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Demand-side response model to avoid spike of electricity price

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ABSTRACT

The aim of this work is to develop a demand-side-response model, which assists electricity consumers exposed to the market price to independently and proactively manage air-conditioning peak electricity demand. The main contribution of this research is to show how consumers can optimize the energy cost caused by the air conditioning load considering to several cases e.g. normal price, spike price, and the probability of a price spike case. This model also investigated how air-conditioning applies a pre-cooling method when there is a substantial risk of a price spike. The results indicate the potential of the scheme to achieve financial benefits for consumers and target the best economic performance for electrical generation distribution and transmission. The model was tested with Queensland electricity market data from the Australian Energy Market Operator and Brisbane temperature data from the Bureau of Statistics regarding hot days from 2011 to 2012.

1. Introduction

Peak demand is a major driver of increasing electricity prices. Peak demand refers to the times when the maximum level of electricity is drawn from the network. In Queensland, peak demand generally occurs on hot days between 10:00 and 20:00. On hot summer days, significant increases in demand occur due to the widespread use of air-conditioning [1]. This means a price spike will be more likely on hot days. Price spikes often occur in the middle of the day when ambient temperatures increase resulting in a significant increase in the use of air conditioners. There is an increased cost with respect to energy markets when many air-conditioners operate at the same time. In addition the transmission and distribution networks must be sized to cope with major increases in demand that normally occur for only a few hours on a few days of the year. For large customers they can be directly affected by market prices and distribution charges. For a regulated customer all the risk is taken by the retail company but if the customer is able to operate in recognition of market and network costs then a potential of sharing of benefits exist. This paper seeks to operate as though the customer were directly affected by these costs so that the potential required from the retailer can be maximized.

The total growth of AC demand could be much higher because of the increasing dwelling area served and the increasing frequency of duration of use of AC as a main factor. AC usage contributes greatly to peak load growth in both the commercial and residential sectors in Queensland. Growth in total energy is not equivalent to growth in demand. In South-East Queensland, energy growth was 28% while demand growth was more than 55% in 2009–2010 [2].

In 2020, cooling energy consumption share by state in Australia, Queensland will be the largest consumer of cooling energy (44%) following New South Wales (27%). Western Australia and the Northern Territory will account for another 14% of consumption, leaving Tasmania and the Australia Capital Territory at only 0% and 1%, respectively [3]. As a result, there will be a greater number of energy users in Queensland than in any other state in Australia.

In this paper, the Queensland electricity market price is chosen for the case studies. Financial benefits are typically the primary consideration for the consumer and retailer so these prices are used to demonstrate the minimization procedure. The wholesale electricity market prices are published on the AEMO website. Detailed information about AEMO price data can be found in Ref. [4].

Based on the regulation of electricity market, small consumer is not allowed direct participation to the wholesale electricity market. Under such a mechanism, only large consumers can offer to curtail or shifting a proportion of their load or bid to wholesale electricity market price and demand. The small-consumer is only able to register in the electricity market through the aggregator. This is envisaged that this mechanism could be rolled out to smaller consumers.

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In the competitive electricity market structure, the aggregator concept describes an independent agent providing its small-consumers with a wide range of innovative services including bill management, home management, home electricity generation, and other services [5,6]. Based on these service provisions, the aggregator combines its consumers into a single purchasing unit to negotiate the purchase of electricity from the retailer [5]. The aggregator also negotiates demand response and behalf of the consumer with the retailer, distribution and transmission company. Many economists believe that the participation of aggregator with innovative services and consumer aggregations can offer potential solutions for small-scale consumers to effectively manage their consumption, and thereby becoming active participants in the electricity market [5–8]. The aggregation methods, the combining multiple electricity load, provides the benefits of retail electric competition for the consumer with lower electric usage called a small consumer.

The following Fig. 1 indicates the competition of power structure in the electrical system. Aggregator is a third party allows to negotiate of electricity market direct to the market operator and transmission company. The physical electricity flows delivery from generator by transmission and distribution companies to the consumer. In contrast, the financial electricity flow delivery from consumer through Retailer Company to the market operator then continues to generator. In the competitive electricity market structure, aggregator is needed to do coordination with the retailer and distribution company to provide good service to the consumer. These services include the information about electricity market price and demand. As a result, small-consumer can participate to the wholesale electricity market.

