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A conceptual approach for managing production in consideration of shifting electrical loads

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ABSTRACT

The key concept of the smart grid is demand response for power consumption comprising actions taken by customers to reduce or shift electrical loads temporarily in response to requests from electric service providers. A demand response program offers time-based rates that allow customers to choose whether to adjust their consumption. In the manufacturing sector, production managers are likely to participate in a demand response program if they can schedule their production operations in response to electricity prices at peak times. The drum–buffer–rope (DBR) scheduling system in the theory of constraints (TOC) is a useful production operation method because it helps managers focus on effectively managing capacity based on the critical constraint that limits performance of the system. This paper presents a conceptual approach to managing production in consideration of shifting electrical loads in an effort to deal with the most expensive hours of the day. A DBR-based operation model is developed to determine the running time of production processes depending on power saving vs. throughput loss. Conceptual cases are prepared to demonstrate how a production manager can shift electrical loads in response to electricity prices.

1. Introduction

The summer season witnesses a tremendous rise in electrical power consumption, and to meet this electric demand, electrical power supply facilities are required to expand. The graph in Fig. 1 shows an example of a very hot summer day [1]. The red line represents customer power consumption throughout the day. The purple line represents what a utility company would have had to generate if interruptible load management programs were not used to reduce customer consumption. You may notice a difference of more than 300 MW at the time of peak consumption. This increased energy demand is usually met by activating additional expensive power plants. The blue line indicates the price of electricity. Electricity prices on peak days can be twice or thrice the price of wholesale electricity on a typical summer day. Hence, reducing electrical power demand in summer by improving the efficient utilization of facilities is critical.

So-called smart grid technology, or the intelligent electricity grid that uses modern IT/communication/control technologies, has attracted increasing attention in recent years and has now become a global trend [2]. It allows real-time monitoring of electric consumption providing end users and utility companies a way to better conserve and plan their use of this limited resource. Smart metering is the fundamental building block of these grids, which are used to provide consumers the information they need to make efficient choices. With the information, utility companies can ensure a higher level of transmission efficiency, thereby saving massive amounts of energy, money, and environmental resources [3].

The key concept of the smart grid is demand response for power consumption comprising actions taken by customers to reduce or shift their electrical load temporarily in response to a request from electric service providers [4]. A demand response program offers time-based rates that allow customers to choose whether to adjust their consumption. In the manufacturing sector, production managers are likely to participate in a demand response program if they can schedule their production operations in response to electricity prices at peak times. Unlike homeowners, however, production managers are concerned that the throughput of their system may be diminished because of suppressing electricity demand during times of peak demand.

However, power management and power-saving efforts in the manufacturing industry are focused on improving efficiency through replacement and improvement of equipment that consumes large amounts of energy considering the heavy burden of investment costs. Recent advances in smart metering, demand response, and communications technologies have significantly increased awareness that will lead production managers to schedule their energy consumption efficiently. They are beginning to

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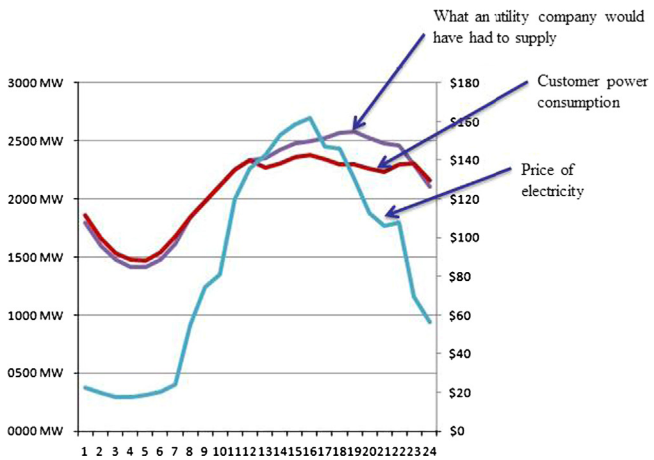

Fig. 1. Example of electrical power consumption and prices for a very hot summer day. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

perceive the ability of the smart grid coupled with automated controllers to control the power consumption of each process automatically in the system, triggered by signals sent by utility companies over the power grid.

Production systems rely normally on the just-in-time (JIT) strategy that strives to reduce process inventory and associated carrying costs by producing only what is required in the correct quantity and at the correct time [5]. Actual orders provide a signal for when a product should be manufactured. To meet JIT objectives, therefore, production systems may need to be operated even when energy prices are increased. However, if electricity prices on these peak days are twice or thrice the regular price of wholesale electricity, production managers are likely to reduce or shift electrical loads while JIT schedules are temporarily suspended.

