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Online estimation and use of price elasticity of demand for shifting loads through real-time pricing

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Abstract

Demand Response programs have been assuming lot of importance in the simulations of electric users' loads' profiles. The evolution of these simulations helps defining new models able to predict power consumption trends for different user types. In order to better match consumption and production energy curves, highly precise forecasts of loads' profiles are needed. This goal can be achieved also thanks to the study of the elasticity factor, that identifies the will of a user to have his consumptions reduced after a remuneration. In this paper, a way to obtain it has been presented, together with an interpolation able to predict it. Its definition is also supposed to help building scenarios that consider the impact of the long-term use of RTP remuneration (Real Time Price). Importance of having a real-time elasticity value able to adapt to specific situations is discussed, as for example user's habits during the weekends or weekdays and weather forecasts.

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Keywords: Demand response programs; Elasticity; Real time pricing; Remuneration

1. Introduction

Elasticity is a relevant parameter of the so-called Demand Response (DR), a program that is supposed to optimize power fluxes in the electric networks [1] by rewarding end-users and, hypothetically, promoting green energy [2]. It can be obtained from $\Delta Q/Q$ over $\Delta P/P$ graphs since elasticity is defined as the ratio of their relative variations before and after DR, where P stands for remuneration and Q for power quantity.

In fact, as presented in [3,4], there is a relation between the slope of the curve and elasticity value. This relation allows to classify users by their own value in order to compute new remunerations ΔP starting from different ΔQ and vice versa. This way to distinguish users basing on computed data (even the most recent ones) represents an

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improvement to the old classification based on fixed values presented on tables, that most of the times are not updated and do not separate correctly user types [5,6]. Even though it represents a detailed and reliable way to get elasticity instead of consulting literature [3], a quicker and more precise mean to get a model is still needed. That is the reason why it has been chosen to develop a method able to get real-time elasticity starting from any type of power data (from the most recent to the oldest ones). Since this value changes depending on user's habits during weekdays and weekend, weather, time and location [7], having an always updated one allows to better correct, in real time, produced power from one side and consumed power on the other. As a result, no big amounts of exceeding power are produced nor needed to be stored, diminishing overall costs. Moreover, grid congestions are avoided, power exchanges with neighbor markets are limited giving more energetic, economic and political independence to each market. Finally, it has been demonstrated that volatility of nodal spot prices can be reduced [8]. In any case, response of consumers to price variations should not be assumed as totally flexible since constraints as maximum load reduction, price caps, load and generation balance are present [9].

In this paper it is presented a scenario from which elasticity can be extrapolated. It will be used to support the remuneration of demand response programs through real-time pricing. By receiving the accurate values of real-time prices, the consumers will shift the consumption to other periods where the electricity is cheaper. After this introduction section, Section 2 will present the adopted methodology. Then, the results are presented in Section 3. The conclusions of the paper are presented in Section 4.

2. Approach

Elasticity has been found by making up a DR scenario: every time high consumptions occurred during highest tariff periods, users' power absorptions have been capped. Power-cap limit was imposed to be the 115% of the average power value during the day. It is supposed to be acceptable by most of the population since power reduction occurs only if high demand periods coincide with highest tariff. Moreover, data showed that generally not more than 11% of consumption has to be reduced. Unfortunately, there is one significant disadvantage of this method: average power is an estimation obtained from historic data. In fact all the measurements over the 24h are needed to compute the average power (and then its 115% value): the same day of the week before can be considered, the same day of the previous year, or simply the day before. All these possibilities present uncertainty related especially to weather conditions that can vary significantly from a day to another. A possible improvement of this method is to impose a "minimum power cap" too in order to maintain absorbed power within a certain gap, e.g. ±15% of the average power. This would guarantee more balance to the grid, allowing power plants to be more constant in electricity production (with benefits both in terms of costs and machine use). In that case end-users should be taught these benefits since they are not intuitive, in fact consumption during night hours could actually increase. Power-cut is going to be the numerator of elasticity expression (1). For what concerns the denominator ΔP/P, an important consideration has to be said. Three tariffs (T1, T2, T3) are scheduled by the DSO (Distribution System Operator) over every weekday: Table 1 shows their prices (values are taken from Portuguese DSO).

