Renewable and Sustainable Energy Reviews 64 (2016) 237–247

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Managing electric flexibility from Distributed Energy Resources: A review of incentives for market design

Cherrelle Eid [a,*], Paul Codani [b], Yannick Perez [c], Javier Reneses [d], Rudi Hakvoort [a]

[a] Delft University of Technology, P.O. Box 5015, Delft, 2600 GA, The Netherlands
[b] Group of Electrical Engineering Paris (GEEPs), UMR CNRS 8507, CentraleSupelec, UPSud, UPMC, Gif-sur-Yvette, France
[c] RITM Université Paris-Sud, LGI CentraleSupélec and Helmholtz Centre for Environmental Research – UFZ, Permoserstr. 15, 04318, Leipzig
[d] Instituto de Investigación Tecnológica, Universidad Pontificia Comillas, c/Alberto Aguilera 23, 28015 Madrid, Spain

ARTICLE INFO

Article history:
Received 11 May 2015
Received in revised form
3 April 2016
Accepted 14 June 2016

Keywords:
Demand side management
Power markets
Demand response
DR
Demand flexibility
Distributed Generation
DG

ABSTRACT

In many electric systems worldwide the penetration of Distributed Energy Resources (DER) at the distribution levels is increasing. This penetration brings in different challenges for electricity system management; however if the flexibility of those DER is well managed opportunities arise for coordination. At high voltage levels under responsibility of the system operator, trading mechanisms like contracts for ancillary services and balancing markets provide opportunities for economic efficient supply of system flexibility services. In a situation with smart metering and real-time management of distribution networks, similar arrangements could be enabled for medium- and low-voltage levels. This paper presents a review and classification of existing DER as flexibility providers and a breakdown of trading platforms for DER flexibility in electricity markets.

Contents

1. Introduction 238
2. From traditional to smart electricity systems. . . . 238
3. Distributed Energy Resources as flexibility service providers within electricity systems 239
   3.1. Consuming DER: residential loads 239
   3.2. Bi-directional DER: electrochemical storage and EVs. 240
   3.3. Producing DER: micro CHP and PV units 241
4. Markets for electric flexibility trading 241
   4.1. DER trading for ancillary services 241
   4.2. DER trading for system balancing and network congestion management 241
   4.3. DER trading in spot markets and generation capacity markets. 241
5. Incentives for efficient operation of Distributed Energy Resources. 242
   5.1. Price based methods for DER management 243
   5.2. Direct load control for DER management. 243
   5.3. Techno-economic alignment of incentives 243
6. Discussion 243
   6.1. The transition towards decentralized system operation 243
   6.2. Settlement of incentives and control: which roles for different actors? 245

* Corresponding author.
E-mail addresses: C.Eid@tudelft.nl (C. Eid), Paul.Codani@supelec.fr (P. Codani), Yannick.Perez@u-psud.fr (Y. Perez), Javier.Reneses@iit.upcomillas.es (J. Reneses), R.A.Hakvoort@tudelft.nl (R. Hakvoort).

http://dx.doi.org/10.1016/j.rser.2016.06.008
1364-0321/

7. Conclusions . . . 245
Acknowledgements . . . 246
References . . . 246

1. Introduction

Traditionally low voltage grids have been designed to transport electricity towards residential users for consumption. However, due to the increased penetration of Distributed Energy Resources (DER), low voltage grids are increasingly used as carriers of bi-directional electricity flows. The penetration of DER such as distributed generation (DG), electric storage and electric vehicles (EVs) significantly affect the operations of distribution grids [1,2]. In Germany for example, the growth of Solar Photovoltaics (PV) reached a level of 38 GW installed in 2013 and affected grid stability in some local areas [3]. Large numbers of PV installations are noticed in The United States (US) within California, Arizona and Hawaii [4]. Other examples of DER rises are a significant growth of EVs in Norway – where EVs stood for 12.5% of new car sales in 2014 – California – with almost 130.000 plug-in vehicles on the roads by the end of 2014 – and CHP in Denmark [5–7].