Rather than keeping inventory levels low as in JIT, it might be beneficial to allow affordable stocks to increase and adjust consumption of electricity by using real-time pricing. However, the nature of manufacturing makes it difficult to require customers to reduce their consumption at critical times in response to electricity prices. Reckless power savings cause chaos on the production line and can lead to greater losses. Therefore, it is necessary to consider a production operation method that allows managers to estimate losses and benefits by shifting consumption to less expensive hours.

The drum–buffer–rope (DBR) scheduling system in the theory of constraints (TOC) is a useful production operation method that emphasizes the optimization of performance within a defined set of constraints on existing processes [6]. The fundamental thesis of DBR is that constraints establish the performance limitations for any system, which suggests that managers should focus on effectively managing the capacity of these constraints if they are to improve performance [7]. Hence, DBR can offer a solution for shifting electrical loads to less expensive hours without degrading overall throughput. This paper presents a conceptual approach for managing production by shifting electrical loads in an effort to deal with the most expensive hours of the day. A DBR-based operation model is developed to schedule production processes depending on power savings vs. throughput losses. Conceptual cases are prepared to demonstrate how a production manager can shift electrical loads in response to electricity prices.

The remainder of this paper is organized as follows. Section 2 reviews the current trends in smart grids, and Section 3 introduces a DBR-based operation strategy for shifting electrical loads in response to requests from electric service providers. Section 4 presents a mathematical model and cases of how a production manager can shift electrical loads in response to electricity prices. Section 5 discusses the implications of the cases, and Section 6 ends with the limitations and suggestions for further research.

2. Industry trends

Recent years have witnessed a significant rise in fuel and electricity costs. Electricity prices on these peak days double or triple the price of wholesale electricity relative to a typical summer day. Hence, customers are motivated to adopt a demand response program that allows customers to choose whether to adjust their consumption by time-based rates. It presents an unprecedented opportunity for utilities, third-party energy providers, and customers to create an interactive, reliable, and efficient power network [8]. As a part of this effort, the electric utilities around the globe are heavily investing in the smart grid to support advanced metering infrastructure (AMI), distribution automation (DA), and demand response (DR).

AMI refers to systems that measure, record, and analyze energy usage, and interact with advanced devices such as electric meters, gas meters, heat meters, and water meters, through various communication media either on request (on-demand) or on predefined schedules [9], and it plays an essential role in smart management of consumer power [10]. A smart meter electronically tracks how much electricity a home or small business uses and when it is used. Smart metering generally involves the installation of a smart meter at a residence, which is used to provide regular readings, processing, and feedback of consumption data to the customer [11]. Its intelligence is incorporated to measure the electricity used (or generated), remotely switch the customer off, and remotely control maximum electricity consumption [12].

DA is a method for real-time adjustment to changing loads, generation, and failure conditions in the distribution system, usually without operator intervention. [13]. Real-time data is available to human operators, enabling them to monitor more and more events in their distribution systems and to control automatic equipment remotely. DA allows individual devices to sense the operating conditions of the grid around them and make adjustments to improve overall power flow and optimize performance [14]. Smart building is a grid-connected building application that can control heating, cooling, and lighting with sensors and automatic control technology and is power-adjustable to reduce energy use, depending on the state of the building [15].

DR is designed to enable customers to contribute to energy load reduction during times of peak demand. According to the Federal Energy Regulatory Commission, one of the main goals of the smart grid is to achieve DR by increasing the participation of end users in reducing the peak demand for electricity and the awareness that will lead them to manage their energy consumption efficiently. In this context, DR refers to actions by customers that change their consumption (demand) of electric power in response to price signals and plays a key role in linking the retail and wholesale sectors of electric markets [16].

DR is similar to dynamic demand mechanisms to manage customer consumption of electricity in response to supply conditions, for example, having customers reduce their consumption at critical times or in response to market prices. [17]. DR can be categorized into two groups: incentive-based demand response and time-based rates. The most common demand response program offered is time-based rates, which are offered to residential customers by 55% of publicly owned utilities [18].

The key strategy of demand response is to offer financial incentives for load reduction during times of peak demand [19]. Some utilities have commercial tariff structures that set a customer's power costs for the month based on top-peak, mid-peak,