STUDYING THE ALLOCATION OF DISTRIBUTION COST WITH A MULTI-AGENT SIMULATOR

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Overview

The traditional approach employed for the design of electricity distribution charges (the distribution component of the overall retail electricity tariff) has been challenged over the last few years as a consequence of, amongst other factors, the substantial integration of distributed energy resources (DER) [1]. Under a traditional approach, distribution charges are mostly composed of volumetric fees (€/kWh) [2-6]. However, the efficiency of those fees has been questioned by many authors in the existing literature, e.g. [6-8]. These authors highlight that, under the assumption that the grid costs are sunk, the allocation of the distribution costs amongst the users of the DSO, when volumetric fees are applied, is not performed in a cost-reflective and non-distortive fashion. Moreover, in the context of DER integration, distorting volumetric network fees provide incentives for potential DER owners to decrease their energy consumption by deploying behind-the-meter devices such as photovoltaic (PV), thus reducing their network charges. In these cases, the status quo amongst users may result unbalanced since the avoided network fees of DER owners are born by non-DER owners, who see their electricity bills increase, creating both cross-subsidies amongst users and a potential spiralling of the distribution prices ("death spiral" of the utility) [8].
As a consequence of the challenges posed by conventional volumetric distribution fees, there is a tendency in Europe and the US to replace these fees with capacity based ones (€/kWp) [9]. Such a shift, nonetheless, is not supported by all studies. For example, in [9,10], quantitative evaluations of the effect of capacity fees show their potential for creating cross-subsidies and increase the distribution fees. Thus, these authors argue that the "death spiral" potential of distribution tariffs is as likely with volumetric distribution tariff designs, as it is with capacity ones.
Most of the existing studies agree that fixed distribution fees are bound to provide stable revenues for the DSO and eliminate potential cross-subsidies amongst users. In [11], the author states that, since a substantial proportion of the network costs are sunk, there is no clear economic guidance on how to allocate those costs, and proposes a fixed fee along with time-varying volumetric adders as the best solution. In [9], the author uses fixed fees as a reference case to be compared against volumetric and capacity based fees.
Studying this problem is, then, of great relevance in the context of the energy transition, where the deployment of DER is being globally stimulated by means of incentive mechanisms. In this context, different studies [6-10] have offered various assessments or solutions (qualitative and quantitative). In our work, we propose a novel multi-agent simulator, in which DSO, consumers, and prosumers are modelled as non-cooperative agents. Under a set of assumptions, we can model the evolution of a stylised distribution network in terms of distribution tariff and DER deployment. We divide the distribution tariff into volumetric, capacity, and fixed terms, introducing the proportion of each one (which is regulated) as an exogenous variable of the simulator. This simulator can be used to quantitatively test the impact of different tariff designs on the evolution of distribution networks (as a function of the distribution tariff and the DER deployment). A sensitivity analysis to those terms is presented in this work, where insights on the most adequate regulated proportions of each term, according to different objectives, is provided.

Methods

In the multi-agent model proposed in this paper, non-cooperative prosumers try to maximise the value of a DER installation. The DSO is entitled to adjust the distribution tariff so that it fully recovers the **costs** of providing the distribution service (accounting for the exogenous proportions of volumetric, capacity, and fixed terms provided as initial conditions). Such **costs** are computed ex-ante, assuming: (1) at the initial conditions the DSO is economically balanced, (2) a number of consumers (*cons*), (3) an annual energy consumption per consumer (*demand*), and (4) a hypothetical fully volumetric distribution tariff (*fee*). Then, once the initial costs are computed (*cons* × *demand* × *fee*), the simulation can be run by assuming those costs constant over time. The various agents then perform actions at every time-step, making the system dynamically evolve. The simulation runs until the horizon of the discrete time dynamical system is achieved. There are three types of agents:
<u>*Consumers*</u> are modelled with annual energy (kWh) and capacity (kWp). At every time-step, they just pay the distribution fee.
<u>*Prosumers*</u> are modelled by means of a yearly consumption profile (hourly resolution), an annual peak demand, and the solar load factor of a potential DER installation (hourly resolution). At every time-step, every prosumer who has not deployed a DER installation yet (potential prosumer) solves a mixed integer linear program (MILP) aiming at

maximising the **value** of an **optimally** sized DER installation (PV and battery capacities are decision variables of the MILP). The **value** of the installation is the avoided electricity costs (commodity, transmission, distribution, and others), in addition to the revenues from the electricity sold to the grid (at a selling price). After the MILP, the electricity cost of every potential prosumer is compared to the value of their DER installations. Then, an investment decision process (IDP) is taken by every potential prosumer, modelled through a Bernoulli distribution whose parameter *p* is biased with the comparison electricity costs vis-à-vis value of DER installation. The result of such an IDP will be either 1, in this case the optimally sized DER installation is deployed; or 0, in this case the potential prosumer does not deploy the DER installation, and another opportunity will be provided for this particular potential prosumer at the subsequent time-steps.

The ***DSO*** is modelled through its remuneration mechanism. At every time-step, the DSO collects revenues from consumers and prosumers. If the revenues match its costs, the distribution tariff remains unaltered. However, if the revenues differ from the costs, the DSO must increase (or decrease) the distribution tariff.

Results

A test case has been generated with 1000 potential prosumers and 5000 consumers. The evolution of the distribution costs and the deployment of DER can be reported as trend curves. The final situation of the distribution network (distribution costs, as well as deployed PV and batteries) can be compared for distinct initial conditions: (i) different proportions of volumetric, capacity, and fixed terms; (ii) different selling prices for prosumers; (iii) different technology costs (PV and batteries); (iv) different discount rates for the DER installations; or (v) different initial costs of the DSO. Results show that, indeed, the prosumers reduce their electricity bills by, amongst other reasons, reducing their contribution to the distribution costs. In consequence, the DSO suffers an imbalance in is remuneration mechanism (less revenues than expected) and must increase the distribution tariff for the following time-step. This effect is observed when volumetric or capacity fees are applied. In the former, the prosumers reduce their energy consumption and, in the latter, they reduce their peak demand (by installing batteries). However, when fully fixed fees are applied, the distribution tariff remains unaltered since the prosumers cannot defect from the grid. Interestingly, a significant amount of DER installations are deployed under a fixed distribution tariff, which indicates that there is an incentive for the prosumers to avoid energy consumption (lowering the commodity component of their electricity bills), and to sell electricity to the distribution network at the market price.

Conclusions

This paper has addressed the topic of evaluating different designs for the cost allocation of the distribution costs. A multi-agent simulator is proposed where non-cooperative potential prosumers try to maximise the value of a DER installation. In this setting, the DSO can adapt the distribution tariff in order to recover its costs. The distribution tariff has been divided into volumetric, capacity, and fixed terms. These terms are introduced as exogenous variables and therefore both the prosumers and the DSO are modelled according to those rules. The main contributions of this work are:

(i) a sensitivity analysis of different proportions of these exogenous variables, assessing their impact on the evolution of distribution networks in terms of distribution tariff and DER deployment.

(ii) a sensitivity analysis to other exogenous variables i.e. technology prices, discount rates, electricity selling prices for prosumers, and initial distribution costs is provided.

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