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Analysis of reflectivity & predictability of electricity network tariff structures for household consumers

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ABSTRACT

Distribution network operators charge household consumers with a network tariff, so they can recover their network investment and operational costs. With the transition; towards a sustainable energy system, the household load is changing, through the introduction of photovoltaics and electric vehicles. The tariff structures which are currently employed in the EU are either capacity and/or energy consumption based. In light of the changes in the household load the question whether these tariff structures are the most suitable merits renewed attention. In this work, the cost-reflectivity of various tariff structures has been computed based on a distribution network planning approach. Next to this, the predictability of a network tariff, i.e. how much change would a household experience in network charges in two consecutive years has also been computed to gain insight into how well users will be able to react to the tariff. The results show that a peak load based network tariffs score best on the reflectivity while having an acceptable level of predictability. The switch from an energy consumption based network tariff, which is now most often applied, towards a peak load based network tariff should therefore, be considered.

1. Introduction

Access to electricity is seen as a public good, not only because of the capital intensive nature of electricity network investments but also because electricity is seen as a primary good. The distribution network operator (DNO) is responsible for the electricity network that connects the residential consumers to the power system. The DNO is therefore often operating in a regulated monopoly environment. This is different from the generation and wholesale of electricity which often takes place in a deregulated market environment. In these unbundled markets the end-user pays a separate tariff for the energy he consumes and for his connection to the network which transports this energy. For the regulated environment in which the DNOs operate, the regulator is charged with setting the maximum income level of a DNO. Depending on the regulations, the method by which the DNO can charge the consumers to generate this income is up to the DNO to decide or fixed by the regulator. The employed tariff structure is dependent on the policy goals one tries to achieve. Ensuring affordable access to electricity, reducing greenhouse gas emissions, and the ease of understanding of the tariff, among others, play a role in the determination of the residential network tariff structure. In most European countries the tariff structure is primarily dependent on the amount of energy a consumer has used. Only Sweden, Spain, and the Netherlands employ a tariff structure which (also) has a capacity component and in Italy, one is being introduced. In these countries, the capacity component in the case of household consumers, is however, a fixed component (AF - Mercados EMI, 2015). The problem with the cost-reflectivity of the grid tariff has already been noted in research by Picciariello et al. (2015), Eid et al. (2014) among others. The need for further research is motivated by the changes in the energy use of residential consumers due to the transition to a sustainable energy system. With rooftop PV, residential consumers are also becoming producers and can feed energy back into the grid. The rise in PV generates additional problems for the operation of the grid. An energy-based grid tariff, for instance, lets the consumers with PV actually pay a lower contribution to the DNO, while in fact, they increase the cost for the network operator. On the other hand, the introduction of electric vehicles (EVs) or heat pumps can double the peak usage of a single household (Nijhuis et al., 2015). These changes give rise to the question whether the current grid tariffs structure employed by DNOs is still tenable or if changes to the tariff structure would be required, see e.g. Cossent et al. (2009) for the effects of distributed generation and (O'Connell et al., 2012b, 2012a) for tariff based congestion prevention in the case of EVs.

The network tariffs should cover the cost of the DNO. DNOs have

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next to the general cost of doing business (overhead, cost of capital, etc.) expenses related to network investments and energy losses within the network. The regulator generally sets the maximum income level the DNO may achieve to cover all these costs. The question of the network tariff is: which part of this cost each of the individual consumers should pay according to their contribution to the energy losses and network investments. The challenge with the creation of a cost-reflective grid tariffs for the residential consumers is the dependency of both these cost components on the other residential consumers. The required strength of a residential low voltage network is based on the combined peak load of the connected consumers (Koliou et al., 2015). The loading of an individual consumer is however volatile and has a low correlation with the load of other individual consumers (Nijhuis et al., 2017a), meaning the peak load of a single consumer is not directly related to the peak load of the network. The losses within the network have a quadratic relationship with the loading of the network, so no simple linear relationship exists between the load profile of a single consumer and the losses within the network. For non-residential consumers, the relationship between the costs and a specific user is more apparent as dedicated network investments are often needed. The available network capacity can be used more easily as a guide for the network tariff for these types of users (Sotkiewicz and Vignolo, 2007; Li and Tolley, 2007; Li et al., 2010). For residential consumers, this is however not the case.