On one hand, this DER development is positive due to reductions in CO_2 emissions with sustainable DG, decreased use of transmission lines, increased self-consumption and the increasing independence of customers from central grid power [8]. However, regardless of those, DER is potentially problematic for grid stability and reliability due to congestion and voltage issues [9,10]. These concerns are mostly posing effects on the distribution network, which is under supervision of the Distribution System Operator (DSO) in Europe or integrated service utility (in some places in the US). The German example shows that due to local electricity over production at the sunny moments of the day, reliability of supply is endangered in distribution grids [11–13]. In France, realistic forecasts count on 450.000 Plug-in Electric Vehicles on the road by 2020 [14]; if this objective is reached, simultaneous charging of these EVs could stand for between 5 and 20% of the annual peak load [14].

Existing research describes effects of DER penetration from both a technical and economic perspective. For example, [9] and [15] discuss the impact of PV penetration on grid stability and the improvements that storage would provide. An holistic approach of DER management has been briefly discussed for the Norway sector [16]. Possibilities exist to use the vehicle to grid systems for benefits of the overall electricity system as described by [17,18]. Research highlights especially the difficulties for the DSO with increasing penetration of DER. The effects of DER on the financial position of the DSO has been presented [19] together with the possible new roles of the DSO [20,21]. A approach on how DSO charges should be set up to incorporate DER has been described [22] as well as methods to remunerate DSOs with high penetration of DER [23]. Research showed that there are problems to be solved especially for distribution pricing [24,25] and therefore an approach for such network tariff design with high DER penetration has been presented [1].

DER can provide value in smart grids with their electric flexibility [26], however a review of DER sources, their technical limitations for providing electric flexibility together with possibilities for economic trading of flexibility services is lacking. Consequently, this paper presents a review and classification of existing DER as flexibility providers and a detailed breakdown of trading platforms for DER in electricity markets.

Finally, this review ends with policy recommendations for management of electric flexibility from DER. Depending on system status and policy objectives, some arrangements might better serve system purposes than others. Due to its scope, this paper is of interest for policymakers in both liberalized and vertical integrated electricity sectors, next to electricity suppliers, network managers and emerging actors like aggregators and Energy Service Companies (ESCOs).

This paper starts with a description of general changes in the electricity system in Section 2. Section 3 presents a review of the most common Distributed Energy Resources and their technical characteristics. Section 4 presents an overview of markets for flexibility trading. Next, Section 5 reviews incentives for DER management like tariffs, contracts and direct control. After, the discussion in Section 6 presents other important factors that should be taken into account for effective market design. Lastly, in Section 7 the conclusions are presented.

2. From traditional to smart electricity systems

The development from traditional to smart systems is seen world wide, with examples in Europe [27], United States, China [28], Australia [29] and Brazil [30]. These developments in electricity sectors challenge the traditional centralized management of electricity systems. The increased penetration of renewable energy sources (RES), the distribution of electricity production, the penetration of Distributed Energy Resources and the move towards smart-metering and demand response call for a different approach on electricity consumption and production.

Supportive Feed-in-Tariffs in for example Germany incentivized the installation of small solar panels in the residential and commercial sector. In 2014 Germany had 38 GW capacity of Solar PV installed, with a large part, (more than 60%) located at low voltage levels [11]. Other examples of rapidly developing residential solar PV segment are found in Belgium (where 1 out of 13 households are equipped with a PV system), Denmark, Greece and the United Kingdom [11]. Likewise, large numbers of PV installations are noticed in The United States (US) in California, Arizona and Hawaii [4]. Electricity generation is thus increasingly placed at the distribution grid as an alternative of at the transmission grid level. This affects the distributed nature of electricity generation [8].

Demand response is a term that refers to "the 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 incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" [31]. Distributed Energy Resources (DER) e.g. Electric Vehicles (EVs), combined heat and power (CHP) units, electric water heaters and storage units are potentially providers of flexibility services, also referred to as demand response (DR). Different from the traditional view of electricity use at the distribution level, residential electricity consumers could be activated to respond on a trigger, which could be for example a price. In order to enable DER participation with the provision of demand response, smart metering together with alternative contracting and pricing methods are important requirements [27,32]. Furthermore, from a technical perspective, investments in distributed intelligence, distributed automation and in-home energy management could further facilitate the efficient operations of appliances connected at the distribution grid.