Table 1. Tariffs with their respective prices

Tariffs classification	T1	T2	T3
Prices [€/kWh]	0.2253	0.1765	0.1016

In this study case the scenario adopted considers Pfin as the price of T2 tariff, while Pin as the most expensive one, T1. Therefore ΔP is given by $0,2253 - 0,1765 = 0,0488$ [€/kWh], meaning that when power consumption is above power cap, T2 tariff is applied to the limited power. Having both ΔQ and ΔP allows to evaluate elasticity: since it is given by variations, it can be defined only during the DR period, namely the flat section. It has been chosen to pay the reduced power at T2 price instead of T3 because it could represent a money loss way too big for distribution operators: costs optimization in fact involves electric system as a whole, considering both consumers' and producers' interests. Since data provide power consumptions every 15 min, many elasticity values can be calculated during DR. These values are then interpolated in order to define a model able to predict consumer's behavior for the next time it will be needed: better results come if same conditions as climate, holidays and period of the day (morning/evening) occur. In order to see the reliability of the interpolation, MAPE value (Mean Absolute

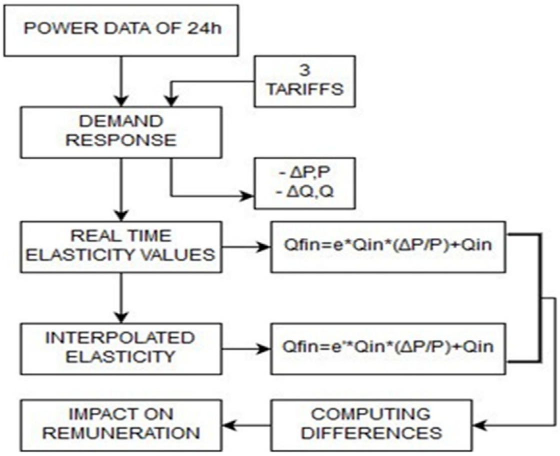

Fig. 1. Scheme of algorithm used to evaluate error on remuneration.

Percentage Error) is computed taking as input "real" elasticities values and the interpolated ones (1).

$$\mathrm{MAPE} = \frac{100\%}{n} * \sum_{i=1}^{n} \left| \frac{Ai - Fi}{Ai} \right| \tag{1}$$

where n stands for the total number of elements, Ai stands for the "Actual ith value" and Fi the interpolated one.

It has also been evaluated how much an error in this scenario can influence ΔQ parameter. In particular, Qfin has been computed with interpolated values of elasticity and then compared with the "original" ones, previously obtained from real values with mean of elasticity definition (2), (Fig. 1).

$$\mathrm{Q_{fin}} = e(\Delta \mathrm{P/Pin})\mathrm{Q_{in}} + \mathrm{Q_{in}} \tag{2}$$

where e stands for elasticity, ΔP is the price difference between after (Pfin) and before (Pin) DR, Qin the initial absorbed power.

It assumes importance to study the economic impact of the new Qfin values and thanks to the interpolation equation it is possible to compute ΔP for each ΔQ given as input. The con of this method is that it is based on historic estimations, needed to evaluate the average power used as cap. They may be different from actual consumptions, so the model can be inaccurate.

3. Results

First of all, power absorption data were plotted with respect time. As already mentioned, a random week was taken as reference and the days studied are: Monday, Saturday and Sunday. These days have been selected because they present different tariff schedules, in particular on Monday all three tariffs are present, on Saturday only T2 and T3 and on Sunday only T3. In this work only graphs about Monday are reported, since it is the day with highest consumptions and number of tariffs. Tariffs follow power demand trend as they are supposed to incentivize energy consumption when it is available in high quantity. By applying this scenario, graph of Fig. 2 is obtained. Red line represents the average power consumption while the yellow one its 115%, that is used as power cap. Green line represents power absorption below the imposed limit, in fact it overlaps the orange one, that shows the real power trend without any constraint. When power absorption exceeds the limit, the cap-value is kept as maximum value: this explains the flat section in the evening hours. By reducing the cap-value, more flat sections may occur and they could last longer: despite it could guarantee a more stable grid, consumers would be asked to a bigger "loss of comfort" that may be not accepted. Power-cut is going to be the numerator of elasticity formula (1). For what concerns denominator ΔP/P, considerations have already been done in the previous section: ΔP is given by $0,2253 - 0,1765 = 0,0488$ [€/kWh], while P is the initial price Pin (the most expensive one, T1). As a consequence, when consumption is above power cap (green flat part in Fig. 2) during highest tariff, T2 tariff

