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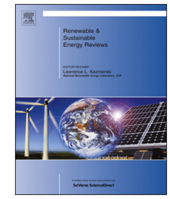

A review of residential demand response of smart grid

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ABSTRACT

Advances in information and communication technologies (ICT) enable a great opportunity to develop the residential demand response that is relevant in smart grid applications. Demand response (DR) aims to manage the required demand to match the available energy resources without adding new generation capacity. Expanding the DR to cover the residential sector in addition to the industrial and commercial sectors gives rise to a wide range of challenges. This study presents an overview of the literature on residential DR systems, load-scheduling techniques, and the latest ICT that supports residential DR applications. Furthermore, challenges are highlighted and analyzed, which are likely to become relevant research topics with regard to the residential DR of smart grid. The literature review shows that most DR schemes suffer from an externality problem that involves the effect of high-level customer consumption on the price rates of other customers, especially during peak period. A recommendation for using adaptive multi-consumption level pricing scheme is presented to overcome this challenge.

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Contents

1. Introduction

Currently, the energy consumption of the residential sector accounts for around 30–40% of the total energy use all over the world [1–3]. The residential loads often contribute significantly to seasonal and daily peak demand [4]. Typically, the electrical power grid is over-dimensioned in order to support the peak period of energy consumption for a few hours in a year span [5,6]. To meet these occasional peak demands, utility companies have been required to increase their generation capacity to match the required demand at all times. Generally, 20% of the power generation capacity is latently available to meet the peak demand that occurs for approximately 5% of the time [7,8].

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Currently, the available solutions to meet such an irregular electricity demand are building new generation capacity, developing new storage technologies, and demand response (DR) [9,10]. The conventional solution involves matching the supply with the required demand. However, this approach is unsustainable and hardly affordable [11]. Building a traditional power plant is not preferred due to increasing greenhouse gas [12,13] and depletion of fossil fuels [8,14]. Furthermore, adding new power plants is not a sophisticated solution because this action matches the demand for a limited time period and then results in wasted power [15,16]. On the other hand, wind and photovoltaic energy are the most industrialized low-carbon generation capacities (renewable energy resources) [17]. However, these resources suffer from an intermittent nature and high cost [18]. Furthermore, they are dependent on certain geographical conditions and thus, cannot be deployed in certain areas. These resources also rely on the weather, which make them less reliable and hard to predict [19,20].

Energy storage is classified as one of the most important parts of the future smart grid. Energy storage supports the grid with a number of applications and ancillary services [21]. The storage options include flywheels, compressed air energy storages, electrical vehicle batteries, and large thermal storage tanks. However, energy storage technologies are currently at the research and test stage. Moreover, the geographical limitation prevents some of these options from becoming practicably applicable [22].

While most of contemporary solutions, which should meet the required demand, are based on the conventional idea of increasing the supply to match the demand, DR aims to contradict this idea by managing the demand to match the available energy [9]. DR helps utility companies and customers to reduce peak demand and price volatility [23,24]. In addition DR presents the customers as active players in the load management market that was invisible for them previously [25,26].

Most of the previous reviews focused on the benefits and challenges of current DR schemes and marketing policies that meet certain objectives. However, limited attention has been given to DR systems, load scheduling techniques, and the latest communication technologies for DR application. This study aims to contribute to filling this research gap and highlights the current problems and challenges for future directions. In particular, using adaptive consumption-level pricing schemes that can be used to save energy and cost is recommended.

The rest of this paper is organized as follows. Section 2 provides an overview of current DR schemes. Section 3 demonstrates the current studies on residential demand response systems and the challenges. Section 4 describes the load scheduling techniques. Section 5 describes the communication technologies of smart grid and application of IoT (Internet of Things) in DR. The recommendations for DR schemes are presented in Section 6. Section 7 provides the conclusion.

2. Demand response scheme

The core element of DR schemes is the motivation of customers via incentive offered by the utility company [27,28]. DR schemes must increase the customer awareness of the benefits of DR to adopt or change their electricity usage. The major reasons for encouraging customers to participate in the DR schemes including cost saving, blackout prevention, or responsibility sensing [29].

Generally, the current DR schemes can be classified into two types: incentive-based and price-based DR schemes [30]. According to some studies, these schemes have other names, such as “system-led” and “market-led,” “emergency-based” and “economic-based” or “direct” and “indirect” DR [31].

1. Incentive-based scheme: in this category, customers are encouraged to reduce their energy consumption upon request offers or according to a contractual agreement [32]. This agreement is between the customer and the utility company, which provides the program administrator some degree of authority to directly schedule, reduce, or disconnect to save cost. Recently, these programs have been extended to cover residential customers in addition to industrial and large commercial customers. The instantaneous demand and operating state of individual devices are managed using centralized controllers, which conduct both the control decision and control action. Examples of programs in this scheme are direct-load controls (DLCs), interruptible tariffs, demand-bidding programs, and emergency programs [33], as shown in Table 1. This approach of direct access to customer premises for on/off operation is very invasive. The lack of customer privacy and system scalability are the major drawbacks of DLC and other incentive-based programs [34].
2. Price-based scheme: in this scheme, the customers offer time-varying rates that reflect the value and cost of electricity for different time periods [35]. Utilities use a distributed process of variable-pricing policies. The customers are encouraged to individually manage their loads by either reducing or shifting their energy consumption from peak hours to less congested hours, thereby favoring load balancing. The price of electricity may differ at pre-set times or may vary dynamically according to the time (day, week, or year) [36]. The customer reacts to the fluctuations in the electricity prices. Examples of this scheme are time of use (ToU), critical-peak price (CPP), and real-time price (RTP) [37,38], as shown in Table 1. Even though price-based programs do not have customer privacy and system scalability problems, offering a price rate for a specific time period to all customers of different consumption levels is unfair to those who already have a normal or low level of consumption (externality problem). Following price changes at different time periods may also be confusing to customers. Moreover, a schedule technique, either manual or automated, is needed to help customers manage the load [39].

According to these DR schemes, the customer load is subject to change based on the price change, incentive offers, or an emergency case that jeopardizes the grid operation [40]. The benefits of DR for the utility and customers can be achieved by saving customer energy and cost, reducing the need for new generation capacity, reducing air pollution, and reducing peak-energy prices [41,42]. However, expanding the DR to cover the residential sector in addition to industrial and commercial sites results in a wide range of challenges [43,44]. These challenges include establishing an optimal DR system that overcomes the current problems of available DR schemes with a win–win strategy for the customers and the utility, as well as load scheduling to balance the energy consumption with the available supply [45]. In addition, the communication system that handles the DR implementation is also a challenge[46]. In the following sections, we detail the current studies and main obstacles for these challenges.

3. Residential demand response systems

One of the greatest obstacles for a DR system is to balance energy and save costs for both the customers and the utility [47]. The customers seek to minimize their energy cost above all other priorities, whereas the utility aims to manage the available energy accurately with minimum cost [48]. The most important factor for DR systems is to maintain balance between the beneficial requirements of both the utility company and the customers.