With the introduction of an advanced metering infrastructure, other tariff structures become possible for residential consumers. To make full use of the additional capabilities of the smart meters more dynamic network tariffs have been proposed, for instance, based on generating a multiple tier time of use tariff (Wang and Li, 2011; Sigauke et al., 2013; De Oliveira-De Jesús et al., 2005). For these dynamic tariffs to induce a reduction in the peak demand, the tariff should be implemented via automation of smart appliances (Newsham and Bowker, 2010) or the tariff should consist of an auction-based pricing structure (Verzijlbergh et al., 2014; Weckx et al., 2013). The reactions (behavioural changes) of users to these more dynamic tariffs have also been investigated (Schreiber and Hochloff, 2013; Stokke et al., 2010; Bartusch et al., 2011; Kobus et al., 2015; Faruqui et al., 2015). These tariff structures can become opaque for the consumer due to their complexity and often require autonomously operating appliances. Next to this, the influence of a single user on the loading of the residential low voltage (LV) network can be large, making more dynamic network tariff structures hard to implement. More simple network tariffs structures, like capacity based tariffs, should therefore still be considered.

The use of a capacity tariff for residential consumers to generate a higher cost-reflectivity has been proposed throughout the years (Berg and Savvides, 1983; Hledik, 2014; Dupont et al., 2014; Jargstorf and Belmans, 2015; Tuunanen et al., 2016). A quantitative assessment of the reflectivity of the network tariff is however often missing. In all of the aforementioned studies the cost-reflectivity is only addressed in the form of the effect on the loading of the network for a single group of consumers, not taking into account the large diversity in the number of consumers connected to a single MV/LV transformer (less than 20 consumers for rural areas, while over 200 consumers for urban areas). In Jargstorf and Belmans (2015) the network cost is assumed to scale with the peak contribution of the user and in Jargstorf et al. (2015) the network reinforcement cost are taken into account. Both of these approaches do not fully assess the investment cost for a DNO based on the contribution of a single user. Therefore an approach in which the influence of a single consumer on the network cost is determined has to be developed.

In this paper, the reflectivity of different network tariff structures for residential consumers will be assessed. The assessment of these different tariff structures will be done based on the part of the network cost which can be contributed to a single consumer. In order to do this a characterisation of the household load which allows for the assessment of the impact on the network of each individual consumer is proposed. Through the use of reference network models, the reflectivity of the network tariff for individual consumers can be determined. Different tariff structures are subsequently assessed in terms of reflectivity and predictability. To get a better idea on the appropriateness of different tariff structures first a small introduction into network tariffs is given in Section 2. The different tariff structures which are assessed are also discussed in Section 2. The approach to the evaluation of the different policies with respect to the tariff structure and the metrics which are used to evaluate the tariffs are discussed in Section 3. The results for the case of the Dutch network are shown in Section 4, after which the conclusions and the implications for the network tariff policy are discussed.

2. Network tariff structures

To start the discussion on the network tariffs, first of all, the goals of a network tariff will be discussed. After the goals are discussed, the current tariff structure in the EU will be examined, followed by a discussion on the household load and the distribution network cost. Based on the characteristics of the household load, different tariffs structures are defined in the Sections 2.5–2.9.

2.1. Network tariff goals

In the determination of the network tariff, the first thing the regulator is concerned with is setting an adequate revenue allowance for the DNO, i.e. the maximum income of the DNO. Multiple options exist for setting the total level of income a DNO can obtain. If multiple DNOs exist in one country, yardstick regulation can be employed. If this is not the case, the revenue allowance can be based on an estimation of the marginal cost of the DNO. Both these methods have been discussed in the literature. Nonetheless, when a certain revenue allowance is set, the question still remains how much each end-user should contribute to this allowed revenue. To distribute the cost among the users, the DNO should determine the tariff structure. The policy goals with respect to the network tariff structure (Pérez-Arriaga et al., 2013; Vivek and Parsons, 2010) are discussed in the next subsections.

2.1.1. Cost-reflectivity

The cost-reflectivity, i.e. the amount of tariff a user pays versus the cost the DNO incurred due to the use of its network, is often the main tariff goal. This can be a combination of two subgoals: cost-causality and equity. These two measures should respectively ensure that a tariff reflects the contribution of each network user to the cost of the network, as well as that the tariff does not discriminate between users. If the cost-reflectivity of the network tariff is not adequate, the user will not face a lower tariff if their network usage is reduced, as the relationship between the network usage and the tariff paid is lacking.

2.1.2. Allocative efficiency

Different consumers have different valuations of energy; in order to achieve a maximum utility, the tariff and the supplied service level should be matched with how much a consumer values the service.

2.1.3. Accessibility to electricity

Access to energy in general and electricity, in particular, is seen as a necessary good. Every user should, therefore, be able to have access to the network irrespective whether it is economically profitable for the DNO or not.

2.1.4. Transparency

How each of the consumers is charged for their network usage should be clear.

2.1.5. Simplicity

The network tariffs should be easy enough to understand for all