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Optimal electricity price calculation model for retailers in a deregulated market

J.M. Yusta[a,*], I.J. Ramírez-Rosado[b], J.A. Dominguez-Navarro[a], J.M. Perez-Vidal[c]

[a]Department of Electrical Engineering, University of Zaragoza, CPS, Maria de Luna 3, E-50018 Zaragoza, Spain
[b]Department of Electrical Engineering, University of La Rioja, Luis de Ulloa 20, E-26004 Logroño, Spain
[c]Energy Services Division of McKinnon & Clarke, Arzobispo Morcillo 40, E-50006 Zaragoza, Spain

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Abstract

The electricity retailing, a new business in deregulated electric power systems, needs the development of efficient tools to optimize its operation. This paper defines a technical-economic model of an electric energy service provider in the environment of the deregulated electricity market in Spain. This model results in an optimization problem, for calculating the optimal electric power and energy selling prices that maximize the economic profits obtained by the provider. This problem is applied to different cases, where the impact on the profits of several factors, such as the price strategy, the discount on tariffs and the elasticity of customer demand functions, is studied.

Keywords: Electricity retailing; Optimization; Electric tariffs

1. Introduction

Nowadays, many countries are involved in developing deregulation and opening processes to promote an economic competition in their electricity markets. The final aim of this deregulation is to enhance the efficiency of the investments and the operation of the electric power systems, by reducing the costs as much as possible. The final result should be that the final consumers would obtain a reduction in the electricity costs and an increased quality and reliability of the electric supply [1].

The restructuring of the electric sector has led to the conversion from a vertically integrated structure, where all the activities are considered together, to a horizontally integrated structure, where the generation, transmission, distribution and retailing processes operate separately. Retailers have emerged as fundamental agents within this new framework [2].

The mathematical model for calculating the prices, maximizing the profits instead of minimizing the costs, was proposed in the 1980s based originally on Ref. [3]. It has been used to obtain nodal prices in electric transmission networks [4] but many other applications have been proposed [5].

For markets to work, there must be an active demand side in which consumers react to price changes [6,7]. Customers should have the opportunity to see electricity prices varying from hour to hour, reflecting wholesale-market price variations. Allowing customers to face the underlying variability in electricity costs can improve economic efficiency, increase reliability and reduce the environmental impact of electricity production [8].

Economic efficiency requires a series of customer choices. Offering customers a variety of pricing options is an essential component of competitive markets and the key to improve customer well-being. The heart of the strategy is an explicit contract between each consumer and the utility [9].

Most consumers of electricity are unlikely to find it profitable to buy electrical energy exclusively on the spot market. This does not mean that they will not be able to take advantage of a liberalized electricity market. Electricity retailers will indeed try to get their business by offering them various types of contracts [10,11]. Retailers' settlement obligations for wholesale power costs will be then based on customers' load-profiled consumption [12].

* Corresponding author. Fax: +34 97672226.
E-mail address: jmyusta@unizar.es (J.M. Yusta).

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This paper defines a model that can be applied to an energy service provider (that supplies electric energy to eligible industrial customers) in the Spanish electricity market. This model results in a quadratic non-linear optimization problem, where the objective function to be maximized is the economic profit obtained by the supplier, and it calculates the optimal electricity selling prices to be applied to the customers.

This problem has been solved for different cases in order to assess the impact of several factors on the final profit: price elasticity of demand from eligible customers, price strategy and discount on price with respect to the regulated tariff applicable to each customer.

2. Electric energy service provider model

This section develops the model that reproduces the behaviour of a retailer firm working in the Spanish deregulated electricity market. This model leads to an optimization problem: the maximization of the profit obtained by the company, from which the optimal electric power selling prices for eligible customers are calculated. The proposed model considers different agents, as it is shown in Fig. 1.

Two factors have an impact on the relationships among the agents, namely, the consumed electric energy and the price. The customer demand will depend on the price, according to the demand price mathematical function that characterizes it. The relationships of the retailer with the electricity market and the distribution utilities are limited to the purchase of the electric power demanded by customers for the former, and to the payment of network access tariffs, associated with each customer, for the latter.

2.1. Agents in the model

2.1.1. Electric energy service provider

The electric energy service provider is responsible for the purchase of the electric power in the market, and for the payment of access tariffs to the utilities. These two factors constitute its operation costs. The retailer profit function is obtained by subtracting these costs from the income (derived from the sale of electric energy to the customers):

$$\text{Profit} = \text{Income} - \text{Energy Costs} - \text{Access Costs} \quad (1)$$

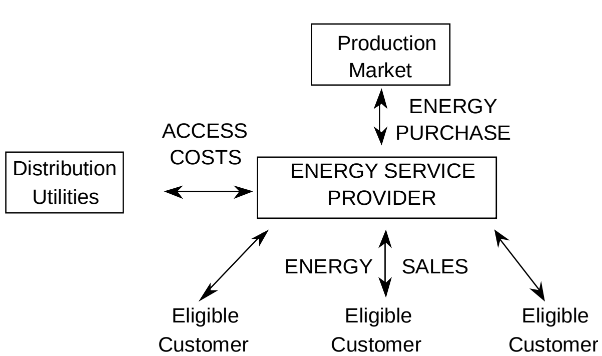

Fig. 1. Proposed model of retailing for an electric energy service provider.

Each element of this profit function is detailed in the following paragraphs.

Network Access Tariffs (Access Costs). The Spanish Royal Decree 1164/2001 [13] establishes the access tariffs applied to high voltage networks. The tariffs are based on a division of the year in six time periods and such tariffs include an invoicing element of power demand and an invoicing element of electric energy.

