Sustainable Energy, Grids and Networks 12 (2017) 40–56

Contents lists available at ScienceDirect

Sustainable Energy, Grids and Networks

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

An optimized energy system planning and operation on distribution grid level—The Decentralized Market Agent as a novel approach

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ARTICLE INFO

Article history:
Received 18 April 2017
Received in revised form 31 July 2017
Accepted 4 September 2017
Available online 20 September 2017

Keywords:
Energy market
Distribution grid
Sector coupling
Renewable energy

ABSTRACT

The present paper proposes a concept to exploit the unused flexibility potentials in Germany's distributed heat, cold and electricity systems and to improve sector coupling and strategic utilization of decentralized systems. The authors suggest a mechanism that ensures the use of distributed heat and electricity technologies to benefit from coupling potential and make decentralized flexibilities available to central markets, simultaneously targeting a cost efficient operation and expansion planning of the distribution grid. It is assigned to a new market role, the Decentralized Market Agent (DMA). The paper discusses the necessary requirements for such a role to be implemented such as sufficient information and communication infrastructure. Furthermore, the approaches to its legal form and implementation in the energy markets are discussed, showing that the ownership structure significantly influences the potential areas of business of the proposed concept. The paper evaluates all possible approaches and shows which political focus can be met best with which concept.

1. Introduction

Considering future energy challenges and projections of continually increasing global energy demand, a transformation towards a renewable-based energy supply is a common target in many countries. This has led to an increase of small-scale generation plants as well as to an introduction of new stakeholders, especially private investors, into the energy market. Consequently, the share of distributed generation plants has increased, mainly driven by environmental factors such as limiting green-house-gas emissions or avoiding construction of new transmission circuits and large power plants. Additionally, expansion is driven by commercial aspects that include reducing price risks in electricity supply from a customer's perspective as well as enhancing national energy supply diversification from a political perspective [1]. This leads not only to a more widespread distribution of energy generation, but also to a reversion of the centralized supply structure of the electricity sector. Yet, in the heat sector, the opposite trend of distributed generation, i.e. single plants per building, towards a higher penetration of heating grids and district heat generation can be observed. According to [2] and [3] an efficient interaction between the heat and electricity sector will be beneficial to reach the goals of a renewable-based energy system. Nowadays, the German heat and electricity sector are rather independent with highly differing structures. To benefit from energy efficiency potentials and reduce primary energy consumption, the sectors will have to be coupled further [2,4].

It has been argued that distributed generation may reduce market power issues and avoid transmission cost by moving generation closer to consumption [5]. However, several challenges arise with the uncoordinated expansion of distributed generation capacities such as power quality, voltage increases and stability issues on the technical side, but also the development of necessary commercial and regulatory schemes [1]. Currently, distributed generation expansion is mainly driven by heat demand and incentives for renewable energy plants [1]. This leads to new challenges for distribution grid operators on the one hand since they face electricity feed-in on low voltage level not foreseen when planning the grid layout. On the other hand, large utilities have to adapt to a quickly changing market environment and develop new commercial arrangements to survive [1]. New stakeholders have entered the electricity markets [6] such as independent power producers (IPP) or virtual power plants (VPP), which already enhance pooling distributed generation [7–9]. However, a thorough market coupling or coordination of distributed generation with distribution grid and heat grid structures is not pursued by currently present market actors [6,10–12]. Additionally, the introduction of new technologies that could provide flexibility, such as storage systems or demand side management, is not encouraged by present structures due to unresolved conflicts of interests between stakeholders and lacking

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http://dx.doi.org/10.1016/j.segan.2017.09.001
2352-4677/

feasibility of multi-use-concepts that would allow recovering the high investments costs of these technologies [12]. Nevertheless, a higher flexibility will be necessary for rising shares of renewable energy in the heat and electricity sector, which requires not only sector coupling as mentioned above, but also means to adapt generation and demand without using high shares of conventional power plants, such as storage technologies and energy efficiency measures [13,14]. In order to tap flexibility potentials and increase renewable energy shares new concepts, aside from feed-in-tariff schemes, are necessary. These concepts should ensure that the grid structure will be transformed jointly with generation and demand structures and that local generation or storage systems support grid stability in an economic way. As stated by [15], sufficient investment signals for distributed generation are difficult to define, as they should consider all benefits of distributed generation, although the benefits might be distributed to different stakeholders.

To close the gaps caused by increasing shares of distributed generation, unused flexibility and energy efficiency potentials, difficult participation of distributed generation at central markets and open conflicts of interest and to overcome the issues discussed in [1,2,6,12,15–17], this paper presents a concept for a new market role within the European energy market structures, the Decentralized Market Agent (DMA). The paper aims at describing this concept and different means of implementation, discuss the potential benefits and constraints as well as exploring necessary prerequisites. The objective of the DMA is first, to aggregate and trade distributed electricity and heat generation as well as flexibility, and, second, to consider the coupling of the heat and electricity sectors, which also serves local grid stability. This includes showing potential ownership structures and discussing the consequences of each possible ownership structure.

