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Demand response with locational dynamic pricing to support the integration of renewables

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HIGHLIGHTS

- The integration of renewables affects the locational and time dependency of costs.
- Locational dynamic pricing reflects cost variability and allows demand response.
- A theoretical framework for designing and assessing tariff schemes is proposed.
- Tariff variability depends on the locational & time dependency of its cost drivers.
- The tariff design should consider the resulting demand response incentive.

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ABSTRACT

Electricity production from centralised and decentralised renewable energy resources in Europe is gaining significance, resulting in operational challenges in the electricity system. Although these challenges add to the locational and time dependency of the underlying cost of operating the system, this variability in time and location is not reflected in residential tariff schemes. Consequently, residential users are not incentivised to react to varying system conditions and to help the integration of renewable energy resources. Therefore, this paper provides a theoretical framework for designing a locational dynamic pricing scheme. This can be used to assess existing tariff structures for consumption and injection, and can serve as a theoretical background for developing new tariff schemes. Starting from the underlying costs, this paper shows that the potential for locational dynamic pricing depends on the locational and time dependency of its cost drivers. When converting costs into tariffs, the tariff design should be determined. This includes the advance notice of sending tariffs to users, and the length of price blocks and price patterns. This tariff design should find a balance between tariff principles related to costs, practicality and social acceptability on the one hand, and the resulting demand response incentive on the other.

1. Introduction

The future electricity system in Europe is covered by blurriness. Due to European emission reduction targets towards 2020 and 2050, thermal technologies at the generation side are complemented with both centralised and decentralised renewable energy resources (RES) such as solar plants and wind farms.

The implementation progress of these technologies leads to challenges at the operational and economic level (Cossent et al., 2011). At the operational level, centralised and decentralised generation from RES lead to local and global problems in the electricity system. Examples of these are adequacy, reliability and power quality issues. At the economic level, these challenges trigger generators and system operators to invest in generation plants and transmission & distribution networks (Chao, 2011).

Currently, residential users are subject to flat or day–night electricity tariffs. These do not capture the operational and economic challenges of a large-scale integration of RES, as they don't reflect their variable, uncontrollable and unpredictable nature. Moreover, a flat or day–night tariff doesn't incentivize residential users to react to the status of the electricity system in order to support the integration of renewables. Instead, operational problems at the global system level are restored by flexibility provision from the centralised generation side. Potentially, this results in high costs. Problems at the local distribution

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level come at the expense of power quality issues, lost load or lost production, unless new investments are made. As residential consumers and producers face flat tariffs, the role of residential consumers and producers is neglected.

Although the traditional pricing system is still prevalent, the setting in which energy companies are operating is changing. Next to the integration of RES, aging transmission and distribution (T&D) networks require utilities to invest in new technologies (Jongepier, 2007). Moreover, technological breakthroughs in ICT, automation and metering lead to the capability of transforming the traditional electricity system into a system in which both RES and demand are valued against their contribution to the whole electricity system. One way to accomplish this is by adopting locational dynamic pricing (LDP).

LDP allows capturing the locational and time dependency of costs (Bohn et al., 1984). In turn, LDP can influence the location and time of consumption and production (Strbac and Mutale, 2005). This is also referred to as demand response (Albadi and El-Saadany, 2008). In this case, residential consumers and producers contribute to a more efficient electricity system, in which flexibility is attained from residential consumption and production in order to overcome the local and global challenges RES bring. The amount of residential flexibility which is triggered depends on the tariff design of LDP.

In order to evaluate the potential of constructing an LDP scheme in view of incentivising demand response, first the underlying costs of consuming and producing electricity need to be assessed. Therefore, a theoretical framework is built, as depicted in Fig. 1. It starts from costs which are incurred at the generation, T&D, and retail level. These costs are translated into a tariff scheme according to some general principles of tariff design. Depending on the potential for locational and time dependency of tariffs and the accompanying tariff design, traditional and locational dynamic pricing can be applied to charge both flexible and inflexible demand & production. Consequently residential flexibility can be triggered based on these locational dynamic pricing schemes.

