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The role of regulatory reforms, market changes, and technology development to make demand response a viable resource in meeting energy challenges

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HIGHLIGHTS

- Demand response is becoming cost-effective demand-side resource to balance the power systems.
- We examine policy and market changes that drive the demand response development.
- Smart-grid technology and open communication standards facilitate demand response deployment.
- We recommend actions needed to capture untapped demand response potentials.

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ABSTRACT

In recent years, demand response and load control automation has gained increased attention from regulators, system operators, utilities, market aggregators, and product vendors. It has become a cost-effective demand-side alternative to traditional supply-side generation technologies to balance the power grid, enable grid integration of renewable energy, and meet growing demands for electricity. There are several factors that have played a role in the development of demand response programs. Existing research are however limited on reviewing in a systematic approach how these factors work together to drive this development. This paper makes an attempt to fill this gap. It provides a comprehensive overview on how policy and regulations, electricity market reform, and technological advancement in the US and other countries have worked for demand response to become a viable demand-side resource to address the energy and environmental challenges. The paper also offers specific recommendations on actions needed to capture untapped demand response potentials in countries that have developed active demand response programs as well as countries that plan to pursue demand response.

1. Introduction

In recent years, demand response and load control automation has gained increased attention from regulators, system operators, utilities, market aggregators, and product vendors. It has become a cost-effective demand-side alternative to traditional supply-side generation technologies to balance the power grid, enable grid integration of renewable energy, and meet growing demands for electricity. The electric grid systems operators are increasingly supporting DR not only as an effective load management tool to ensure reliable operations of power systems during times of peak load but also cost-effective options in providing high-value services to facilitate interoperable and distributed grid integration and address variable generation characteristics of renewable resources [1,2]. According to the US Department of Energy, demand response reflects "changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentivize payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized [3]." The California Energy Commission defines DR as "a reduction in customers' electricity consumption over a given time interval relative to what would otherwise occur in response to a price signal, other financial incentives, or a reliability signal [4]."

DR increasingly plays an important role in addressing the demand, especially at the peak. A 2009 report issued by the Federal Energy Regulatory Commission (FERC) estimated that up to 20% of US peak demand can be potentially reduced through DR programs [5]. According to FERC, the DR resource contribution from all US

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Nomenclature

Abbreviation

AMI	Advanced Metering Infrastructure
Auto-DR	Automated Demand Response
CSP	Curtailment Service Provider
DR	Demand Response
FERC	Federal Energy Regulatory Commission
HAN	Home Area Network
ISO	Independent System Operator
LSE	Load Service Entity
RTO	Regional Transmission Organization
TOU	Time of Use

programs was about 72,000 megawatts in 2011, about 9.2% of the nation's total peak demand. This was an increase of about 13,000 megawatts from the 2010 survey results [6]. A study of the DR potentials in European Union (EU) estimates that EU-wide deployment of DR by 2020 would create 100 TWh of annual energy savings, resulting in an annual reduction of 30 million tons of CO_2 [7].

Deployment of DR brings significant benefits. From an economic perspective, the infrequent spikes in electricity demand have a significant economic impact: in many power systems, 10 percent (or more) of costs are incurred to meet peak demands that occur less than 1 percent of the time in the year [8,9]. In many places, a certain percentage of reserve (10–15 percent in the US for example) is required on top of the forecasted peak demand, making expensive peaking capacity remain idle most of the time. Reducing the peak demand as well as idled capacity through DR programs means that the capacity requirements, which drive investments in generation, transmission, and distribution assets can be proportionally reduced. Research conducted in the US found that a 5 percent reduction in peak demand would have resulted in avoided costs of $2.7 billion for generation, transmission, and distribution capacity per year [9].

The use of DR can result in significant savings in terms of the cost of procuring power during the peak load. In deregulated wholesale markets, spot energy prices can skyrocket during the peak due to high demand. Similarly, energy prices in vertically integrated, non-wholesale market systems can increase during the peak periods, as less efficient generation units have to be utilized in order to meet the rising demand. As retail electricity rates tend to not reflect the true cost of energy during peak periods, the expensive utilization of generation during these times is however socialized among all customers. By reducing the need for purchasing high-priced power, all customers in a system are positively affected.

From the environmental perspective, DR reduces or avoids the utilization of peak units and their associated emissions through reducing peak electric demand to ensure the sufficiency of existing supply, rather than increasing supply to meet rising demand at the peak. Moreover, because DR capacity is a distributed resource and located at the point of use, there are added environmental benefits as a result of the avoided electricity losses in the transmission and distribution lines typically associated with centrally-generated power plants. This benefit is even greater during the peak demand periods as the line loss is larger at the peak when transmission lines are heavily loaded. Because DR avoids line losses, a DR resource of 5 MW is comparable to a 5.5 MW of reserve capacity provided by a centralized generation asset when average line losses on the grid during a DR event reach 10 percent [10].

In addition, because DR is often procured on a forward basis, it may not only offset the operation of power plants but also their very construction. In this manner, the environmental benefits of DR extend to the avoided emissions associated with the production of the materials for the power plant itself (i.e. cement, steel, etc.), as well as the potential environmental impact that may have resulted should the unit have been built.

The use of DR for non-peak-shaving purposes such as for ancillary services to balance supply and demand also comes with significant environmental benefits, despite the very short dispatch duration requirements of such resources. In many power systems, the plants in running operating mode primarily provide ancillary services (also known as spinning reserves), as there may be an insufficient number of quick-start generating units able to start, synchronize, and export power to the grid in the requisite period of time. When being in running operating mode, these plants tend to be fueled by diesel or oil, which add to air pollution. Increased use of fast-response DR can reduce the need for power plants to run in operating mode, as well as potentially lead to a more efficient overall use of resources within the power system. Further, the ability of DR to provide fast and prompt response by either ramping up or reducing the load helps balance the supply and demand on the power systems. This can facilitate grid connection of intermittent renewable generation. The promotion of greater use of renewable resources adds more environmental benefits.

In addition to these economic and environmental benefits, there are other types of benefit. Because the wholesale power markets are traditionally dominated by generation resources, increased participation of demand resources such as DR programs in these markets can diversify market participants, which in turn helps minimize the potential of market participants abusing their market power in the spot market [11].

Regulatory changes, power market reform, and technology advancements have all played a role to make DR a viable resource in addressing peak demand, enhancing power system reliability, and facilitating the grid integration of renewable resources. In the following sections, this paper discusses separately the experiences in select countries in developing enabling policy that gives DR an equal opportunity with supply options, creating new markets to allow DR to be procured as a resource, and adopting technologies that enable DR applications. Although the discussion includes activities in several countries, it focuses primarily on the US experiences because the market for DR in the US is more active and thus relevant information is richer compared with other part of the world. The paper also presents concrete recommendations on actions needed for increasing DR potentials in countries that have developed active DR programs as well as countries that start pursuing DR.

2. Analytical framework

There are existing researches on evaluation of demand response programs in various countries. Our literature reviews found that most of these studies focus on a wide range of issues related to DR, including (1) the empirical evidence of DR activities in terms of enrollment, performance, and contribution from the third party providers [7,8,12], (2) barriers to market penetration of DR [7], (3) assessment of economic and technical potential for DR [5,7], (4) evolution of policies on DR [7], (5) emerging technologies in DR applications [13], or (6) specific applications of DR in providing

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