INCENTIVIZING CONSUMER RESPONSE THROUGH COST-REFLECTIVE DISTRIBUTION NETWORK CHARGES

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ABSTRACT

The emergence of distributed energy resources (DERs) provides the alternative to consumers to partially or fully self-provide electricity needs. In this context, efficient tariff design should guide efficient DERs deployment. Retail electricity prices, composed of energy prices, network charges and other regulated charges, play a role in influencing the short- and long- term decisions taken by consumers. In order to incentivize consumer response, correctly designed tariffs are needed that reflect consumer's impact on network cost while fully recovering those costs. Through numerical case studies, this paper demonstrates how different tariff designs are able to yield to different consumer responses. Within each tariff design, the consumer takes optimal decisions to minimize his total costs. Three different tariff designs are presented: first, a tariff that includes a flat energy price with fixed network charges; secondly a volumetric network charge instead of fixed; and thirdly, cost-reflective network charges consisting of distribution locational marginal prices to price energy, advanced demand charges to allocate part of the network costs and fixed charges to allocate the residual part of network costs.

INTRODUCTION

The nature of distribution network is changing as it serves an increasing demand and accommodates higher penetrations of Distributed Energy Resources (DERs), through which they hold many concerns as well as opportunities. While the major concerns are related to the increasing cost of the network due to necessary investments to cope with the new situation, opportunities arising from demand response have the potential to fully or partially resolve them. The deployment of DERs could mitigate or postpone network reinforcements. Thus, regulators are interested in integrating demand response into the planning phase in order to efficiently use the existing network and invest only in the required reinforcements. In [1], the potential benefits of demand-side flexibility, are discussed such as improving long- and short- term security of supply, reducing market prices and network costs, along with environmental and social benefits. The report also discusses some barriers to demand response where one of which is the current grid tariff structures that could create an unfair allocation of costs among network users and inefficiently guide them through DER investment decisions.

The energy and distribution network costs are recovered through two components of the electricity bill: the energy prices and the network charges. For energy prices, some suppliers provide their consumers with hourly averaged energy prices, others use Time of Use (ToU) tariffs, while the rest use a flat tariff. Whereas for network costs, they are commonly either integrated within the energy prices if the Distribution System Operators (DSOs) charge consumers through volumetric tariffs, or they are charged according to the coincidental peak consumption with network use or the maximum peak consumption of each consumer. If the tariff design is able to correctly signalize the consumer regarding those two parts, the consumer will react accordingly. A number of researches have drawn the attention to the importance of energy prices in demand response through dynamic pricing as in [2], [3], while others included the locational aspect as in [4]–[6]. However, the link between network charges and demand response remains missing, where an attempt was presented in [7] as the authors allocated distribution network usage costs among distributed generators and demand response resources using optimal power flow (OPF) and MW-mile approach. To the authors' knowledge, no other papers addressed the gap between distribution network tariff and demand response.

Consumers could be passive, as they have been traditionally known, or active, as they react to prices. There are different types of demand response programs as in [8], which are divided into two main options: price-based and incentive-based. Price-based provide economic signals to consumers to modify their consumption profile through time-differentiating tariffs. Incentive-based options such as demand bidding/buyback, direct load control, etc, provide incentives for consumers to curtail their consumption during certain periods such as network congestion. Moreover, consumers could further respond to tariffs by investing in DERs and becoming prosumers, i.e. producers and consumers, where they can withdraw and inject power into the network. Hence, the way the tariff is structured influences the consumer's reaction, whether to respond or not, and the type of demand response.

Currently, the main barrier for consumers to provide demand response arises from the tariff structure's lack of incentives. Why would consumers modify their consumption habits, curtail power or invest in DERs even though the current tariff they are receiving does not signalize them with the need to do so? This is because consumers are not paying the real value of their consumption as traditional tariff designs do not reflect their actual impact on the network, and costs are usually averaged or socialized. Thus, DSOs need to depart from traditional network tariffs to a cost-reflective tariff. According to the conclusions and recommendations of [9], cost-reflective network tariffs are expected to contribute to demand response while providing adequate revenues for DSOs. Therefore, to incentivize and promote consumer response, consumers should receive a cost-reflective tariff that assigns network costs to them according to their impact on the network, guiding them to efficiently use the network through economic signals affecting their short-term operational decisions and their long-term DER investment decisions, while recovering network costs.