The invoicing element of power demand corresponds to the expression

$$FP = \sum_{j=1}^{6} t_{pj} P_{cj} \quad (2)$$

where

P_{cj} electric power demand contracted during the period j, in kW
t_{pj} annual price of the electric power demand during the period j, in €/kW

The t_{pj} element is settled according to the supply voltage level and the time period.

The invoicing element of electric energy corresponds to the following expression

$$FE = \sum_{j=1}^{6} t_{ej} E_j \quad (3)$$

where

E_j electric energy consumed during the period j, in kWh
t_{ej} price of the electric energy during the period j, in €/kWh

Costs of the Purchased Electric Energy (Energy Costs). It is calculated as the result of multiplying the kWh purchase price in the generation pool, in a specific time period, by the electric energy consumed during this period. Therefore, for any consumer, the electric energy purchase cost is

$$CE = \sum_{j=1}^{6} \alpha_j E_j \quad (4)$$

where

E_j electric energy consumed during the period j, in kWh
α_j electric energy price in the pool during the period j, in €/kWh

Income. The element of the profit function that corresponds to the income is obtained by multiplying the kWh selling price applied to each customer, during each time period, by the electric energy consumed during such period. Then

$$I = \sum_{j=1}^{6} \rho_j E_j \tag{5}$$

where

E_j electric energy consumed during the period j, in kWh
ρ_j electric energy selling price during the period j, in €/kWh

2.1.2. Electric power production market

The electric energy service provider buys electric energy from the pool, a competitive production market, whose prices change every hour. In the present model, an average price in kWh for each one of the six time periods of a year has been considered. Nevertheless, the optimization model of this paper can be extended to consider hourly spot prices in the pool. These average prices have been calculated from the hourly final prices in the pool during the year 2000 (Table 1).

2.1.3. Eligible customers

In practice, customers generally respond to prices by changing their electric power demand. In order to characterize this response, one of the easiest and most reviewed models has been used [3,14]. According to that model, the customers follow a demand function (Fig. 2), defined (in a E_{0j} and ρ_{0j} environment) by the equation

$$E_j = E_{0j}\left\{1 + \frac{\beta_j[\rho_j - \rho_{0j}]}{\rho_{0j}}\right\} \tag{6}$$

where

E_j electric energy consumed during the period j, in kWh
E_{0j} nominal electric energy consumed during the period j, in kWh
ρ_{0j} nominal electric energy selling price during the period j, in €/kWh
ρ_j electric energy selling price during the period j, in €/kWh
β_j demand elasticity in the period j ($\beta_j < 0$)

For each customer six demand functions have been defined, one for each time period. The coefficients E_{0j} and ρ_{0j} of each of them have been obtained using the daily load curve of customers. Nevertheless, the response of each customer to the price variations, characterized by the elasticity β, has to be empirically assigned. The price elasticity of demand β measures the degree of response of the demand to the changes of price in the market, being defined as the ratio of the variation of the demand quantity of some good or service, in percentage terms, to the variation of its price ρ, in percentage terms [15]. It can be expressed as:

Table 1
Electricity average price in the pool

Period	Price (€/kWh)	Period	Price (€/kWh)
1	0.051206	4	0.045677
2	0.043465	5	0.037635
3	0.048393	6	0.027695

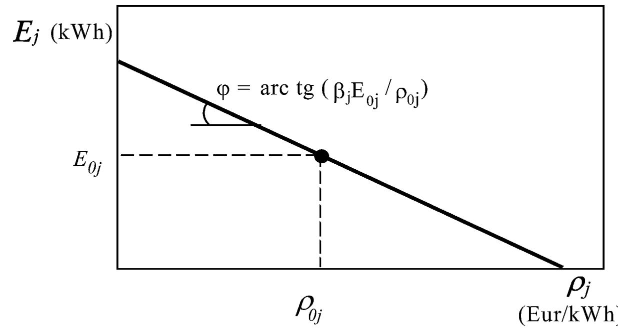

Fig. 2. Demand function.

$$\beta = \frac{\Delta E/E}{\Delta \rho/\rho} \tag{7}$$

The demand is 'elastic' if β is higher than 1, and 'inelastic' if β is lower than 1. As it is shown in Fig. 2, as a price increase is accompanied by a demand decrease and vice versa, the elasticity has a negative sign in this case.

Taking as a reference different studies performed to characterize the customers response to several price strategies [16–22], elasticity values ranging from -0.01 to -0.25 have been chosen.

2.2. Setting prices

The setting prices have two key elements to be considered. On the one hand, it is necessary to fix the number of different prices at which the retailer may offer electric energy to the customers, in other words, the price strategy to be applied. The simplest strategy is the flat rate, that is, apply the same price to all time periods, and the most complex one is the strategy that offers a different price per period. On the other hand, the price regulation has to be considered too, since due to the low elasticity of the customer electric demand, a maximization of the profit without limit of price will produce unrealistic results, as it is shown in case 1 (presented in Section 5).

2.2.1. Price strategy

This model considers different price strategies applied to each customer by the retailer, and they are:

- *Flat rate*. Only one price for the customers during the whole year.
- *Two prices*. One price for three time periods and another price for the other three periods.

- *Three prices*. This strategy has two alternatives, depending on the division of the time periods. In the first alternative, periods 1 and 2 have the same price, as well as periods 3 and 4, and periods 5 and 6. In the second alternative, periods 1 and 6 have different prices and the rest of the periods have a single price.
- *Six prices*. A different price for each period.

2.2.2. Price regulations

As above-mentioned, the profit maximization problem considered in the model of this paper needs some restrictions of prices, in order to avoid an excessive increase of them, due to the low elasticity of the customer electric demand, that is, due to its limited capacity of response to price changes.

The tariff that a customer would obtain in a regulated framework has been used as upper limit of the setting prices: in this way, eligible customers only would have an incentive to exercise their right to choose a supplier if they would obtain electricity at a price lower than the tariff.

