Energy and Buildings 89 (2015) 112–122

Contents lists available at ScienceDirect

Energy and Buildings

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

Power re-allocation for reducing contracted electric power costs

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ARTICLE INFO

Article history:
Received 5 September 2014
Received in revised form 6 November 2014
Accepted 16 December 2014
Available online 24 December 2014

Keywords:
Electric power
Allocation
Smart grid
Micro grid
Virtual power plant
Electricity
Fairness

ABSTRACT

Electric bills consist of a cost related to the consumed energy and a cost related to the maximum demanded power. This latter part usually accounts for approximately 25–40% of the bill. Demanded power by big consumers is measured in real time and electric companies highly penalise them if the maximum demanded power (along the billing period) exceeds the contracted power by the consumer. In this paper we propose a new method that, given the demanded power of close consumers for a time window (power profile), power costs are reduced by re-allocating the demanded power among consumers in order to keep all of them below or equal to their contracted power. We also propose and analyse some strategies to set a preference when not all power profiles can be kept below the contracted power. We tested this method using real-based simulated power profiles of eight different business buildings located in Girona and the power cost reduction achieved reached approximately 20%.

1. Introduction

Electric companies charge their customers for the amount of energy demanded and for the contracted power they have. Contracted power is supposed to be the maximum power at which the electric service will be interrupted (by some physical device) if the power required by the customer exceeds it. However, the popularisation of maximeters (devices that measure the maximum demanded power) has brought about electric tariffs that do not interrupt the electric service. Instead, these metres allow electric companies to apply maximum-power-dependent prices. For example, electric companies apply different prices depending on whether the demanded power of the customer exceeds the contracted power, or whether it is lower than a particular percentage of this contracted power.

Power cost is related to the infrastructure costs of electricity distribution companies. Trading companies use (and pay for) the infrastructure and in turn charge their customers for providing the required service (providing energy). As a consequence, trading companies have no margin to decrease the power cost (they are set by distribution companies), but they are interested in advising their customers on how they could reduce this part of their electricity bill.

Usually, maximum-power-dependent pricing is a demand-response strategy used by electricity companies which highly penalises the customer when it exceeds its contracted power even if it does so for a short period of time. For this reason we propose a new method called PRA (power re-allocation) whereby customers consent to be assigned demanded power from others in order to keep all of them below the contracted power. So customers that do not use all of their contracted power transfer their surplus to neighbours who do exceed it. Therefore, power costs are reduced without reducing the sum of demanded power by all customers; it just re-allocates the demand among them. We also present some strategies to establish which customers have priority when not all can be put below the contracted power.

The benefits of using the PRA method compensates from large the investment required to implement the approach, mainly, individual customers converted to a single one, in a close distance.

This paper is organised as follows: first we present some work related to cost reduction to deal with demand response strategies; second we formulate the problem of minimising power costs under maximum-power-dependent prices; then we explain our method called PRA; next we present our experiments and the results obtained; finally we expose the conclusions of the work and propose some further work.

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http://dx.doi.org/10.1016/j.enbuild.2014.12.030
0378-7788/

2. Related work

A great deal of current literature concerns applications to reduce energy costs from the System Operator's (SO) point of view. For example Mohsenian-Rad et al. [13] present a new approach of demand-side management (including several consumers) based on game-theoretic energy consumption scheduling under variable prices (time-dependent and volume-de-pendent). It is a demand-side management approach that assumes that consumers will give their best response to price changes re-scheduling their consumption profile. Also from the SO point of view, Jia et al. [6] establish a multi-agent system to represent the interactivity between SO and terminal consumers. The authors propose a continuous analysis on demand response using strategies that they present, which reflect the interactive response between the SO and terminal consumers. Faria et al. [3] present an approach based on particle swarm optimisation to manage demand response on simulated power systems. Moreover, Ketter et al. [7] describe an energy market simulator used to study the dynamics of customer and retailer decision-making. Our work does not concern the SO but a coalition of customers. In this sense this paper proposes a methodology to reduce power costs from the terminal consumer point of view.

The concept of creating coalitions of energy consumers has also been proposed by Vinyals et al. [18]. They propose that consumers can create a coalition of consumers through their contacts in a social media network. The aim of the coalitions is to flatten their aggregated energy consumption profile and then allow consumers to buy energy together. Our work differs from Vinyals et al. [18] because we focus on costs related to the maximum demanded power by the consumer and in doing so consumers of the coalitions must be close geographically due to power constraints. Furthermore, we propose a centralised approach to manage coalitions while Vinyals et al. [18] propose a decentralised approach without a technological solution. In addition to energy or power issues, Leng et al. [10] analyse space-exchange problems between retailers. This work shares with our paper the concept of exchanging a good that is sometimes in excess, without involving monetary units. However, the application field is completely different and thus, the features of the problem.