This paper aims to discuss the impact of different tariff designs composed of energy prices and network charges on consumer response. The paper demonstrates how different tariff structures (volumetric, demand and fixed charges) affect the consumer's investment decisions. It illustrates how cost-reflective tariffs are capable of incentivizing consumer response opposing to traditional tariffs. Case studies are carried out on a simple 2-bus network. Traditional tariffs presented are based on flat energy price with either fixed network charges or volumetric network charges. Whereas the cost-reflective tariff is as proposed in [10], and it is based on Distribution Locational Marginal Prices (DLMPs) to price energy, Advance Demand Charge (ADC) to allocate a portion of the network costs according to the consumer's contribution to the peak hours of the network based on a threshold, and a fixed charge to allocate the residual (remaining part of) network costs.

IMPACT OF TARIFF STRUCTURES ON CONSUMER RESPONSE

Different tariff structures yield to different consumer responses. Volumetric tariffs are commonly used, where network charges are allocated to consumers based on their energy consumption (€/MWh). Thus, if a consumer is capable of reducing his consumption, he is also able to avoid part of the network costs. This would encourage consumers to increase onsite generation, which would increase the whole system costs, leading consumers to take inefficient decisions. On the contrary, fixed charges are not related to the consumption, the consumer is assigned a fixed charge (€/consumer). Fixed charges are aimed to ensure the full or partial recovery of the network costs, and they intend not to distort other economic signals.

Moreover, capacity charges aims to incentivize consumers to reduce their peak consumption. Charges are allocated to either the consumer's peak consumption or the contracted capacity (€/MW). However, it does not accurately reflect the consumer's impact on the network since network reinforcements are related to the peak hours of the whole network, not individual peaks. Thus, ADC was proposed in [10], which allocates part of the network costs to consumers based on their individual contribution to the peak hours. A threshold based on the peak network usage is set, and an approximate charge along with the expected peak hours are notified in advance (ex-ante), which are subject to change based on consumers' reaction. Then, the actual ADC and the peak hours are announced and allocated ex-post. The ADC has two objectives depending on the network's utilization level. First it aims to send awareness economic signals to consumers regarding their impact on the network. Then, if the utilization level is expected to increase requiring network reinforcements, it aims to send potential preventive economic signals guiding the consumers towards DER investment decisions. The key issue regarding setting the charge of ADC, is considering the investment opportunities available for the consumer. The ADC is set below the DER investment opportunities when awareness economic signals are required, in order for consumers not to invest in DERs. The ADC is set above them when preventive economic signals are required, persuading consumers to invest in DERs. Hence, ADC is linked to the long- term elasticity of consumers.

CASE STUDY AND RESULTS

Several case studies were carried out on a simple 2-bus network as in [11] and illustrated in Figure 1. The distribution network consists of one infinite generator, resembling grid generation, connected to one consumer, resembling a group of consumers in a MV distribution feeder. The consumer has a discrete load profile presented in Table I, where the annual load varies between 0.5 MW and 2.5 MW. Besides supplying the consumer's load from the grid, the consumer has three distributed on-site generator (DG) options to invest in to supply his load. Generator 1 (G1) acts as a base-load generator, with a fixed cost of 80€/MW/h and a low variable cost of 1€/MWh. Generator 2 (G2) acts as a intermediate-load generator, with a fixed cost of 23€/MW/h and variable cost of 100€/MWh. Generator 3 (G3) acts as a peak-load generator, with no fixed cost and a high variable cost of 300€/MWh. Whereas the grid has a fixed cost of 30€/MW/h and a generation variable cost of 50€/MWh.