3. Optimization problem

This section analyzes the optimization problem proposed to maximize the profit obtained by the electric energy service provider.

3.1. Objective function

As above-mentioned, the objective function to be maximized includes an income element related to the sales, and two other elements of electric energy purchase and access costs. When a retailer supplies electric power to eligible customers, the obtained profit can be expressed by the following expression

$$B(\rho) = \sum_{i=1}^{n}\sum_{j=1}^{6} E_{ij}\rho_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{6} E_{ij}\alpha_j - \sum_{i=1}^{n}\sum_{j=1}^{6} P_{ij}\sigma_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{6} E_{ij}\gamma_{ij} \tag{8}$$

where

E_{ij} electric energy consumed by the customer i in the period j, in kWh
P_{ij} power demand contracted by the customer i in the period j, in kW
ρ_{ij} electric energy selling price applied to the customer i in the period j, in €/kWh
α_j electric energy price in the pool during the period j, in €/kWh
σ_{ij} element t_{pj} (network access tariff) of the retailer, associated with the customer i in the period j, in €/kW
γ_{ij} element t_{ej} (network access tariff) of the retailer, associated with the customer i in the period j, in €/kWh
n number of customers

3.2. Mathematical constraints

The constraints of the problem arise from the cases considered in Section 2.2. The regulation of prices includes constraints on the maximum average price $\rho_{i,\max}$ for each customer i

$$\sum_{j=1}^{6} \frac{E_{ij}\rho_{ij}}{E_{i,\text{tot}}} \le \rho_{i,\max} \quad \forall\, i = 1, 2, \ldots, n \tag{9}$$

where $E_{i,\text{tot}}$ is the total electric energy consumption of the customer i, that is, the combination of its consumption of all the time periods. Therefore, there is a constraint for each customer.

Since the electric energy consumption E_{ij} depends on its price, according to the demand function (6), the resulting constraint is a quadratic price function. A suitable linearization process allows to transform these mathematical constraints into linear constraints (the corresponding linear approximations have been experimentally validated, by checking them against to the non-linear ones).

The price strategies considered in the problem include the other group of constraints. Depending on the chosen strategy, one of the following expressions has to be considered:

$$\begin{aligned}
&\text{Flat rate:} \quad \rho_1 = \rho_2 = \rho_3 = \rho_4 = \rho_5 = \rho_6 \\
&\text{Two prices:} \quad \rho_1 = \rho_2 = \rho_3;\ \rho_4 = \rho_5 = \rho_6 \\
&\text{Three prices:} \quad \rho_1 = \rho_2;\ \rho_3 = \rho_4;\ \rho_5 = \rho_6 \\
&\qquad\qquad \text{or } \rho_2 = \rho_3 = \rho_4 - \rho_5 \\
&\text{Six prices:} \quad \text{There are no constraints}
\end{aligned} \tag{10}$$

3.3. Mathematical formulation of the optimization problem

The complete formulation of the problem (where the terms of the objective function have been grouped) is as follows:

$$\max B(\rho) = \sum_{i=1}^{n}\sum_{j=1}^{6} [E_{ij}(\rho_{ij} - \alpha_j - \gamma_{ij}) - P_{ij}\sigma_{ij}] \tag{11}$$

$$\begin{aligned}
\text{subject to} \quad & \sum_{j=1}^{6} \frac{E_{ij}\rho_{ij}}{E_{i,\text{tot}}} \le \rho_{i,\max} \quad \forall i = 1, 2, \ldots n \\
& \rho_{ij} = \rho_{i,j+1} \qquad \text{(according to the price strategy)}
\end{aligned} \tag{12}$$

4. Optimization problem resolution

The software CPLEX [23] has been used to solve the optimization. This computer tool uses a primal–dual interior point algorithm, incorporating a predictor–corrector method.

The problem has been solved considering an electric energy service provider supplying electricity to five eligible customers, each one with its corresponding electric load curve (Fig. 3). The numerical adjustment of the model is achieved from the daily electric load curve of each customer (the model considers approximately that the daily electric load curve is the same one during the year). From these electric load curves, the nominal electric energy consumption and the contracted electric power demand in each period are calculated.

The electric energy consumption or nominal energy demand E_{0j} is calculated from the area under the electric load curve corresponding to the hours of each time period, multiplied by the number of days of the year that belongs to it. The contracted power demand will be the maximum one during each period, with the restriction that the contracted power demand in a period cannot be lower than in the previous period, according to the aforementioned Royal Decree 1164/2001 [13]. Table 2 gives the corresponding electric energy consumption, in kWh, and the contracted power demands, in kW, by customer (for each one of the time periods 1–6).

In order to calculate the nominal selling price ρ_{0j} applied to the customers, it is assumed that (in the situation of nominal demand E_{0j}) the retailer sells electricity at a price 10% higher than the whole cost, that is, it is assigned a profit on income of 10%.

The problem has been solved in 37 cases with different hypothesis of discounts, price strategies and demand elasticity. Tables 3–5 describe the main characteristics of these cases.

In cases 1–6, a trial of the model is developed considering different discounts on the price with respect to tariff. For all the cases six prices are calculated and the demand elasticity remains constant, with a value of -0.1. Case 1 does not include constraints, providing only theoretical results. In case 2, the maximum average price is equal to the price of tariff, thus implying a zero discount. Cases 3–6 consider discounts of 5, 10, 15, and 20%, respectively.

Cases 7–10, as well as case 5, evaluate different price strategies. In all of them, the discount on the tariff remains unchanged (maximum average price equal to 85% of tariff). In case 5 six prices are calculated; cases 7 and 8 use the three-price strategies; case 9 uses the two-price strategy; and the case 10 uses the flat rate. As in the previous group of cases, the demand elasticity is -0.1.

