Energy 67 (2014) 1–18

Contents lists available at ScienceDirect

Energy

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

Assessment of the theoretical demand response potential in Europe

Hans Christian Gils*

Institute of Technical Thermodynamics, German Aerospace Center (DLR), Wankelstraße 5, 70563 Stuttgart, Germany

ARTICLE INFO

Article history:
Received 6 March 2013
Received in revised form
3 February 2014
Accepted 4 February 2014
Available online 1 March 2014

Keywords:
Demand response
Flexible electricity demands
Demand side management

ABSTRACT

DR (Demand response) measures typically aim at an improved utilization of power plant and grid capacities. In energy systems mainly relying on photovoltaic and wind power, DR may furthermore contribute to system stability and increase the renewable energy share. In this paper, an assessment of the theoretical DR potential in Europe is presented. Special attention is given to temporal availability and geographic distribution of flexible loads. Based on industrial production and electricity consumption statistics, as well as periodic and temperature-dependent load profiles, possible load reduction and increase is estimated for each hour of the year. The analysis identifies substantial DR potentials in all consumer sectors. They add up to a minimum load reduction of 61 GW and a minimum load increase of 68 GW, available in every hour of the year. The overall potential features significant variations during the year, which are characteristic for specific consumers and countries.

1. Introduction and theoretical background

DR (Demand Response) actions are defined as "changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" [1]. In contrast to demand side management, which also comprises energy efficiency measures and permanent and/or regular utility-driven changes in the demand pattern, DR is focused on load flexibility and short term costumer action [2,14]. In electricity systems primarily relying on fossil and nuclear fuels, interventions in customer load can increase the profitability of power plants and help to avoid investments in additional generation or grid capacities [3,17]. Most demand side measures are thus designed to either enable load curtailments in times of peak demand or to shift loads to times of low demand [13]. In supply systems with high capacities of intermittent solar PV(photovoltaic) and wind power, the flexibility provided by DR can create additional benefits [4–6]. By adjusting the demand to the present availability of fluctuating resources, curtailments can be reduced and the overall RE (renewable energy) share can be increased. With shifting times ranging from some minutes to a few days, DR competes with alternative balancing options, such as batteries and pumped storage power stations, as well as grid extension, but also thermal storages in combined heat and power or heat pump systems [7–9]. Modifications in the demand pattern are typically realized by direct or indirect load management programmes [10]. Existing DR measures include time-based rates on one hand, and incentive based programmes on the other [11]. Technical requirement for the participation in DR programs is the availability of an information and communication infrastructure allowing for the transmission of and reaction to load, price and control signals. Communication channels include radio and telecommunication, as well as power lines [12,13]. Markets for flexible loads range from on-site peak load reduction and increased internal PV consumption to the participation in energy trade, the provision of operating energy, as well as the clearance of imbalances in the TSO (transmission system operator) area and the management of supply shortfalls [14,15]. Due to various technical, economic, legal and societal barriers, the use of DR is limited so far [16,17]. Existing programmes are mostly focusing on large industrial consumers, however, residential and commercial demand is increasingly also taken into consideration [18].

Demand response resources have been identified in a broad range of processes and devices [19,20,25,27,31,57]. In Germany and Austria, their average shiftable and sheddable loads add up to several GW [29,31,57]. The ENTSO-E (European Network of Transmission System Operators for Electricity) has quantified a load reduction potential of around 11 GW available throughout continental Europe [21]. Assuming a DR market potential equivalent of 2% of the annual peak load, a possible benefit of €53 billion achieved by smart meter installation and dynamic pricing on a European level has been estimated [22]. The impact of feedback and

* Tel.: +49 711 6862 477; fax: +49 711 6862 747.
E-mail address: hans-christian.gils@dlr.de.

http://dx.doi.org/10.1016/j.energy.2014.02.019
0360-5442/

time-of-use tariffs on electricity demand and potential DR contribution of residential appliances has been investigated in field trials realized in Austria and Northern Italy [23,24].

A consumer and country-specific analysis of the flexible loads on the European continent is missing so far. In this paper, the theoretical DR potential in Europe and North Africa is assessed.[1] Its aims are the characterization of electricity consumers that are able to shift or shed their load for a given period of time and the provision of a first estimate of their loads in Europe. Three different DR actions are taken into account: load shedding, load shifting to an earlier time and load shifting to a later time. Network load reductions achieved by the usage of costumer-owned onsite generation are not included in the analysis. DR potentials are determined across all demand sectors: industry, as well as the tertiary and residential sector.

