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Future-proof tariff design: Recovering sunk grid costs in a world where consumers are pushing back

Tim Schittekatte [a,b,c,*], Ilan Momber [c], Leonardo Meeus [a,c]

[a] Florence School of Regulation, Robert Schuman Centre for Advanced Studies, European University Institute, Via Boccaccio 121, I-50133 Florence, Italy
[b] Réseaux Innovation Territoire et Mondialisation Université Paris-Sud, 91400 Orsay, France
[c] Vlerick Business School, Vlerick Energy Centre, Bolwerklaan 21, B-1210 Brussels, Belgium

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ABSTRACT

Traditional analysis of distribution network tariff design assumes a lack of alternatives to grid connection for the fulfilment of consumers' electricity needs. This is radically changing with breakthroughs in two technologies: (1) Photovoltaics (PV) enable domestic and commercial consumers to self-produce energy; (2) Batteries allow consumers and self-producers to gain control over their grid energy and capacity parameters. Contributing to the state of the art, the grid cost recovery problem for the Distribution System Operator (DSO) is modelled as a non-cooperative game between consumers. In this game, the availability and costs of the two named technologies strategically interact with tariff structures. Four states of the world for user's access to technologies are distinguished and three tariff structures are evaluated. The assessed distribution network tariff structures are: energy volumetric charges with net-metering, energy volumetric charges for both injection and withdrawal, and capacity-based charges. Results show that in a state of the world with new technology choices for grid users both efficiency and equity issues can arise when distribution network charges are ill-designed.

1. Introduction

In Europe and the USA there is an observable trend towards volumetric network tariffs (in €/kWh) being gradually replaced by capacity-based network tariffs (CEER, 2017; European Commission, 2015; Hledik, 2015). Especially a volumetric tariff accompanied with net-metering,[1] the network tariff design historically in place, is challenged both in the media[2] and in academic circles (e.g. Comello and Reichelstein, 2017; Darghouth et al., 2011; Eid et al., 2014; Pérez-Arriaga et al., 2017). Volumetric network charges with net-metering are inefficient as they over-incentivise PV adoption. Namely, under net-metering active consumers installing PV panels see their electricity bill decrease not only because of lesser electricity consumption, but also because of significantly lowered network charges. This is an issue as their costs inflicted on the network do not necessarily change. Net-metering is also perceived unfair; the total network costs need to be recuperated and therefore passive consumers without PV panels see their electricity bill increase by the network charges that active consumers manage to offset. In this paper, a game-theoretical model is applied to address the following two research questions:

1. (1) Do capacity-based network charges solve the efficiency problems experienced with volumetric charges with net-metering?
2. (2) Do capacity-based network charges allow active consumers, investing in PV and batteries when incentivised, to be better off at the expense of passive, sometimes vulnerable, consumers?

It is shown that the answers to both research questions depend on the technology cost scenario. The answers are further nuanced as a result of the chosen modelling approach. Conventionally, papers analysing network tariff design (e.g. Borenstein, 2016; Brown et al., 2015; Hledik and Greenstein, 2016; Simshauser, 2016) qualitatively

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* Corresponding author at: Florence School of Regulation, Robert Schuman Centre for Advanced Studies, European University Institute, Via Boccaccio 121, I-50133 Florence, Italy.
E-mail addresses: tim.schittekatte@eui.eu (T. Schittekatte), ilan.momber@vlerick.com (I. Momber), leonard.meeus@vlerick.com (L. Meeus).

[1] Net-metering is the practice by which consumers are accounted solely for their net electricity consumption from the grid when distribution charges are determined.

[2] E.g.: Pyper, Julia. 2015. "Ditching Net Metering Is in the 'Best Interest' of Solar, Say MIT Economists." *Greentech Media*. Accessed on 15/04/2017. www.greentechmedia.com/articles/read/MIT-Economists-Say-We-Should-Ditch-Net-Metering.

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discuss or exogenously consider the interaction between the adoption of in Distributed Energy Resources (DER) and network tariff design. In this paper, the grid cost recovery problem for the DSO is represented as a non-cooperative game between consumers. In this game, reactive consumers can strategically opt out of part of the grid use by investing in DER. Their investment in DER is endogenous and differs depending on the grid tariff design in place. By opting out of part of the grid use, reactive consumers shift grid costs to passive consumers and at the same time compete to reallocate the grid costs to one another. The added insight obtained from this modelling approach is that it considers uncoordinated investment decisions by reactive consumers. Uncoordinated consumer decisions can result in an overall efficiency loss when price signals, in this case network charges, are not designed properly.

The reallocation effect is not captured by Borenstein (2016), Brown et al. (2015), Hledik and Greenstein (2016), and Simshauser (2016). Hledik and Greenstein (2016) and Simshauser (2016) argue that capacity-based charges (in € per kilowatt (kW) peak) are an attractive option to replace volumetric network tariffs. These authors contend that capacity-based grid charges would avoid inequitable bill increase and allow for better cost reflection. However, not everyone agrees. Borenstein (2016) reasons that challenges arise as a significant part of the network costs are residual or sunk costs.[3] He states that there is no clear guidance from economic theory on how to allocate such costs as cost causation is unclear. He argues that almost surely a combination of higher fixed charges and an adder to time-varying volumetric charges would be the least bad policy option. Similarly, Brown et al. (2015) do not identify any single best option for the recovery of residual costs. They state that the recovery of residual costs through fixed charges would result from prioritising the principle of efficient prices.