In cases 11–22, a sensitivity analysis of computer results is performed by varying the discount on the tariff and the price strategy. In cases 11–14, the impact of a change in the price strategy on the retailer profit is studied. Cases 15–22 represent different trials of the model, assuming different hypothesis of the contract negotiation with the customers.

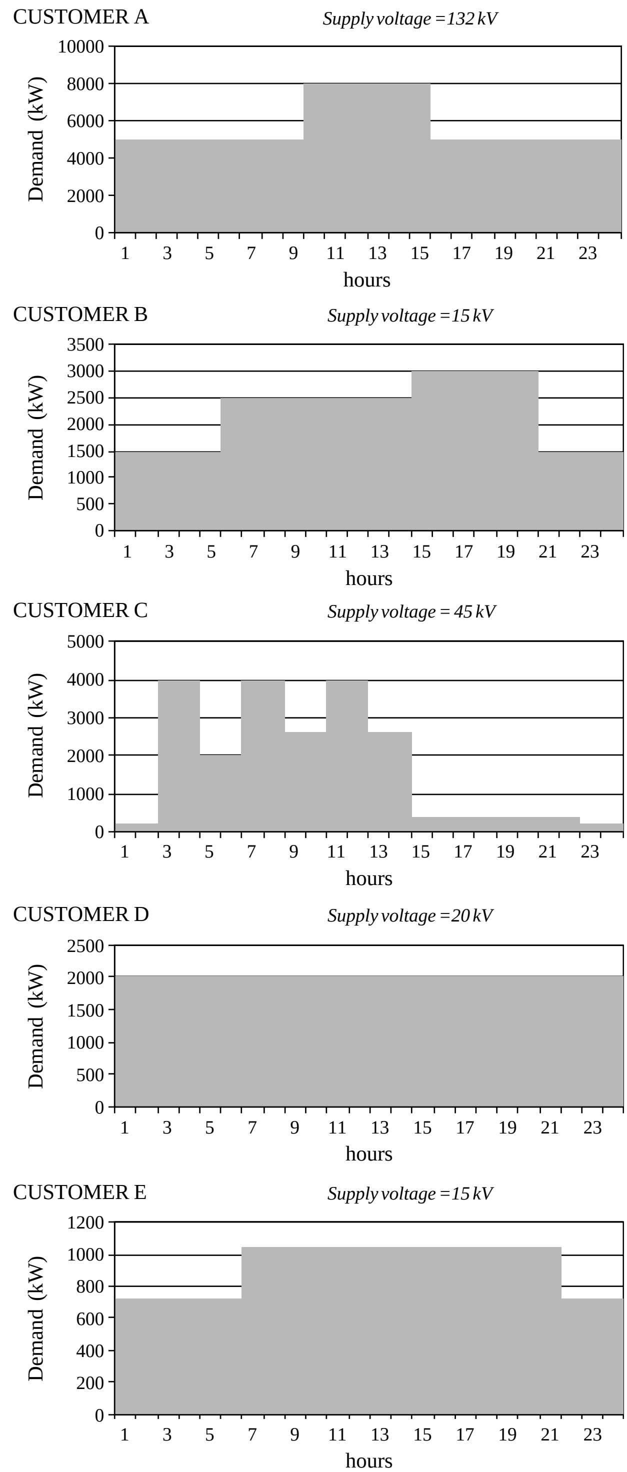

Fig. 3. Customer electric load curves.

In cases 23–28, as well as in cases 5, 7 and 10, the influence of the demand elasticity is analyzed, for cases of six prices, three prices and the flat rate. In cases 23–25, a passive response of the customers is represented (elasticity of -0.01), while in the cases 26–28 customers with a higher response capacity are considered (elasticity of -0.25).

Table 2
Consumption of electric energy and power demands

		Customer				
		A	B	C	D	E
Consumption (kWh)	1	2.400.000	1.200.000	192.000	960.000	478.000
	2	5.440.000	192.0000	1.568.000	1.600.000	788.000
	3	3.936.000	1.271.000	1.328.400	984.000	516.600
	4	4.100.000	1.927.000	475.600	1.640.000	781.050
	5	6.370.000	2.535.000	1.430.000	2.080.000	1.028.625
	6	28.222.000	10.896.000	10.504.000	1.028.000	4.553.925
Demand (kW)	1	5.000	3.000	400	2.300	1.200
	2	9.350	3.000	4.000	2.300	1.200
	3	9.350	3.000	4.000	2.300	1.200
	4	9.350	3.000	4.000	2.300	1.200
	5	9.350	3.000	4.000	2.300	1.200
	6	9.350	3.000	4.000	2.300	1.200

Finally, in cases 29–37 a sensitivity analysis is performed by varying the demand elasticity according to the customers or the periods. Cases 29–34 include elasticity variations according to the customers, considering that not all customers will have the same capacity to change its demand in response to the changes in the price. In cases 35–37, elasticity variations are used for the time periods, assuming that there are more incentives to vary the demand if the electricity price is higher.

5. Analysis of the computer results

5.1. Cases 1–6

This group of cases (Table 3) constitutes a first trial of the model in order to assess the impacts of the constraints (upon the selling kWh average price applied to each customer) on the profit obtained by the retailer.

The first case has not constraints. In case 2 a constraint is imposed, setting (as maximum price of each period) the tariff price. These maximum prices are going to decrease progressively until they reach the 80% of the tariff price in case 6, where no profit and no profitability is practically obtained, as it is shown in Fig. 4. The profitability has been calculated as the quotient between profit and income. The results of case 1 are not indicative of a real situation, due to the lack of constraints upon the maximum electricity price.

In case 5, with a maximum average price of 85% of the tariff price, the customer gets a discount of 15% with respect to the tariff and the retailer profitability is around 6.5%. These values coincide approximately (in the evolution of the Spanish electricity market from 1998 to 2000) with the prices that the eligible customers obtained in their contracts and with the profit obtained by the retailers. It can be said that it is an appropriate constraint for the real market.