When assessing the potential future contribution of DR to the system integration of RE, the temporal availability of flexible loads is of particular importance [25]. The demand response behaviour of non-residential consumers is directly correlated to industrial production activity and business hours. In the residential sector, time-related electricity demands can be derived from an evaluation of household activity level and occupancy variance [26,27]. In the work presented here, exemplary load profiles of all relevant consumers are either estimated or extracted from metered data available in literature. Based on these profiles, potentials for load reduction and increase are calculated for each hour of the year. In the context of the balancing of RE fluctuations, also the duration of load interventions, the shifting time and the frequency of DR actions are of special importance. These parameters have decisive impact on the quality of the corresponding DR potential. In order to facilitate follow-on studies of the interaction of DR measures with the electricity grid utilization, also the geographical distribution of flexible consumers is evaluated. Given that the application of DR is subject to constraints, different kinds of potentials need to be treated separately. It can be distinguished between the theoretical, technical, economic and practical potential [28,29]. Whereas the theoretical potential comprises all facilities and devices of the consumers suitable for DR, the technical potential includes only those that can be controlled by the existing information and communication infrastructure. A subset of the technical potential is the economic potential of all DR consumers that can be operated in a cost-efficient way. Another independent subset of the technical potential arises from the acceptance of load interventions. The effectively usable, practical potential consists of the intersection of economic potential and accepted use. This work is restricted to the assessment of the theoretical DR potential. Limitations for technical reasons not related to industrial production processes, costs or refusal to participate will at this point be neglected.

2. Data and methodology

The analysis is performed in four steps. First, processes and appliances suitable for DR are identified (Section 2.1). Then, their characteristic load profiles are assessed (2.2). In the third step, annual electricity demands and installed capacities in the year 2010 are quantified, and a flexible load share for each consumer is evaluated (2.3–2.5). Finally, the geographical distribution of DR potentials is investigated (2.6).

[1] Countries that are included: Albania, Algeria, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Egypt, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Libya, Liechtenstein, Lithuania, Luxembourg, Macedonia, Malta, Moldova, Montenegro, Morocco, Netherlands, Norway, Poland, Portugal, Romania, Serbia and Kosovo, Slovakia, Slovenia, Spain, Sweden, Switzerland, Tunisia, Turkey, United Kingdom, Ukraine.

2.1. Identification of shiftable loads and required parameters

In this study, a total of 30 different processes and appliances are taken into consideration. Shiftable loads typically feature one of the following characteristics: heat or cold storage (e.g. space heating, refrigerators), demand flexibility (e.g. washing, ventilation) or physical storages (e.g. cement industry, fresh water supply). Industrial load shifting may be limited by technical constraints, process requirements and availability of unutilized plant or machine capacity. For processes with very high utilization rates – as they are found in energy-intensive industries – only load shedding without previous or subsequent balancing can be implemented. In residential and commercial sector, typically both load shifting and shedding can be realized. Due to higher costs and losses of comfort, this study evaluates load shedding only for energy-intensive industrial processes. Table 1 provides an overview of processes and appliances included. The analysis is limited to those loads that can be shifted or shedded for at least 1 h. Detailed descriptions of their technical properties and DR behaviour can be gathered from the references cited in Table 1.

For each country, DR consumer and hour of the year, potential load increase P_{increase} and load reduction $P_{\text{reduction}}$ are assessed. Load reduction can be realized either by shedding or delaying demand, whereas load increase is equivalent to advancing the operation of processes or devices. Loads can thus be shifted to both an earlier or later point in time. In case of load shifting, every load increase is followed by a decrease due and vice versa. Flexible loads are calculated from characteristic load profiles and annual electricity demands. Furthermore, shares of used and free capacity that can be activated for DR are assessed. Annual demands are obtained from statistics or estimated based on industrial production capacities and equipment rates of domestic appliances. Given that for the North African countries no tertiary sector electricity demands and appliance equipment rates are available, only potentials in energy intensive industries are considered there.

Power demand flexibility can be compared to a functional energy storage with limited storage period. Its charging capacity is determined by the flexible load, its reservoir capacity by the maximum duration of DR interventions $t_{\text{interfere}}$, and its maximum storage period by the shifting time t_{shift}. The shifting time defines the maximum duration until load that has been advanced or delayed needs to be balanced again, whereas the intervention time reflects a limit in duration of changes in the normal demand pattern. Taking into account an annual limit in number of DR interventions f_{DR}, the storable energy per year can be calculated. Parameters limiting DR are typically depending on process cycles, physical storage capacities for intermediate products or the thermal capacity of heated/cooled goods or rooms. The assumed values for interference and shift times, as well as frequency of DR events are summarized in Table 1.

2.2. Demand profiles of shiftable loads

In order to analyse the variability of the DR potential during the year, exemplary load profiles are taken into account. As no own measurements have been performed, metered data and information about typical demand pattern available in literature are used. The share of every hour in annual electricity demand $s_{\text{load},i}$ is evaluated separately for all consumers suitable for DR. Depending on energy usage, the load profile is assumed to follow characteristic periodic seasonal, weekly and daily profiles. For technologies providing heat or cold, hourly demands are further correlated to outside temperature. Whether the electricity demand is assumed to depend on the time or temperature is indicated in Table 1 for each DR consumer.