COSTING NETWORK SERVICES FOR CONSUMERS WITH PV SELF-GENERATION

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ABSTRACT

Consumers are increasingly adopting self-generation for a part of their electricity consumption thanks to the sharp decrease in solar production costs.

Most European distribution grid tariffs are mainly related to the amount of energy withdrawn from the grid. The adoption of self-generation can consequently offer a substantial reduction of the network bill, which raises equity and efficiency issues, related to network costs allocation among customers. It also points towards a need for a better identification, costing and pricing of the different services provided by the grid.

This study proposes a methodology to allocate network costs among customers in the perspective of grid tariff design. It is partly based on the average probability, at the utility company level, that an additional load may induce a need for network reinforcement. Then, the impact of self-consumption from solar panels on this allocation is estimated. Finally, average cost reduction attributed to self-consumption, in France, is estimated to be in the range of 12€-16€ per self-consumed MWh, at a low penetration of photovoltaic. These results represent an average estimation for all possible situations in the distribution system, in order to yield total DSO revenue requirements, while actual, local situations and values are very heterogeneous.

To avoid an important loss of economic efficiency at the energy system level, a rebalancing of network tariffs towards lower rates for energy withdrawn and higher fixed rates -or as a substitute, higher price rates for guaranteed power or capacity- in combination with time-of-use prices according to season and time of day for the energy component, is proposed.

SELF-CONSUMPTION DEVELOPEMENT AND GRID COST IMPACTS

Consequences of self-consumption development for grid operators

As solar production costs are sharply decreasing and feed-in tariffs are reducing in most of European countries, decentralised photovoltaic producers are increasingly adopting self-generation for a part of their electricity consumption [1].

Grid customers that adopt self-generation need a different bundle of services from the grid: they can largely reduce their withdrawn energy and may even inject energy, change how they use their guaranteed power, however not necessarily during coincident peak use, and they still require network access as well as voltage and frequency quality.

However, the structure of most European distribution grid tariffs is dominated by the amount of energy withdrawn from the grid [2,3]. For a consumer, the adoption of self-generation can consequently offer a substantial reduction of the network bill, which raises equity and efficiency issues, related to network costs allocation among customers and to the appropriate pricing of the provided services.

Previous studies of costs impacts

Few studies have analysed distribution network costs induced by distributed PV generation. Using grid simulation of representative distribution feeders, Cohen et al. [4] have studied effects of distributed PV on different aspects of the California's distribution system: system losses, peak load, transformer aging, power quality, reverse power flow, etc. Then, they have estimated these impacts in terms of economic valuation for the distribution grid [5].

Their results are greatly dependent on the topology of the circuit, as well as on the penetration level of distributed generation. The impact on network investments is in most cases quite low but substantial on a small part of circuits at a low level of PV penetration. In this California study, most of the potential cost reduction for the grid derives from investment deferral induced by the decrease of peak net loads and from the diminution of energy losses [5].

However, grid cost reductions related to PV production are likely to occur mainly for low levels of PV penetration on a circuit. Indeed, some studies find that once a certain threshold is reached, whose value is related to the feeder's location area, further increase in PV production capacity is likely to entail additional network costs [6,7].

COST ALLOCATION BY GRID SERVICES

In this paper, our approach adopts a costing perspective, based on a probabilistic methodology. We obtain the expected cost that is to be allocated to any client across all his possible situations in grid circuits of the Distribution System. This is a relevant first step from the perspective where distribution grid tariffs do not discriminate clients by location, as implemented by most companies [8] and by the French regulatory regime.

Definition of grid services

Our costing methodology is based on the services provided by the grid. In this paper, customer support services, also provided by the DSO, are not described as they are considered to be independent of self-consumption. Using the same terminology as in [2], the services provided by the grid are:

- **Network access :** all grid services are provided at the location contracted by the client ("at home") and a share of the network costs is induced by the sheer minimum number of kilometres required to reach efficiently all the clients over a geographical territory[1]. Customers adopting self-generation still rely on the geographical extent as much as previously.
- **Guaranteed power, energy transit, and power quality:** clients contract the maximum power they can call[2] instantly; withdraw energy when required within the limit set by this guarantee; and benefit from several power quality standards like frequency stability and well-controlled voltages. These services determine costs related to the sizing of network circuits and equipments and redundancies.