From consumers' point of view, Torrent-Fontbona and López [16] present and analyse some approaches of resource allocation for minimising costs under time-dependent and volume-dependent energy prices in a project scheduling problem (assigning energy consuming resources to activities). Simonis and Hadzic [15] calculate some lower limits for solving the workflow scheduling problem under time-dependent prices. Our work is complementary to these demand response applications because we propose that some consumers in the same zone, that have already scheduled their activities in order to minimise energy costs, share their *power rights* to keep all of them below their contracted power. Also, from the consumer point of view, there are many works like Zhang et al. [19] that present methodologies to optimise energy costs when the consumer has a particular energy generation capacity.

Focusing on the private sector, there are several companies such as Arista Power (US), MeasurLogic (US), EnerNoc (US) or Circuitor (Spain), that offer technological solutions for reducing power costs. These solutions are based on using storage systems and controlling and managing loads (disconnecting non-critical loads when the consumer surpasses the contracted power). However, there is not any solution based on making coalitions of consumers and taking advantage of the different power profiles to reduce power costs as we propose in this paper.

There are some works that analyse household behaviour regarding energy consumption and energy prices as Gottwalt et al. [5]; Brounen et al. [2] and introduce new indexes to measure demand response and models of consumers [8]. For further literature of demand-side management, Law et al. [9] describe the key objectives of demand-side management and surveys demand response architectures.

Table 1
Notation

t	time index
k	period index
i	customer index
W	time length between two bills
N_p	number of periods
N_c	number of customers
$c_{i,k}$	contracted power by customer i for period k
c_k^u	aggregated contracted power of the umbrella entity for period k
$\alpha_{i,k}$	under-power demand parameter
$\beta_{i,k}$	over-power demand parameter
$p_{i,k,t}$	demanded power by customer i in period k at time t
p_i	power profile
$m_{i,k}$	maximum demanded power by customer i along period k
m_k^u	aggregated maximum demanded power by the umbrella entity
$\pi_{i,k}$	power price (€/kW) of customer i for period k
$\tau_{i,k}$	target power of customer i for period k
$APR_{k,t}$	accumulated power rights by all customers in period k and at time t
$ADP_{k,t}$	accumulated demanded power by all customers in period k and at time t
$PS_{k,t}$	power sharing (capacity of all customers to accept power from others) at time t of period k
$priority_{i,k}$	priority value of customer i for period k
$x_{i,k}$	amount of time customer i has received power from other in period k
$z_{i,k,t}$	amount of power customer i has received from others at time t of period k

3. Problem modelling

In recent years the problem of determining the power cost of a customer has been changed due to the smart grid. The use of maximeters allows electricity companies to charge consumers for their maximum demanded power m, along a time window W. However, electricity companies penalise customers when m exceeds the contracted power c. For example, in Spain, when $m < 0.85c$ the electric company charges for 85% of c; when $0.85c \le m \le 1.05c$ the company charges for m; and when $m > 1.05c$ the company charges for $m + 2(m - 1.05c)$. Moreover, electric companies apply different billing periods that consist of classifying the demanded power according to the time-slot (time of the day) it is required. In this way, each period represents a particular part of every day, i.e. from 00:00 to 08:00. Continuing with the Spanish example, Spanish law says that each day must be divided into three periods, and therefore, there must be a maximum demanded power for each one (Table 1).

In the general case, the payment or power costs of a customer can be formalised according to the following notation.

Customer: i is the customer index ($i \in [1, N_c]$).
Time window: W, time duration between two bills of a set of customers (usually a month).
Period: k, fraction of a day corresponding to a power tariff; $k \in [1, N_p]$; N_p is the number of periods which divide each day.
Slot: t, is the time index in a period; $t \in [1, W/N_p]$.
Contracted power: $c_{i,k}$, the contracted power that gives the customer i the rights of demanding up to $\beta_{i,k}c_{i,k}$ (kW) in period k without paying extra charges. $\alpha_{i,k}c_{i,k}$ is the minimum power to pay for.
Under-power demand parameter: $\alpha_{i,k}$.
Over-power demand parameter: $\beta_{i,k}$.
Demanded power: $p_{i,k,t}$, the demanded power of customer i in period k at time t.