Table 3
Case definitions 1–14

Case	Price strategy	Elasticity	Price limitation (with respect to tariff) (%)
1	Six prices	−0.1	–
2	Six prices	−0.1	100
3	Six prices	−0.1	95
4	Six prices	−0.1	90
5	Six prices	−0.1	85
6	Six prices	−0.1	80
7	Three prices (1 2345 6)	−0.1	85
8	Three prices (12 34 56)	−0.1	85
9	Two prices	−0.1	85
10	Flat rate	−0.1	85
11	A and E: flat rate, B–D: 3 prices	−0.1	85
12	A: flat rate, B–E: 3 prices	−0.1	85
13	A and E: flat rate, B–D: 6 prices	−0.1	85
14	A and E: flat rate, B–D: 3 prices	−0.1	85

Table 4
Definitions of cases 15–22

Case	Price strategy	Price limitation (with respect to tariff)
15	A and E: flat rate, B–D: tou rate	A: 80%, E: 85%, B–D: 90%
16	A and E: flat rate, B–D: tou rate	A and E: 85%, B–D: 90%
17	E: flat rate, A–D: tou rate	A: 80%, E: 85%, B–D: 90%
18	E: flat rate, A–D: tou rate	A and E: 85%, B–D: 90%
19	A and E: flat rate, B–D: tou rate	A: 80%, E: 85%, C: 95%, B and D: 90%
20	A and E: flat rate, B–D: tou rate	A and E: 85%, C: 95%, B and D: 90%
21	E: flat rate, A–D: tou rate	A: 80%, E: 85%, C: 95%, B and D: 90%
22	E: flat rate, A–D: tou rate	A and E: 85%, C: 95%, B and D: 90%

tou, time-of-use.

Table 5
Case definitions 23–37

Case	Price strategy	Elasticity
23	Six prices	−0.01
24	Three prices	−0.01
25	Flat rate	−0.01
26	Six prices	−0.25
27	Three prices	−0.25
28	Flat rate	−0.25
29	Six prices	P1 −0.25; rest −0.05
30	Three prices	P1 −0.25; rest −0.05
31	Flat rate	P1 −0.25; rest −0.05
32	Six prices	P1 −0.25; P2 −0,2; P6 −0.05; rest −0.1
33	Three prices	P1 −0.25; P2 −0,2; P6 −0.05; rest −0.1
34	Flat rate	P1 −0.25; P2 −0,2; P6 −0.05; rest −0.1
35	Six prices	A: P1 −0.25; P2, P3 −0.01; rest −0.05 C: P1 −0.25; P6 −0.01; rest −0.05 B, D, E: P1 −0.25; rest −0.05
36	Three prices	A: P1 −0.25; P2, P3 −0.01; rest −0.05 C: P1 −0.25; P6 −0.01; rest −0.05 B, D, E: P1 −0.25; rest −0.05
37	Flat rate	A: P1 −0.25; P2, P3 −0.01; rest −0.05 C: P1 −0.25; P6 −0.01; rest −0.05 B, D, E: P1 −0.25; rest −0.05

5.2. Cases 7–10

These cases (Table 3), as well as case 5, constitute the group used to analyze the impact of the price on the final profit obtained by the retailer. All of them have the same constraint upon the maximum price (85% of the tariff) and the same elasticity (with $\beta = -0.1$). As it can be observed in Fig. 5, the three-price strategy of case 8 does not obtain an effective segmentation of the prices, since the prices of the first four periods are practically the same.

As it is shown in Fig. 6, the highest profit is obtained when six prices are calculated and the lowest profit is achieved in the flat-rate situation. This behaviour is due to the displacement of the prices far away from the optimal ones (understanding by 'optimal' prices those of the six-price case, that is, case 5) caused by the inclusion of the corresponding constraints into the price strategies. The reduction of the profitability between the case 5 of six prices and the flat-rate case is 11.26%.

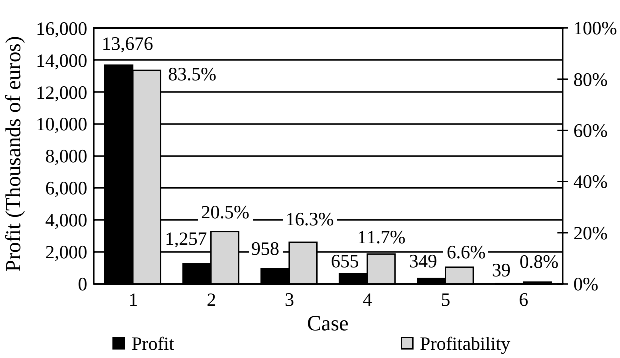

Fig. 4. Profit and profitability in cases 1–6.

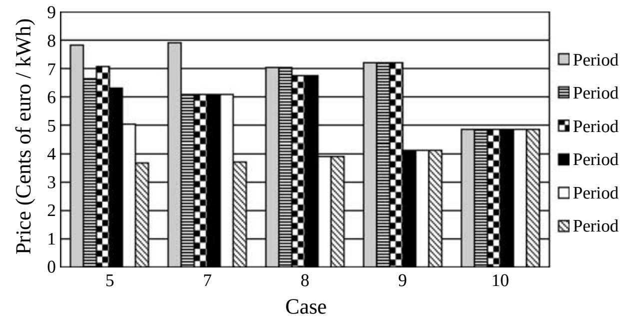

Fig. 5. Electricity selling price applied to customer A in cases 5, 7–10.

In Fig. 6, it can be observed that (although the profitability is very similar) the most suitable of the two three-price strategies is the one considered in case 7. This fact, together with the ineffective segmentation of the prices obtained with the strategy of case 8, have led to select the three-price strategy of case 7 for the rest of the cases.