Typically, models with a similar mathematical structure as in this paper have been used to analyse imperfect competition in (power) markets (see e.g. Gabriel et al., 2012; Gabriel and Leuthold, 2010). In such equilibrium problems, the numerous optimisation problems are connected, e.g. via either an equilibrium constraint (supply equals demand) or the inverse-demand function in each agent's objective function. In the past, there was no need to apply a similar modelling approach when studying distribution network charges as consumers had little means to react strategically to the tariffs imposed on them. However, this assumption does not hold true anymore. This is mainly due to the sharply decreasing costs of two technologies: photovoltaics (PV) and batteries (see e.g. Lazard, 2016a, 2016b; MIT, 2016; RMI, 2015). These two technologies allow grid users to react to the way electricity supplied by the grid is priced. PV enables consumers to self-produce energy and lowers the net energy need from the grid, while batteries enable self-producers to regulate both their grid energy flows and capacity parameters. Suddenly, network tariff design has become a concern. As described by Pollitt (2016): "The rise of distributed energy resources (DERs) offers increased opportunities to exploit the existing system of network charges in ways that were not originally envisaged." If network tariff design does not anticipate the new sets of actions available to consumers, grid cost recovery for the DSO and a fair allocation of costs are at risk.

In this new setup, instead of an equilibrium constraint or inverse-demand functions, the optimisation problems are linked by introducing a 'grid cost recovery (equilibrium) constraint'. More precisely, the stylised game-theoretical optimisation model presented in this work consists of linked individual optimisation problems of consumers which are minimising their cost to satisfy their electricity demand. The individual optimisation problems are linked with a "grid cost recovery constraint", stating that the total network charges paid by all consumers should equal the total network costs to be recovered by the DSO. By doing so, the optimisation problem of one consumer is impacted by decisions of other consumers. An equilibrium is found when the grid costs are recovered by the DSO and the consumers have no incentive anymore to change their reaction to the network tariff.

Three illustrations have inspired this paper: Zugno et al. (2013), Momber et al. (2016) and Saguan and Meeus (2014). Zugno et al. (2013) build up a game between an electricity retailer and consumers who are reacting to the electricity price set by the retailer by shifting their load. Similarly, Momber et al. (2016) model an aggregator which takes decisions on optimal bidding strategies in the electricity market and on the retail price, while being subjected to decisions of cost-minimising electrical vehicle (EV) owners. Saguan and Meeus (2014) introduce a competitive equilibrium model to calculate the cost of renewable energy in four states of the world, i.e. with renewable trade versus without renewable trade, and with national transmission planning versus international cooperation on transmission planning.

The remaining parts of the paper are structured as follows. In Section 2 the methodology of the paper is highlighted. In Section 3, the proposed model is described in detail. In Section 4, the setup of the numerical example, data and the technology cost scenario matrix is presented. The results are discussed in Section 5. Lastly, a conclusion is formulated and possibilities for future work are summarised.

2. Methodology: three tariff structures, two metrics and four states of the world

Three different tariff structures (TS) are analysed[4]:

- **TS1**: Volumetric network charges with net-metering.
- **TS2**: Volumetric network charges without net-metering, bi-directional metering is applied. Network charges are paid for both each kWh withdrawn and injected and at the same rate.
- **TS3**: Capacity-based charges based on the observed individual peak power withdrawal or injection from the grid over a certain duration (e.g. hourly or quarter-hourly).[5]

The outcomes of the tariff structures are benchmarked with the application of fixed network charges. Fixed network charges serve as a reference as they do not distort the volumetric (€/kWh) and capacity (€/kW) price signal and grid costs are assumed sunk.[6] Going entirely off-grid is not considered an option for consumers in this paper. This is not a strong simplification as Hittinger and Siddiqui (2017) find that the financial case for grid defection is limited or non-existent given current costs and prevalent policies. Two metrics are introduced to quantify the results. Firstly, a proxy for (in)efficiency is used to quantify the increase of the total system cost as compared to the reference case with fixed network charges. Secondly, a proxy for equity is introduced by looking at the allocation of the sunk costs for different consumer's types under the different tariff structures.

A 'Technology costs matrix', with four extreme states of the world, is set up to analyse the impact of dropping investment costs in PV and batteries (Lazard, 2016a, 2016b; MIT, 2016; RMI, 2015). This matrix is displayed in Table 1. Each state of the world represents a unique combination of costs related to the technologies.

In the past, a consumer did not have much means to react to electricity prices as DERs were too expensive to invest in. Today, residential PV

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[3] This is especially true in networks experiencing low or no load growth for which costs occurred in the past to dimension distribution grids to the expected peak capacity needed in the local system (Pérez-Arriaga and Bharatkumar, 2014).

[4] No time or locational variation in the rates is assumed, solely the 'structure or format' of the tariffs differ. See Pérez-Arriaga et al. (2017) for a discussion more focussed on the time and locational granularity of distribution tariffs.

[5] Currently, in most cases, low voltage users are being billed by the contracted capacity, and not through an observed maximum capacity. However, with the envisioned mass roll-out of smart meters accurate maximum capacity charging of network users will be enabled (Eid et al., 2014).

[6] Other quantitative work on network tariff design (Brown et al., 2015; Hledik and Greenstein, 2016; Simshauser, 2016) assume 'revenue neutrality' for the network operator when assessing different tariff structures with a consumer database. Assuming revenue neutrality is from a modelling perspective not different than assuming grid costs are sunk.