Grid costs allocation by services

In order to estimate, for France, a sharing of network costs among customers with different grid services uses, this paper relies on a splitting of operational costs and capital amortization costs among network access and network sizing.

Costs for the network access service

Spatial network costs are directly related to the geographical coverage of the grid. Conversely, these costs are considered independent from the energy consumption behaviour of customers.

An internal assessment of distribution costs for Enedis (about 95% of distribution grid customers in France), provides that around 35% of network costs, without including energy losses and customer services, are related to the geographical coverage of the grid. This outcome has been obtained through expert analysis of the capital and operating expenses for year 2015, using detailed accounting data.

1. On this topic, see for instance [9].
2. In countries like France, Italy and The Netherlands, all clients, including small residential clients, can adjust their guarantee to a lower level than their connection capacity. It is not the case however in Germany.

Costs for services related to network sizing

Network sizing costs (the other 65% of the total) includes billable costs related to the services of guaranteed power, energy withdrawal and voltage quality. Due to important interdependencies, a breakdown of the costs among these services is still to be studied. The costs of energy losses are treated separately.

The allocation is based on a peak-load method: peak demand levels are used as a proxy driver for the current and future sizing of transformer stations.

For any substation, peak-load occurrences are dependent to climate hazards as well as to potential technical failures in another circuit due to redundancy in high and medium voltage networks. As a result, considering several possible climate conditions and the different circuits at a given voltage[3], a peak load may occur at almost any hour of a normalized calendar (n^{th} week, m^{th} day, i^{th} hour), but with contrasted probabilities.

This utility-wide probability distribution depends in theory on the number of critical peaks considered per circuit, but the outcomes are satisfyingly stable over a range of typical numbers. For this paper, local peaks are defined as the top 5% occurrences[4] for medium voltage circuits; 20% for high voltage; and only 0.5% for low voltage circuits, where there are no real-time reconfigurations.

Then, total network sizing costs of a tension level are divided up among the hours according to the probability distribution of peaks of the corresponding tension level. Finally, the allocated cost for an hour is divided by the total load demand (in MW) of this hour, which obtains a cost of use in €/MWh (see also [10], which to our knowledge pioneered an hourly cost allocation of network infrastructure, albeit different from ours[5].)

Billable costs for the services related to network use are therefore allocated in proportion to whether an additional power demand may induce a need for a network redesign or capacity reinforcement project. It is important to understand that for most of the circuits, this need will arise only in the distant future and has a low present value, while for a small fraction of the circuits the cost of anticipated redesign will be very substantial. This is also highlighted for PV network value by Cohen et al. [5].

3. The French distribution network comprises more than 2.000 substations and 700.000 MV/LV transformers.
4. This fraction and the corresponding days are taken from the all-events load curve which compounds years with different climate years and network conditions.
5. CRE, the French regulator, worked out a different methodology for the hourly allocation [12] and includes costs related to spatial extent.

Energy losses costs

At the national scale, for each voltage level, energy losses are measured annually and then estimated on an hourly basis, using polynomial equations related to the current load demand [11]. Network losses are separated in two categories.

First, there are losses directly related to energy transit, primarily Joule heating. These losses would be reduced by self-consumption, not considering potential injection on the network. Secondly, other losses as iron, dielectric or non-technical losses are accounted differently, as there are not directly related to energy transit. These losses are considered constant over time.

Costs related to Joule heating losses are estimated by multiplying losses volume by electricity prices on the spot market during the relevant period. For other types of losses, an average annual price for electricity is used.

Cost allocation to consumption by voltages levels

Power demand in lower voltage levels implies energy transit at upper voltage levels; therefore network sizing costs have to include all the voltage levels necessary to transport and to distribute electricity to the final grid user.

Costs not directly related to the level of power demand, i.e. spatial network and non-Joule losses, are distributed evenly across all electrical point of delivery of a voltage level, whether grid users or transformers. Costs allocated to transformers are then redirected to point of delivery at lower voltage levels. This allocation is based on the premise that grid tariffs do not discriminate by location.

As network sizing costs are allocated on an hourly basis for three different voltage levels (high, medium and low voltages), the hourly costs for delivering 1 MWh at a given voltage level is a weighted sum of these hourly costs at all upper voltages levels, taking into account the power load due to transit for lower levels and including energy losses.