The profit and the profitability obtained in each one of the time periods are very varied, as it is shown in Fig. 7.

Furthermore, as it can be observed in Fig. 7, the sixth period is the one that provides the highest profits in all cases, so that all the profit is obtained in the situation of flat rate (case 10), compensating the considerable economic losses that are produced in the first four periods.

The sixth period is also the most profitable one in all the cases, except case 7. It is worthwhile to highlight the huge negative profitability obtained in some cases, particularly in the tenth one. This is logical, as it is in the situation of flat rate where the prices of the time periods are far away from the optimal prices.

5.3. Cases 11–22

In these cases, a sensitivity analysis of the results is carried out (by changing slightly the hypothesis of maximum average prices and the price strategy) in order to study the impact on the resulting profit obtained by the retailer.

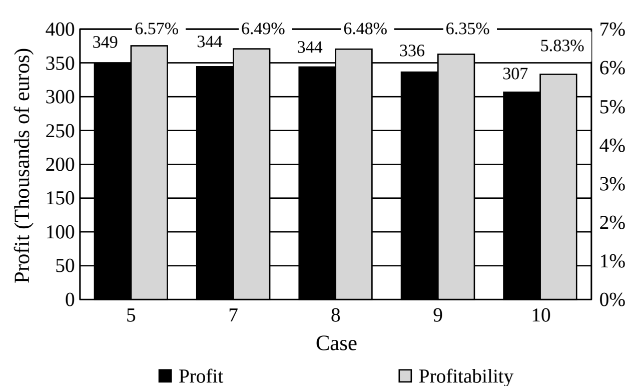

Fig. 6. Profit and profitability in cases 5, 7–10.

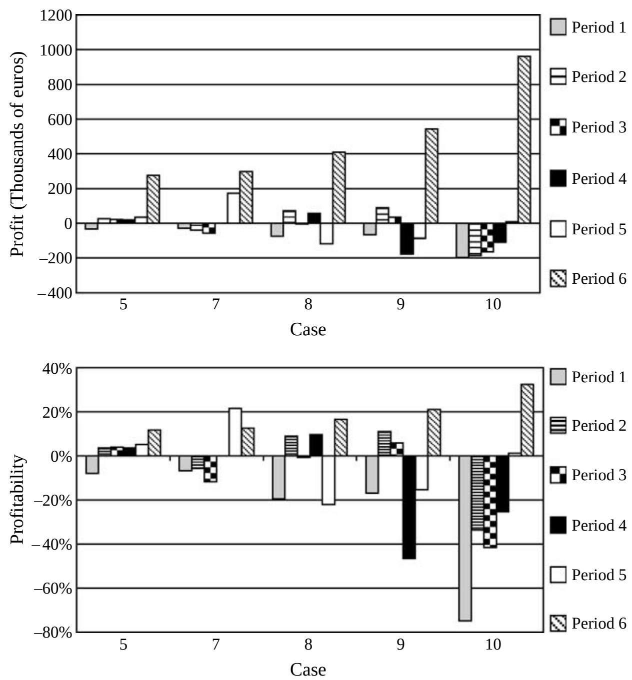

Fig. 7. (a) Results of each of cases 5, 7–10: profit. (b) Results of each of cases 5, 7–10: profitability.

In cases 11–14 (Table 3), the impact on the profit of a change in the price strategy applied to an only customer is assessed. In particular, a change to the flat rate for the customers A and E is carried out, in two situations: from a situation where the customers have a six-price strategy and from another situation where they have a three-price strategy. Fig. 8 shows the reduction of the profitability for each customer, A and E, that change to the flat rate. As expected, the customer A decisively influences the profit and the profitability obtained by the retailer: the change in the price strategy causes an important profit and profitability decrease.

Nevertheless, the same change applied to the customer E does not lead to an effect so marked, because it is a customer with a lower electricity consumption.

Cases 15–22 (Table 4) represent different trials of the model assuming different hypothesis of the contract negotiation with the customers, since different price strategies are

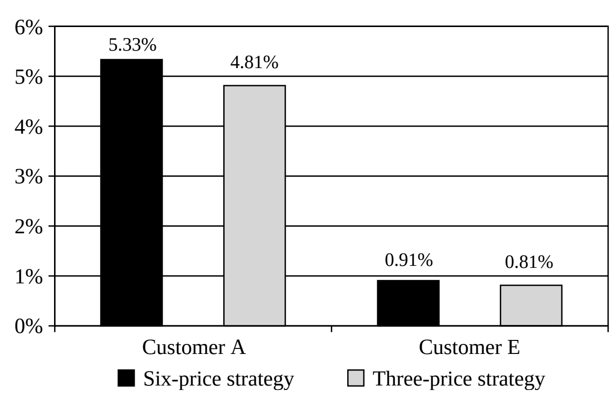

Fig. 8. Profitability decrease.

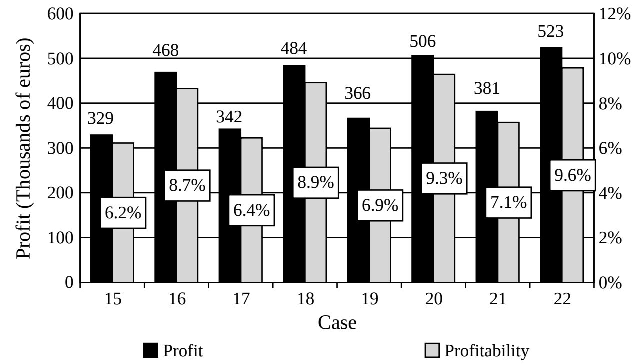

Fig. 9. Profit and profitability in cases 15–22.

combined with different maximum average prices. Fig. 9 shows the profit and the profitability of each case, obtaining the best results in case 22.