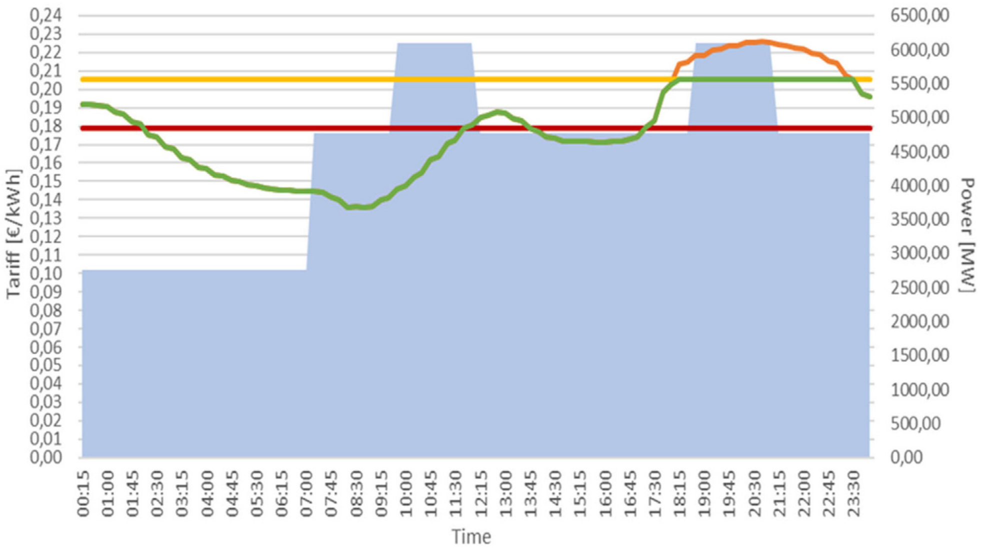

Fig. 2. Tariff (blue area) and power trend (green and orange lines) on a weekday. Average consumption (red) and its 115% value (yellow). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

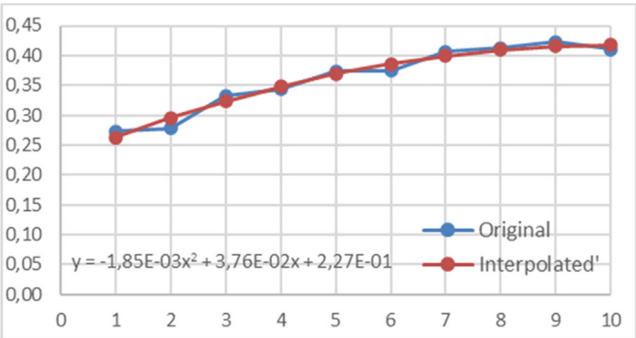

Fig. 3. Elasticity values interpolation.

Table 2. Real and interpolated elasticity values during DR.

Real Qfin	Computed Qfin	Difference: Real-computed
5565.2329	5577.4033	12.1704
5565.2329	5543.7511	−21.4818
5565.2329	5577.4248	12.1919
5565.2329	5559.3648	−5.8681
5565.2329	5570.6899	5.4571
5565.2329	5550.4154	−14.8175
5565.2329	5574.0748	8.8419
5565.2329	5569.8387	4.6058
5565.2329	5574.7247	9.4918
5565.2329	5554.8849	−10.3479
Total [MW]	Total [MW]	Total [MW]
55 652.3291	55 652.5726	0.2435

is applied to the limited power (instead of T1 to the actual consumption). Next step is given by elasticity points interpolation (Fig. 3). That line was used to evaluate new elasticity values, reported in Table 2.

In this work it has been evaluated how much an error in this estimation can influence ΔQ evaluation. In particular, Qfin has been computed with interpolated values of elasticity and then compared with the "original" ones. There is not big difference between real Qfin values and computed ones, proving that the found interpolation is quite precise. A way to demonstrate it is given by MAPE. According to Montaño Moreno et al. [10], measures under 10 of MAPE are to be considered of highly accurate forecasting. In this case MAPE = 2.3846 meaning that this method is reliable.

The difference between final values of power absorption computed with the interpolation line and real values is not sensible, proving then that the model obtained could have been used by a TSO without great losses. In this work the worst-case scenario from an economic point of view has been computed. In particular, elements that now play the role of new ΔQ were selected with positive sign in order to avoid compensation between negative and positive values as happened in the simulation. Then, using the relation between ΔP and ΔQ, new ΔP values were obtained. MAT (high voltage level) user has been chosen as default user, since DR programs will involve very likely high voltages in the first steps. Any other voltage user could have been studied.

