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Review and comparison of demand response options for more effective use of renewable energy at consumer level

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ABSTRACT

Power grids have faced major challenges such as increasing consumption, peak demand and CO_2 emission. Distributed Generation (DG) as a solution to these issues is affected by source intermittency, grid-side limited storage capabilities and supply/demand mismatch. In order to achieve more benefits and profits for both customers and the utility, integrated demand management techniques can be used. This paper reviews the issues caused by high penetration of renewables in power production, depending on utility characteristics. In addition, several methods in the literature were reviewed and their both single and combined use was investigated with a comparison study in Turkey. In field data based simulations, consumption of refrigerators were scheduled according to the output of a small scale PV system and changes in consumption in a year were calculated. The results were analyzed and compared with each other from the standpoint of change in amount of power taken from grid, number of active operation hours shifted to solar periods, change in annual consumption and achievable savings in electricity bills. In addition to the analysis and comparison of several management methods, the paper also proposes a number of terms that widens applicability and can be used in decision-making processes.

Contents

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1. Introduction

Power grids with aged infrastructure and conventional management methods are having radical changes. Main issues like continuously growing demand, raising concerns on CO_2 emissions and varying consumptions motivate researchers for finding new solutions. World's electricity demand has increased by 38% since 2003 [1]. In Turkey, demand growth in last 10 years is 65% [2]. Future expectations are also similar. As an example, annual demand in Turkey is expected to be around 75–91% more in 2020, compared to 2011 [2].

In order to keep up with the raising demand, generation capacity is being increased by constructing new power plants. The plants that rely on fossil sources (with high carbon footprints and include risk of extinction in the future) represent the major percentage of today's electricity generation. Percentage of fossil fuels in generation is 70% in USA and 63% in Turkey [3,4].

Grid has a nature in which the demand should always be in balance with the supply. Consequently, during the process of putting new targets for future generation capacity additions, peak demand is considered. Because of fluctuations sourced by consumption behavior of customers, daily, weekly, monthly and annual peaks occur in load profiles. Annual peak demand occurs for short times in a year. In 2006, duration of Ontario's peak demand is approximately 1% of the whole year [5]. Similarly, according to Turkey's load duration curve of 2011, peak demand with more than 1.2 GW additional demand in other times was only seen during 1% of the year [2]. Establishment and operational costs of peaking power plants occupies a major percentage of expenses. According to a study, reducing Ontario's estimated peak in 2020 by 1% can save the utility around $870 million [5].

Under the topic of Smart Grid, various solutions are being investigated to make the grid operate in a more efficient, environment friendly and reliable way. Distributed Generation (DG) is expected to increase the use of renewables in power generation, while reducing consumer affections caused by the problems in the transmission and distribution level [6]. Another profit of DG is decreased transmission losses, because of generating a portion of energy closer to the customers. However, intermittency of sources like solar and wind and unavailability of efficient storage techniques are the main barriers against its wide usage [7]. There are two main issues that utility operators dealing with because of high percentage of renewables in electricity production, according to their regional utility characteristics.

In the utilities that have high number of base load power plants like US, the preliminary problem is about the rapid changes in solar and wind generation occurring during daily operation and named as "The Duck Curve". According to the net load curves (the remaining amount of demand when the current generation from renewable sources is subtracted from the actual demand) and future expectations of California Independent System Operator (ISO), peaks are becoming higher, while valleys are going to be deeper and ramps are becoming steeper [8] (Fig. 1). Similar expectations (rise of ramp rates from 20–60%) can be found in [9] for load curves of Germany and Britain in 2050.

In addition to daily ramps, there are wind generation caused extreme ramps during storm times. According to the records of 5 European countries and USA provided in [10], the extreme ramps according to,

- hourly speed are up to 1067 MW/h in Spain,
- minutely speed are up to 16 MW in North Germany,
- capacity are up to 83% in Denmark.

As conventional power plants are slow to follow these rapid changes, peaking plants are mostly dispatched. Peaking plants are fast-acting fossil-fueled thermal plants and hydro power plants.

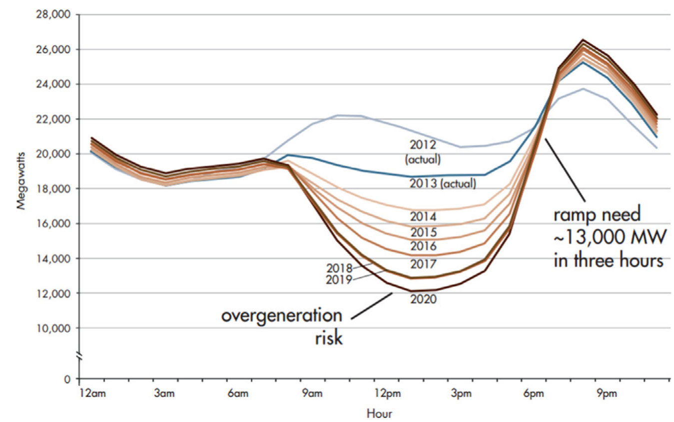

Fig. 1. Daily net load curve estimations of California ISO until 2020 [9].

However, promoted dispatch of these, increases energy costs and reduces system efficiency [11].

In the grids of northern European countries, where renewables have the majority of sources in electricity production like Denmark, another issue arises: surplus electricity production. Although there is export option to other countries, the transmission capacity may not be sufficient during extreme surplus production periods and supply system may break down. As indicated in [12], the critical surplus-electricity production (not exportable to other utilities), is going to rise from 170 GW h in 2005 to 1330 GW h in 2020. Surplus generation may force the system operator to stop many wind turbines until supply and demand are balanced and avoid huge amounts of generation from renewables. The mentioned problems limit the penetration of renewables in generation mix around 20% [13].

Because conventional methods are either based on using high cost/low efficiency peaking plants or periodical avoidance of renewables, the system operators need to deploy more flexible and cost-effective, fast responding resources. At this stage demand response is one of the topics that researchers put spotlight on.

Demand response (DR) as another subtopic of Smart Grid, focuses on influencing consumptions according to the needs of the grid. The main services that DR can offer in electricity market are categorized as capacity (of power that can be reduced, when price signals are not sufficient for balancing), energy (both price responsive day-ahead and real-time balancing) and reserve (consisting of regulating, spinning and nonspinning reserve) [14]. In addition, DR can be deployed without a market structure during emergency situations. There are six main DR objectives such as load shifting, peak clipping, valley filling, strategic load growth, strategic conservation and flexible load shaping [15]. From the perspective of mitigating the challenges of renewable integration and meet the varying supply with demand, one or several DR objectives can be benefited from.

The review studies on DR in the literature are focused on programs and policies [16,17], business cases [18], multi-agent system implementation [19], load profiling integration [20], scenarios [21,22], applicability to markets [23–25], aggregation techniques [26], benefits and challenges [27]. Among these studies, use of DR for better integration of renewables is one of the commonly mentioned; but rarely detailed topics. A detailed review on large scale DR deployment methods and implementations for improving renewable integrated operation is presented in [28]. In addition to studying large scale aggregated management approaches from utility operator side, there is need for evaluation of local management methods at the end user side, considering their influence on device operation and energy consumption.