5.4. Cases 23–28

These cases (Table 5), as well as cases 5, 7 and 10, allow to assess the impact of the elasticity of the customer demand function on the final profit obtained by the retailer. Cases 23–25, with $\beta = -0.01$ (also 26–28 with $\beta = -0.25$) are similar to cases 5, 7 and 10, with $\beta = -0.1$, except for the elasticity of the customers. For the customers, the maximum average price has been fixed at 85% of the tariff in all cases.

In Fig. 10, it can be observed that the highest profit is obtained using a low elasticity, since the customers have less disposition to vary their consumption in response to a change in the prices. As it can be observed in Fig. 10, according to the elasticity increase, the difference among the results (corresponding to each strategy of prices) rises. Thus, the difference in the profit (and in the profitability), between the six-price case and the flat-rate case, grows with the most elastic behaviour of the customers: with $\beta = -0.01$ (cases 23 and 25), it is the minimum difference, 1%; with $\beta = -0.1$ (cases 5 and 10), it is 12%; and finally with the elasticity $\beta = -0.25$ (cases 26 and 28), the difference reaches 30%.

As it has been already explained in the study of cases 7–10, the price strategies move the prices of each time

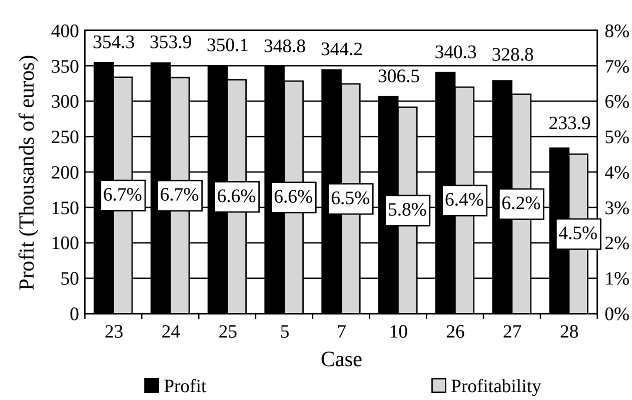

Fig. 10. Profit and profitability in cases 23–28 and 5, 7, and 10.

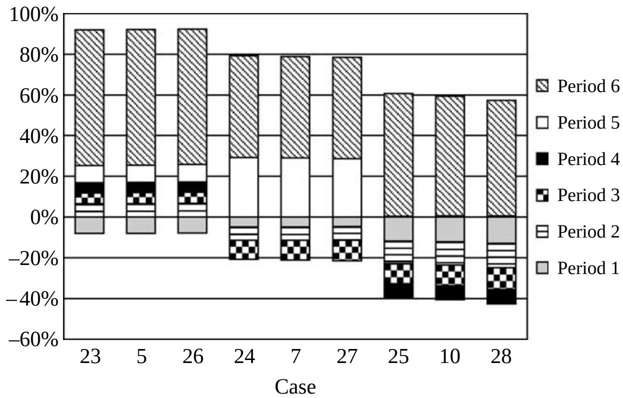

Fig. 11. Profit distribution among periods (cases 23–28 and 5, 7, and 10).

period far away from the optimal ones, and it causes a decrease in the profit and the profitability. However, according to the conclusions obtained from Fig. 10, the more inelastic the demand is, the less relevant this repercussion of the price strategy in the profit has.

The profit distribution among periods (Fig. 11) also presents variations (caused by the elasticity) in the trials performed for the price strategies. This conclusion can be specially observed in the situation of flat rate (cases 25, 10 and 28), where a more elastic behaviour causes a profit decrease in the sixth period and an economic losses increase in the rest of the time periods.

5.5. Cases 29–37

This collection of cases represents different trials of the model considering that the elasticity can be different for each time period (cases 29–34) and for each customer (cases 35–37), as given in Table 5. The results are compared with the reference cases 5, 7, and 10.

According to the results shown in Fig. 12, it can be observed that, for the situations with six and three prices, the largest profitability is obtained when $\beta = -0.1$ (cases 5 and 7).

Nevertheless, for the situation of the flat rate, this elasticity provides the lowest profit (case 10). This fact is based on the elasticity of the sixth period in cases 29 and 34

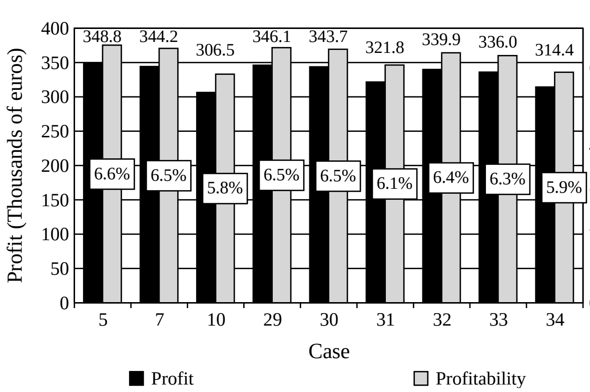

Fig. 12. Profit and profitability in cases 29–34 and 5, 7, and 10.

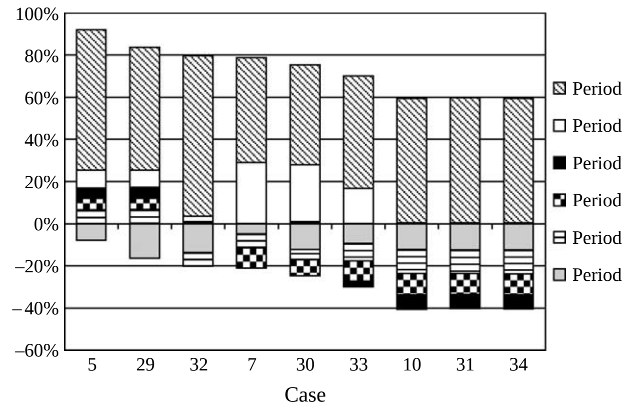

Fig. 13. Profit distribution among periods (cases 29–34 and 5, 7, and 10).

that is lower than in case 10 and this causes, in this last case, a lower consumption and a lower profit.