Two different set of case studies were carried out: first, for an ideal optimal network where the line capacity is 1.7MW, and second, for an actual network, where the line capacity is 2.5MW. Within each set, traditional and cost-reflective tariffs were implemented to analyze the consumer's response through his optimal generation investment decisions in order to reduce his total annual payment. For the traditional tariff, two cases were implemented: case 1 is based on a flat energy price with fixed network charges (NC), and case 2 is a volumetric charge consisting of a flat price for energy and network costs. The cost-reflective tariff is based on three components: DLMPs, ADC and fixed charge. DLMPs are used to price energy and generate a surplus devoted to recover part of the network cost. ADCs allocate a portion of the network costs to the consumer, which is 1% in case 3 and 2% in case 4, according to the consumer's contribution to the peak hours of the network. Those peak hours are based on a threshold of 2 MW, i.e. the ADC is allocated during the hours where the load exceeds 2 MW. Then, the fixed charge allocates the residual network costs to the consumer, which is 99% in case 3 and 98% in case 4. The consumer objective is to minimize the total electricity costs subject to the tariff structure and available generation technologies. The optimization problem was modeled on MATLAB and solved using mixed integer linear programming MILP. The results are presented in Table II.

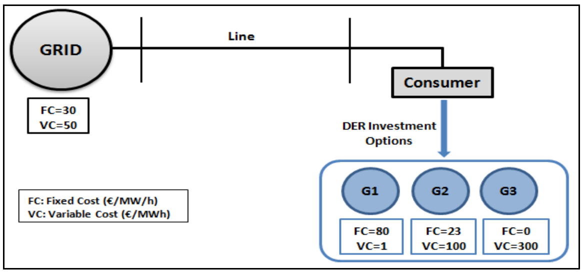

Figure1: Case Study

Table I: Consumer's Annual Load Profile

Load (MW)	No. of Hours	Load (MW)	No. of Hours
2.5	88	1.5	1752
2	350	1.4	1752
1.8	438	1.1	1314
1.7	438	0.8	526
1.6	1752	0.5	350

Ideal Optimal Network

First the problem was formulated to compute the optimal size of the line connecting the consumer to the grid, which led to a line capacity of 1.7MW and the consumer investing in 0.8MW of G3. Now, having the line capacity set to 1.7MW, three case studies were carried out to analyze the consumer's reaction to different tariff structures. First, with tariff based on flat energy prices and fixed network charges, the consumer's optimal decision was as in the optimal case, which is to invest into 0.8MW installed capacity of G3 as a peak generator to serve during the hours of load above 1.7MW. This led to full recovery of network costs, as illustrated in case 1 under the ideal optimal network in Table II. to the traditional tariff with volumetric charge (case 2) and the cost-reflective tariff (case 3). For case 2, which was based on volumetric tariff, the consumer reacted differently than the optimal case, investing in 1.1MW of G1as a base load, and using the grid's generation to supply peak consumption of 1.4MW, causing a deficit in network recovery of 70.77%. In this way, the consumer was able to avoid part of network charges by the investment decision he took, reducing his total annual payment. As for the third case, cost-reflective tariff was implemented. Since the network is optimally designed, only DLMPs were implemented as its surplus is sufficient to recover network costs. The consumer reacted as in the optimal case, and invested in 0.8MW of G3. The congestion rents were able to recover networks costs (the network recovery was slightly above 100% due to discrete load values) mitigating the need of ADC and fixed charge.

Actual Network

In reality ideal optimal networks cannot be attained, as distribution planners try to design networks avoiding overload situations, and due to the fact of discrete and lumpiness of investments. The network is now designed to fully serve the load with a line capacity of 2.5MW. The same cases were carried out for the traditional tariff. For case 1 using the fixed tariff charges, the consumer did not take any investment decisions, as his most economical solution to fully supply his load was through the grid. Thus, the network fully recovered its costs. As for case 2, using the volumetric charges, the consumer was again able to avoid part of the network charges through investing in installed capacity of G1 as base generator, leading to a greater deficit of 74.8% as the network costs are higher for the 2.5MW network. Although fixed charges perform better than volumetric charges, recovering the total network costs, both tariff designs do not send any economic signals to the consumer regarding future need for network reinforcements. The consumer has no incentive to modify his consumption, nor does he have any signals reflecting his impact on the network. If the consumer decides to increase his load in the future, the grid will have to be reinforced to cope with the new situation. Yet, it might be more economical for the consumer to invest in a generator instead of reinforcing the network. Thus, the consumer should be aware, in advance, of his impact on the network through network charges. Moreover, those charges should correctly guide him whether to invest or not in other generators.