Cost allocation results

Figure 1 displays the time-dependent allocation of network sizing and losses costs at the low voltage level, per MWh withdrawn, averaged for each month.

We can notice that most of network sizing costs are distributed between November and March. However, some network costs are allocated during spring and summer months, as some circuits have peak-load events during these periods.

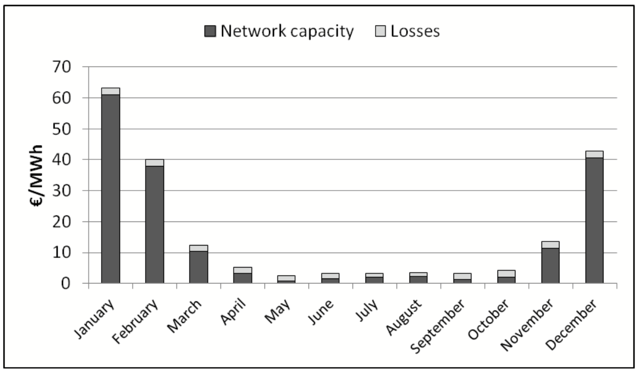

Figure 1 : Mean network costs by month for a low voltage grid user (without annual network access costs)

For an average day, cost allocation highlights two potential peak-load periods: during the evening (19h-21h) and around midday (11h-14h). If self-consumption of energy can occur in winter during these hours, it may contribute to reduce future network costs. Users load profiles with self-consumption

Load curves of typical grid users

Three different groups of grid users are considered in this study. Non-residential customers have been selected to represent different types of load curves. For each group, typical annual load curves, on an hourly basis, are selected:

- **Residential:** A user without temperature-sensitive electricity usage (3.5 MWh/year) and another user with electric heating and water heater (11.5 MWh/year, mainly in winter).
- **Farm sector:** One farmer with crop cultivation (consumption primarily in summer) and one with cattle breeding.
- **Business & Industry:** One large hypermarket and one industry directly connected on the medium voltage level (paper industry).

Solar panel production simulation

A first step is to determine solar production capacity installed for each segment of customers. For residential customers, an average capacity value has been obtained from observed recent installations for self-consumption in France: 2kWc for the standard user and 2.5kWc for the temperature-sensitive one.

For other sectors, the sizing of solar installations is estimated by maximising net present value of the project considering the reduction in the electricity retail bill.

User group	Type	Annual self-consumption (MWh)	Self-consumption / Production	Self-consumption / Consumption
Residential	Low consumption	1.3	46%	37%
	Temperature-sensitive	2.2	64%	19%
Farm	Crop	5.2	72%	9%
	Cattle	88	96%	21%
Business	Hypermarket	242	94%	27%
	Industry	344	100%	1%

Table 1 : Annual self-consumption for typical grid users with PV

A PV generation simulation model has been used to produce PV load curves. It integrates real climate conditions at the location of the customer, including data on irradiance received by an inclined surface.

Estimation of self-consumption

PV load curves are combined with typical customers load curves as described above. Therefore, it is possible to estimate the share of solar panel production that is self-consumed according to different groups (Table 1).

IMPACTS OF SELF-CONSUMPTION ON NETWORK COSTS ALLOCATION

Once network costs have been allocated either on a per connection point basis, either on an hourly basis, it is possible to attribute network costs to a grid user based on its load curve and voltage level.

Impacts of self-consumption on the allocation of network costs are therefore the difference between the attribution of costs for a customer before and after installation of solar panels. In this situation, annual fixed costs per connection point remain unchanged.

Results interpretation

Network costs, which tariff bills will have to cover[6], are attributed to a consumer according to the likelihood that his use of the services provided by the grid may contribute to the need of future network investments. When a customer starts to self-consume his own electricity and require less energy transit, this likelihood may be reduced. It is important to understand that these results do not represent an average 'value for the grid' of self consumption, but an 'allocation of billable costs' based on consumer loads and utility-wide likelihoods of contributing to peaks.

