic pricing rates and an enabling technology in Michigan. Steve et al. [43] develop econometric models to examine the responses of participants in CPP programs in Minnesota and South Dakota. Wolak [44] reported an experiment that evaluates the performance of CPP programs in Washington DC for households that differ in terms of income levels, electricity using appliance holdings, and whether they own a smart thermostat. On the other hand, dynamic pricing in Europe and China are mainly focused on TOU tariffs [45–47] and the data of CPP programs is limited. The progress of pioneer work in dynamic pricing in Asia (e.g., China, Japan, Korea, and Indonesia) is summarized in [48].

All the above-mentioned efforts focus on residential programs targeting household applications. The CPP programs targeting industrial customers have been largely neglected. Industrial electricity use is fundamentally different from residential electricity use [39,40,49]. For example, electricity is a major form of energy source in manufacturing activities. Manufacturing processes such as machining and assembly involve utilizing equipment that is much more energy-intensive. Business customers together contribute 83% to the potential peak demand reduction for CPP programs in 2012 in the U.S.; in comparison, the contribution of residential customers is only 17% [50]. Besides, most of manufacturing businesses run multiple shifts [51–53] and have less flexibility with their production processes than the operation of residential appliances such as air conditioners, refrigerators, washers, dryers, and ovens [54,55]. Therefore, studies show that it is still challenging to simultaneously coordinate production activities,

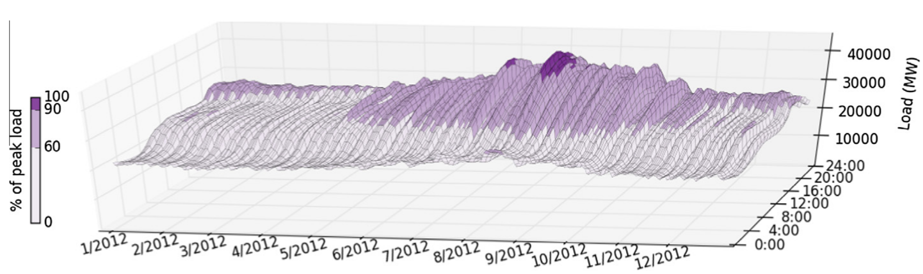

Fig. 1. Hourly total electric load on the CAISO market (raw data is in [14]).