The cost-reflective tariff for the 2.5MW network was implemented in cases 3 and 4. The only difference between the two cases is the percentage of network costs allocated through the ADC. In case 3, 1% of the network cost was allocated, leading to an ADC of 200 €/MW above 2 MW (the threshold) during peak hours. Since the charge is below the cost of the peak generator (G3 of 300€/MWh), the optimal decision for the consumer was not to invest and fully supply his load from the grid. Thus, the network was fully recovered. The objective of the tariff in this case was to guide the consumer away from the investment decision, while signalizing him regarding his impact on the network. For case 4, the objective of the tariff is different. It is assumed that a load increment of 0.1MW is guaranteed in the following year. Due to discrete network investments, the least network reinforcement that could be carried out is 0.5MW, leading to a line capacity of 3MW. The total cost of supplying a load of 2.6MW from the grid costs 1,407,750€, including both energy and network charges. Whereas, if the consumer invests in 0.5MW of G3, and supplied 2.1MW of his load base from the grid, it would cost a total of 1,287,350€, leading to a saving of 120,400€. Therefore, the objective of the tariff in case 4 is to incentivize the consumer to take an investment decision of 0.5MW. The ADC charge is set to be 300€/MW/h, corresponding to 2% of the network total cost, equivalent to the cost of G3, for each MW above the threshold of 2MW during the peak hours. In this case, the consumer finds it economically beneficial to invest in G3 of an installed capacity of 0.5MW to avoid ADC. However, this promoted a deficit in network recovery of 2% as shown in Table II. The deficit is 13,200€, which is below the savings gained by mitigating network reinforcements, accomplishing an optimal solution that maximizes the social welfare. Notice that in real application of ADC, the full residual network costs would be allocated to the rest of consumers that are inelastic, in order to guarantee full network cost-recovery.

CONCLUSION

As electricity demand increases along with competitive DERs, traditional tariff designs lack to fulfill the main objectives of smart distribution networks; recovering network costs and incentivizing consumer response. Thus, cost-reflective tariffs are required to incentivize and guide consumers through economic signals. The case studies demonstrated how different tariff structures have different influences on the consumer's response and total system costs. Volumetric tariffs distort the signals leading to network deficits, whereas fixed charges guarantee the full recovery but lacks to incentivize consumer response. Network charges should be carefully designed considering the consumer's elasticity to avoid distorting network signals. In the case of expected network reinforcements, coincidental peak demand charges are needed in order to promote optimal solutions to maximize the social welfare.

Table II: Consumer's Optimal On-site Generation Investment Decision and the Resulting Network Cost Recovery

		Ideal Optimal Network			**Actual Network**			
		Line Capacity = 1.7 MW			**Line Capacity = 2.5 MW**			
		Traditional Tariff		**Cost-Reflective Tariff**	**Traditional Tariff**		**Cost-Reflective Tariff**	
		Case 1	**Case 2**	**Case 3**	**Case 1**	**Case 2**	**Case 3**	**Case 4**
		Flat Energy Price + Fixed NC	**Flat Energy Price + Volumetric NC**	**DLMP + APS + Fixed NC**	**Flat Energy Price + Fixed NC**	**Flat Energy Price + Volumetric NC**	**DLMP + Fixed NC + ADC* (for T=2 MW & 1% of NC)**	**DLMP + Fixed NC + ADC* (for T=2 MW & 2% of NC)**
ADC (€/MW/h)		-	-	0	-	-	200	300
FC (€/MW/h)		30	-	0	30	-	29.598	29.397
VC (€/MWh)		50	91.87145	DLMP	50	103.077	50	50
Consumer Response	**Grid**	Base 1.7 MW	Peak 1.4 MW	Base 1.7 MW	2.5 MW	Peak 1.4 MW	2.5 MW	Base 2 MW
	G1		Base 1.1 MW			Base 1.1 MW		
	G3	Peak 0.8 MW		Peak 0.8 MW				Peak 0.5 MW
Total Consumer Payment (€)		**1,120,471**	**1,065,868**	**1,232,160**	**1,275,910**	**1,100,718**	**1,275,910**	**1,273,705**
Network Cost Recovery (€)		**446,760**	**130,587**	**446,760**	**657,000**	**165,537**	**657,000**	**643,800**
Network Cost Recovery (%)		**100%**	**29.23%**	**100%**	**100%**	**25.20%**	**100%**	**98%**

NC: Network Charge.
* ADC is applied when the consumption exceed the threshold of 2 MW.

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