The research reported in this paper aims to build a new model to minimize the expected cost of air-conditioning to allow for the possibility of a price spike. This paper is organized in five sections. Section 1 introduces the introduction; Section 2 describes background; and Section 3 discusses the model description and formulation. In Section 4, numerical result. Section 5 concludes this paper.

2. Background

Based on a review of current utility programs, the Electric Power Research Institute estimated that DSR had the potential to reduce peak demand in the United States by 45,000 MW [9]. Most importantly, by enabling end-users to observe electricity prices and congestions on the electrical network, it allows users to positively share responsibility by reducing and optimizing energy consumption and experiencing electricity savings [10]. Therefore, the implementation of DSR programs can be expected to improve economic efficiency in the wholesale electricity market.

In Australia, implementation of the DSR programs was conducted a number of years ago. In late 2002, the Energy Users Association of Australia conducted a trial to demonstrate the benefits of a DSR aggregation process which would enable electricity consumers to respond to both the extreme prices and extreme peak demands [11]. This experiment was conducted by consumers to determine the value of an effective DSR and its impact in terms of supporting an energy saving program. The project was supported by the Victorian, New South Wales, and Commonwealth Government, as well as the Commonwealth Scientific and Industrial Research Organization (CSIRO), to implement a Demand Side Response Facility [11].

In the experiment described above, the Australian Government through the EUAA invited consumers to participate in the DSR trial. This experiment was conducted in three regions that fell under the National Electricity Market operation, namely, New South Wales, South Australia and Victoria [12]. These areas were regarded to represent the electricity load in Australia, and the results showed some significant benefits of using DSR for consumers and electricity providers. Hence, in December 2003, the Ministerial Council for Energy advised the Council of Australian Governments (COAG) on the need for further reform of the energy market to enhance active energy user participation [12].

It is very important to electricity consumers and the Australian economy that electricity costs are minimized. DSR is an effective way to ensure cost effectiveness and address peak demand. The need for customer awareness of the opportunities from DSR is critical and projects like the one conducted by the EUAA play an important role in demonstrating the benefits that can be achieved.

In the United Kingdom, various techniques have been used to develop load electricity management. One of the methods, developed in the early 1960s, is called the responsive demand or demand-side management program [13]. This system served to maintain the security of the electricity supply and limited the facilities for electricity generation, transmission and distribution. This program aimed to improve the economy, security and reliability of the electricity industry and address the environmental concerns [13]. Later, in 2007, the British Government initiated the Energy Demand Research Project which focused on the actual benefits of demand response for consumers [14].

The British Government has continued to consider the economic benefits of a demand-side response program, as such a system requires a high implementation cost. In addition, the government has first sought to conduct reform of the electricity industry to support a demand-side response program by restructuring the electricity price and market, transmission and distribution as well as the retail sector. According to Ref. [14], much of the debate around the economic potential of demand-side response focuses on the actual benefits of DSR for consumers, with benefits and weaknesses for both the government and the user. Hence, there are five technology specifications that a DSR project can potentially comprise such as: a minimum meter specification, smart meters that substitute old meters, dumb meters combined with smart boxes, retrofitted devices, and clip-on consumer display units [14].

Similar to what has occurred in the UK, interruptible programs as a part of the demand-side response model have been used in Finland for several years as a disturbance reserve [14]. Utilization of this demand-side response program has been effective to overcome peak load, breakdown and manage the electricity supply to all customers. This plan is not just applied by small consumers but also has been used by large-scale industry. In 2005, the total demand-side response potential in Finnish large-scale industry was estimated at about 1280 MW, which represented 9% of the Finnish power demand peak [15]. Following that, in 2008, the Finnish main electricity utility invested in an advance metering reading system to automatically read, control and manage all 60,000 of its customer metering points [14].

There are various ways to implement the DSR in the use of air-conditioning. The Markov birth and death process has been developed to manage small package air-conditioner loads based on a queuing system. This model enables residents with small air-conditioner loads to participate in various load management programs whereby they can receive incentives and lower their electricity bills while their conveniences are taken into account [16]. This model provides effective and convenient load management measures to both the power company and the consumer. Incentives and compensation are recognized by the utility company based on the level of participation of the consumers [16]. In these models, the electricity price was not based on the electricity market price. Therefore, the aggregator was not required to control small consumers. On the other hand, these models are not appropriate for anticipating a price spike and seasonal climate changes in Australia.