In the literature, demand response is often neglected when constructing a tariff scheme. The design is mainly based on principles related to cost and practicality (Pérez-Arriaga and Smeers, 2003; Reneses et al., 2011). Other papers, which are primarily based on experimental projects, mainly focus on incentivising demand while harming some of the cost related principles (Herter and Wayland, 2010; Reiss and White, 2005). In contrast, this paper discusses the impact and relationship between costs and practicality on the one hand, and demand response on the other. This is done by following a structured approach in which the impact of RES on the need for locational and time dependency of tariffs is pointed out.

The remainder of this paper is structured as follows. In Section 2, general principles of tariff design are discussed and applied to traditional and LDP tariff schemes. Afterwards, Section 3 gives a more detailed perspective on LDP for consuming electricity by evaluating the potential of making each tariff component locational and time dependent. Section 4 elaborates on the potential of LDP for residential production of electricity. While the previous sections focussed on the theory, Section 5 highlights some practical considerations which should be taken into account. Next, Section 6 assesses how the tariff design of LDP can affect the incentive for demand response and how this relates to the general principles of tariff design. To clarify the theoretical concepts discussed in this paper, Section 7 constructs and assesses four illustrative tariff schemes. Finally, Section 8 concludes.

2. Locational dynamic pricing based on general principles of tariff design

2.1. Principles of tariff design

In a liberalised electricity system, a distinction is made between the regulated and competitive part of the system. Typically, the T&D network is considered as regulated and operated by a transmission system operator (TSO) and a distribution system operator (DSO) respectively, while competition is introduced in generation and retail activities. Both regulated and competitive parties incur costs and convert them into tariffs taking into account general principles of tariff design.

In the literature, a wide variety of general principles of tariff design is provided. In Bonbright (1961) general principles for public utility tariffs are discussed. (Berg and Tschirhart, 1988) focusses on

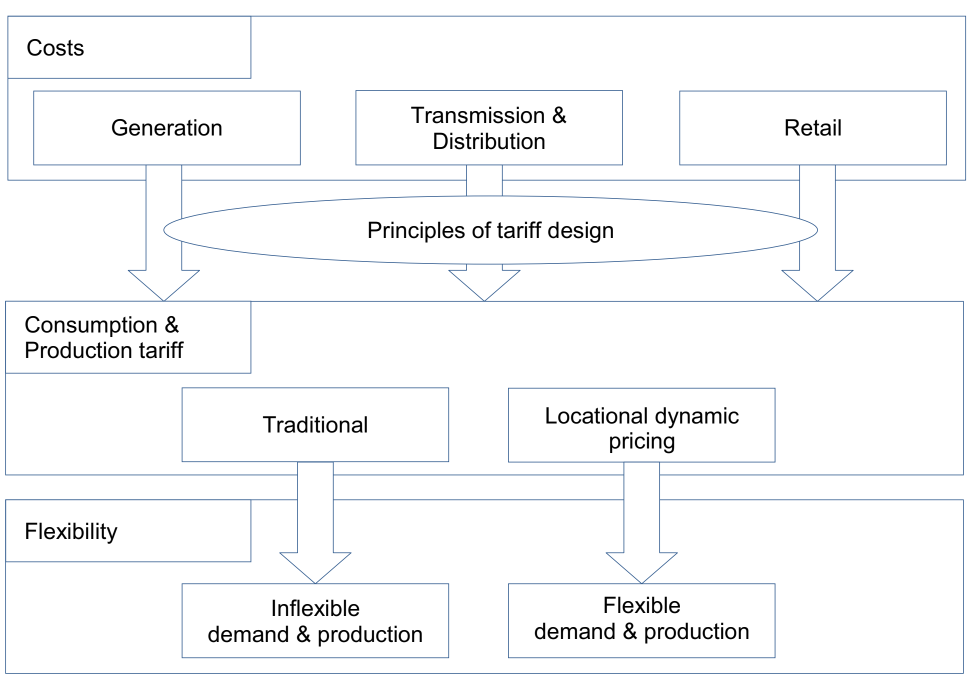

Fig. 1. Theoretical framework of locational dynamic pricing.

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