Further, there are some simplifications that should be improved on in future works:

- The contrast in costs allocated to identical clients, with or without self-consumption is based on a **cost allocation derived from the current network loads. An updating of these loads to account for a large additional development of self-consumption would reduce this contrast**, while not reducing the total amount of costs to recover from the clients. Besides, in cases self-consumption develops by local clusters, the resulting high PV penetration rates may entail additional network reinforcement costs [6,7], if large injections of non-consumed self-generation occur.
- **Time related consumption behaviour changes with the installation of solar panels for self-consumption have not been implemented**, as comprehensive data on this subject are not available.

In order to have a simple and common indicator of self-consumption impacts on the allocation of costs for different types of clients, the clients' annual gains in cost allocations are presented on a per MWh basis of annual self-consumption. One should recall, however, and take into consideration for the analysis, that costs are very unevenly allocated over hours and seasons.

Results by segment group

In the current situation of low self-generation penetration, a residential customer with self-consumption may be attributed less billable network costs averaging around 14€-16€ per self-consumed MWh (Table 2). As mentioned, these value average local as well as seasonal heterogeneities, e.g. the gains per MWh are about three times higher during winter and four times lower in summer, reflecting seasonality in both hourly costs and in volumes of PV self-consumption.

Outcomes are relatively close for consumers with very different consumption profiles. Temperature-sensitive customers who adopt self-consumption have gains that average at a slightly higher value per self-consumed MWh. This is so because their rate of self-consumption during peak load periods is relatively more important than for other clients.

For businesses and farms, adopting self-consumption reduces the attributed network costs to a lower value than for residential customers: around 12-13€ per self-consumed MWh for a user connected to the low voltage network, and 8€ for an industrial site connected to the medium voltage network.

6. Since revenues should equal costs for DSO, costs considered in this analysis gather not only reinforcement and network creation, but all network operation expenditures and depreciation of existing assets. However, billable costs for new connections as well as expenditures on customer services and management (including metering) are not included.

User group	Type	Reduction of attributed costs, per self-consumed MWh (part due to losses)			
		High voltage	Medium voltage	Low voltage	All voltage levels
Residential	Low consumption	-3.7€	-5.2€	-5.0€	-14€ (-1.9€)
	Temperature-sensitive	-4.3€	-6.0€	-5.5€	-15.7€ (-2€)
Farm	Crop	-4.1€	-4.7€	-4.7€	-13.4€ (-2€)
	Cattle	-3.6€	-4.2€	-4.3€	-12.1€ (-2€)
Business	Hypermarket	-3.7€	-4.2€	-4.4€	-12.3€ (-2€)
	Industry	-3.7€	-4.2€	/	-7.8€ (-1.2€)

Table 2: Self-consumption attributed reduction in costs for typical grid users with solar panels

The differences with residential customers arise largely because businesses have a higher ratio of PV self-consumption, notably during summer when the grid costs per MWh are very low (see Figure 1).

CONCLUSION: REGULATORY ASPECTS

The methodology developed in this study provides an estimate of billable network costs attributed to consumers according to their loads, with a focus on the difference between clients with or without self-consumption.

While distribution network costs are local, our allocation provides utility-wide averages in order to compare with grid tariffs that do not discriminate consumers by location, not only for historical, but also practical reasons [8], such as social acceptability and price intelligibility.

These results are a first step; some simplifications and data we had to use tend to overvalue the gain for self-consumption, which would become quickly limited to energy losses in case of a widespread and fast development. Yet, the difference we obtain in costs for self-consumers and usual consumers is still considerably narrower than the actual decrease in network bill when a consumer adopts self-consumption, given the current network tariffs structure in most European countries [8].

This is consistent with other analyses that suggest that a typical self-consumer pays a network bill lower than his share of the costs when grid tariffs remain mainly related to the amount of energy withdrawn from the grid [12].

Such discrepancies raise distributive [12] and efficiency issues about consumption choices. Consumers face an increasing number of energy solutions for their heating, mobility, and other final needs. These solutions can be electricity powered or not, and rely on electricity supplied from the network or from or self-generation. Not considering that the tariff can induce substitution effects may lead to rising deadweight losses [13].

This could be corrected through a rebalancing of network tariffs towards lower rates for energy withdrawn and higher fixed rates –or as a substitute, higher price rates for guaranteed power or capacity– in combination with time-of-use prices according to season and time of day for the energy component of the tariff.

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