To assess the concept of the DMA, this paper is divided in four Sections. Following this introduction (Section 1), a short overview of the German heat and electricity sectors as well as existing concepts are presented in Section 2 to show the crucial future challenges and regulation gaps. The concept of the DMA, areas of responsibility and potential actions and areas of business are described in Section 3. This is followed by a qualitative analysis identifying the barriers and constraints as well as regulative implications on the DMA. Section 4 contains concluding remarks and an outlook.

2. Status Quo of systems, markets and regulation

2.1. Stakeholder and market overview

Fig. 1 gives an overview of current stakeholders in the electricity and heat and cooling market in Germany based on [10,18–22]. The electricity market is characterized by a competitive generation and distribution sector, with generation plants being mainly located at a considerable distance from the consumer [10,20], whereas the heat sector end consumers are the main decision drivers regarding the technology mix since most plants are installed locally and paid for by the building's owner [23]. There is no spot or reserve market for heat, whereas electricity can be traded at these central markets as well as over the counter [24–27]. In the electricity market, a trend towards higher shares of distributed generation can be observed. This has mainly been driven by incentives such as the feed-in tariff, which basically allows risk-free investment into an RE plant. In both sectors, grid operation remains a monopoly, regulated by national entities [20,28,29]. However, a trend towards remunicipalization, especially of electrical distribution grids, can be observed in Germany [30,31]. More and more municipalities try to regain the concession for their local electricity distribution grid because they feel the need for more power in local energy supply decisions and previous management is not perceived as sufficient. A remunicipalization requires public support from citizens that has to be gained and maintained. Furthermore, municipalities lack the technical knowledge other stakeholders in the market have, giving room for doubt whether the realization and active management will actually be efficient [32–34]. In the case of remunicipalization, communities take over the role of grid operators or utilities, thus they are not included separately in the graph. According to [31], the majority of Germany's electricity distribution is now municipal.

In the heating sector, a trend towards a higher use of heating grids can be observed [35]. Central combined heat and power (CHP) plants often have better efficiencies than smaller plants used in single buildings, making heat generation less expensive [36,37]. Currently, coupling technologies are mainly of interest for end consumers who want to increase their self-consumption or integrated utilities that already possess a heating grid. However, there are scientific studies that argue coupling technologies to be essential for a successful energy system transformation [2,3]. Another part of a renewable energy system is supposed to be demand side management (DSM) as well as energy efficiency and smart grid infrastructure, neither showing high market penetration yet [12,16]. On the consumer side, it is expected that heat and electricity consumption will be coupled further, especially by electrification of heat demand [2,38].

2.2. Challenges in the electricity and heat sectors

Various political and societal discussions conceptualize the future of the energy system as holistic, integrating all relevant sectors instead of changing each sector separately. Analyzing the current structure also shows that more flexible electrical technologies, storages, power to heat or demand side management will be essential for future renewable-based energy systems [10,13,14]. In order to not only discuss these sectors jointly, but to implement and benefit from interactions various gaps will have to be overcome. **Currently none of the presented market actors pursues the market introduction** of such technologies. Although there are several incentive schemes in Germany, storage systems still lack economic viability; CHP and heat pump expansion is mainly driven by heat demand so that the systemic benefits these technologies offer are not achieved. **This lack of economic viability** and clear assignment of responsibilities to existing stakeholders hinders technology deployment [12,39].

Coupling the power and heat sector promises additional flexibilities for the electricity sector as well as a higher share of renewably generated heat for the heat sector. Both would support Germany's CO_2 reduction targets [2]. General differences between both sectors in the market structures lead to the question of **who will pursue these technologies since those who profit from a higher flexibility** in the electricity market generally, such as grid operators when flexibility is used to balance fluctuations from renewable energy sources, have little influence on technology decisions for heating systems or flexibility technologies. From the other perspective, a house owner does not benefit directly from a more flexible electricity market, thus the decision for a local CHP plant is mainly driven by heat demand, not considering other factors [5].

Those conflicts of interest, that hinder system-beneficial developments, are also visible for electric storage systems or demand side management [12,16]. A vertically integrated utility that could install and operate a storage system does not benefit directly from grid services provided by the storage, whereas the grid operator does not benefit from the utility's increased revenues at the spot market. Thus, in order to operate storage systems in a system-oriented manner, either one party has to resign part of its interest or new business models have to be found. The use of storage systems is currently rather limited to self-consumption concepts that aim at consuming electricity on which no fees have to be