An error of ∼48.5€ represents more or less 0,0231% of the money volume that has been shifted from T1 tariff to T2. It can be considered an acceptable loss compared to benefits brought by DR. It should be noted that 48.5€ represents the money loss if a DSO decides to use an interpolation model instead of computing present values of elasticity: in fact, it does not represent the money difference between a user that participates DR programs and one who does not. As mentioned above, elasticity interpolation can be used by DSO in order to compute how much power will be available the day after thanks to DR programs. In the past, when every user type was classified by a specific constant elasticity value, available power was calculated. This gave a unique value supposed to work the entire day/week/year. For instance, let us consider e = −0.38, here classified as "literature elasticity" (0.38 is indicated for Industrial consumers): given the initial power Qin and a ΔP = 0.0488 [€/kWh], Qfin is easily calculated. In order to compare Qfin for different elasticity values in a quick way, an average value of Qfin using the "literature elasticity" value and an average value of Qfin using the "interpolated elasticity" value were calculated: successively, a comparison between them and the "real elasticity" value was done in order to see how much power is being wasted due to a non-accurate elasticity definition. Difference between the first 2 values is −21.7229 [MW] whilst the difference between 2nd and 3rd value is 0.02435 [MW]. That shows how an elasticity interpolation brings an average error, in terms of excess unexpected power, of only 24 [kW] while the fixed value gives a lack of almost 22 [MW]. Some considerations about weekends elasticity values should be made, since it is a topic that can assume lot of relevance in DR programs. First of all, being elasticity strictly correlated to ΔP and ΔQ, it can be defined only whether a consumer is participating DR program. Data that have been used revealed that on Sunday it is not necessary for the consumer to cut his power, since only a small amount of it is requested by the entire grid (comparing to the weekdays) and no congestions occur anyway. That is why elasticity is not usually defined for this day. Double/triple tariffs contracts indeed present only one tariff on Sundays and moving loads into different periods would result in a useless loss of comfort for the consumer. As already mentioned, other factors influence elasticity value, as the weather, user's habits and routines or even unexpected events (e.g. a fault in the domestic electric system). These reasons are responsible for very different values of elasticity even along the same day when participating DR. Now then, a comparison between elasticity during a Monday and a Saturday day will be discussed. Only daily average values will be considered, since the goal is to demonstrate the difference between a given elasticity value for a weekday and for a weekend day. Average "real elasticity" value is 0.3627672804 while average "interpolated elasticity" value is 0.3627672803. In order to get an objective result, 0.363 (their average) will be used for this final small consideration. This value is needed only to have a comparison with the Sunday value that is now going to be defined. In order to compute it, even in this Saturday case it will be imposed a power cap of 15% of the average power: if there will be exceeding power during the highest tariff, that will be paid at the cheapest one (knowing that on Saturdays only T2 and T3 are present). Calculations brought user to participate to DR from 18:45 to 22:00, where there was high consumption during the most expensive tariff. The average value of elasticity (in absolute terms) found out for that period is 0.185, almost half of the value during the week. As a conclusion, it can be said that during the week a consumer is more willing to participate DR thanks to highest remunerations rather than during weekends. A social aspect has to be considered too: during weekends people may need more electric energy for leisure activities or other type of needs.

4. Conclusion

In this work a simulation of a made-up DR scenario was presented. Since the aim of the study was to get a "cross-elasticity" value, meaning a parameter that considers switching loads into different periods, a model to get it was first presented. An initial consideration about fixed values of elasticities has been done, showing that it cannot be a tool for modern DR programs anymore giving their lack of precision. Successively, results showed that using an "already ready" model instead of keep computing current elasticity values brings to a money loss of a very small quantity (around 0.02%): that could be considered a good improvement respect fixed elasticity values. Focusing on the method used to create the scenario, a not negligible disadvantage consists in using historic data. Data, that are relative to absorbed power, can vary indeed a lot from one day to another since they follow climate, holidays or faults in the grid. For that reason, this method is not 100% reliable but a quantification of its error could improve it making it more applicable to DR scenarios. The scenario used in this work is supposed to bring a "loss of comfort" to all users who participate it. Nevertheless, that loss has been quantified as less than 11% of the peak-power, meaning that consumers would be allowed to use up to 89% of their peak-power, but only in high tariffs periods.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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