The profit distribution among customers is not affected by the changes of the elasticity. However, such elasticity changes have impact on the profit distribution among periods, as it is shown in Fig. 13.

According to the obtained results, it has been verified that a change of elasticity has a large impact on the situations of three and six prices, while the profit distribution remains almost unchanged for the flat rate.

In the situations of six prices (cases 5, 29 and 32), a large variation in the relative distribution of profit in periods 1 (P1) and 6 (P6) can be identified. In the period P1, its relative contribution is doubled (cases 5 and 29), because the economic losses increase significantly, due to the increase of the elasticity and the subsequent price decrease. This causes that the relative weight of the sixth period (P6) decrease, in spite of its contribution to the profit increase in absolute value. Nevertheless, in case 32 the contribution of P6 increases again. In the situation of three prices (cases 7, 30, and 33), a similar situation occurs with respect to the behaviour of the periods 1 and 6, but this time a significant part of the profit is obtained in period 5 (P5).

These phenomena show that, although the overall profit and the overall profitability are not significantly influenced

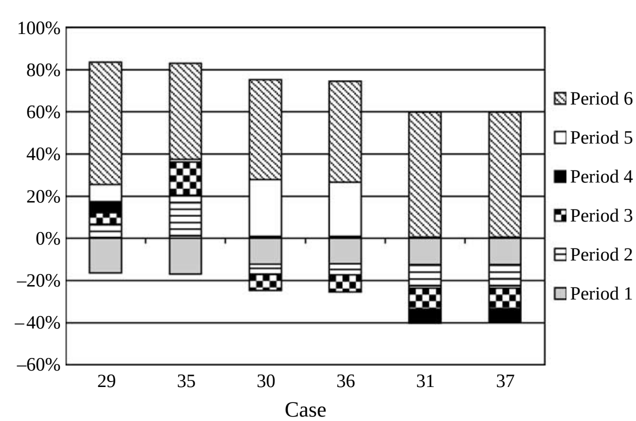

Fig. 14. Profit distribution among periods (cases 29–31 and 35–37).

by the elasticity changes, the profit distribution among periods is indeed affected.

Referring to the profit distribution among periods, when the elasticity of the customers changes (cases 29–31 and 35–37), Fig. 14 shows that the most important changes occur in the six-price situation (cases 29 and 35). If case 29 is compared with case 35, a very marked increase of the relative profit distribution in periods 2 and 3 can be identified (in case 35), as a consequence of a less elastic behaviour of the customer A in these time periods. On the contrary, the profit and the profitability obtained in the rest of the periods decrease.

In the situations of three prices (cases 30 and 36), there is no difference in the relative profit distribution among periods: the relative profit distribution among them remains as constant. This phenomenon is due to the price strategies that introduce constraints reducing the possible differences. The same comments can be said for the flat-rate situations (cases 31 and 37).

6. Conclusions

The following conclusions can be drawn from this paper:

- The most profitable ('optimal') price strategy for retailers is the six-price one, because it allows for an independent calculation of the best possible price for each time period. From the point of view of consumers, the most appropriate strategy is the flat rate, because it does not imply defining time periods.
- A compromise strategy is the three-price one as it has a relatively simple time division quite similar to the classic time-of-use structure of peak, mid-peak and off-peak periods.
- In general terms, the more elastic the behaviour of customer demand, the lower the profit obtained by retailers, as customers have an increased response capacity to price changes. On the other hand, more inelastic customers will tolerate price increases without reducing considerably consumption, thus generating more revenues and higher profits.
- Therefore, price strategies have more impact on more elastic consumption patterns and, thus, on profits and profitability. Elasticity is the factor that determines the relevance of discounts (on the tariffs) and price strategies in terms of profits.

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Jose M. Yusta received the Industrial Engineering degree from the University of Zaragoza (Spain) in 1994, and the PhD degree in Electrical Engineering from the University of Zaragoza in 2000.He is currently Professor of Electrical Engineering at University of Zaragoza, and a registered Professional Engineer. He has been responsible for several research and engineering projects in the Power Systems Economics area.

Ignacio J. Ramírez-Rosado was Visiting Research Associate, and Fulbright Researcher, at the Department of Electrical and Computer Engineering of the University of Missouri-Columbia under the Fullbright Program (1984–1985). He received the PhD degree in Electrical Engineering from the University of Zaragoza (Spain), in 1986, where he was Professor Titular de Universidad and the Subdirector of the Departamento de Ingeniería Eléctrica e Informática. In 1998, he moved to the University of La Rioja (Spain) where he is, at the present, Full Professor of the Department of Electrical Engineering.He has been responsible of several research projects in the Power Systems area, mainly in Networks Planning, Load Forecasting and Regional Energy Planning. His current interest areas are Integrated electricity resources planning and operation, Applications of novel computational techniques and intelligent systems to electric power systems, and Electricity markets.

Jose A. Dominguez-Navarro received the PhD degree in Electrical Engineering from the University of Zaragoza (Spain), in 2000.In 1992 he joined the University of Zaragoza, where he is, at present, Professor. He has been involved in some research projects referred to optimization of power distribution networks.His current interest areas are applications of soft computing in electric power systems, power distribution networks planning, electric markets and meta-heuristic optimization.

Jose M. Perez-Vidal received the Industrial Engineering degree from the University of Zaragoza (Spain), in 2002.He is now with the Energy Services Division of McKinnon & Clarke, where he is providing support on various technical and competitive issues related to energy costs.