INFLUENCE OF LOAD MODEL IN DISTRIBUTION MARKET EMULATION

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ABSTRACT
This study presents the results of the implementation of a methodology for electric energy tariff’s calculation approach. Two distinct steps in the calculation approach are described: (i) the flexibility of the price schedule definition so as to permit the establishment of different price schedules for each voltage level concerning their duration as well as their quantity; and (ii) the inclusion of price-elasticity in the revenue reconciliation procedure. Preliminary results show that this approach allows the regulator to precisely establish the regulatory revenues predicted in the tariff-revision processes. It also permits tariffs to be effectively used as load management mechanisms as well as maximize consumer welfare. The methodology described produces tariffs close to the costs endured by the DISCO besides not losing the adequate economic signal for the distribution network efficient use.

INTRODUCTION
Issues concerning electrical energy tariffs have been intensely researched and discussed for a long time in national and international forums. In Brazil, the debates have historically been concentrated more on tariff level rather than on tariffs structure itself. Internationally, the question of tariff structure had its turning point in the seventies (reflex of the oil crisis). Since then, hundreds of studies on the subject have been published, leading to a technical improvement which permitted the dissemination of several pricing mechanisms [1], [2].

In the eighties, a pricing system using the “Green Tariff” approach was implemented in Brazil. Nonetheless, even though all the recent industrial and technological sectors changes were considered, it still did not progress much at the time.

In recent years, the pressure for changes has increased mainly due to the difference between the tariffs applied by the transmission network and those applied by the distribution systems. This study suggests betterments in the procedures utilized for the establishment of tariff structure in Brazil in the light of international practices and the difficulties of adjusting these practices to the national reality.

TARIFF STRUCTURE
In 2006, a survey conducted in the United States examined their 50 largest utilities and 15 large utilities overseas and verified that 93% of the utilities surveyed had some demand interaction program (Demand-Response - DR). In Brazil, the TOU pricing system is available only to consumer units connected to high voltage level. One of the characteristics of the Brazilian TOU pricing is the inflexibility to establish the duration and the number of price schedules at the different voltage levels. This inflexibility results in an inefficient economic signal.

Studies carried out for distribution companies (DISCO) indicate that the peak load may occur at different time periods at each voltage level. It shows that the establishment of the price schedules should be flexible, both concerning the duration as well as the number of price schedules along the time [3].

Although the DISCOs regularly send the Brazilian electricity regulator (ANEEL) the update of load profile and the system design, the actual computation maintains the historical relations of the peak/off-peak price. This attitude reflects either the regulator’s conservative behavior or the lack of knowledge on load modulation and on the impact of consumption behavior changes in the network loadability.

With the purpose of promoting a debate about the theme, the outline of a revenue reconciliation model is presented. It considers, in its roots, the economic signals obtained from the use of TOU price mechanisms [3].

REVENUE RECONCILIATION
The TOU price mechanisms are used to optimize the distribution system loading. In other words, the signal obtained through the joint analysis of the load and network profiles may optimize the use of the systems. However, they do not guarantee the DISCO’S economic sustainability.

The literature points out four different options for the achievement of revenue reconciliation [1]:

- **Fixed adder** – ADDER – adds or subtracts a constant for revenue adjustment;
- **Fixed Multiplier** – MULTI – multiplies by a constant for revenue adjustment;
- **Reliability sensitive adder** – LOLP – allocates revenue in proportion to the load loss probability;
- **Ramsey Derivation** – Ramsey Prices - allocates revenue in the inverse proportion to load elasticity.

In this paper, the revenue reconciliation is considered through Ramsey prices, since this method stands out from the others. Regardless of the degree of elasticity verified in the DISCO’s market, Ramsey prices always generate a larger surplus compared to the remaining technical options available [1]. It is important to note that Ramsey prices are widely used by the
North American regulators. In 1983, for example, the United States Interstate Commerce Commission adopted Ramsey prices as basic principles for the establishment of railway fees. [4].

In Brazil, the electricity regulator uses the "Fixed Multiplier" and it considers as means of computation the most recently observed market. However, this observed market brings information about the revenues of prior-established tariffs. When tariffs or price schedules are changed there is a rupture between the observed and ongoing markets. After all, the new price schedule will certainly shift the maximum demand and energy consumption in the future will also be different. Therefore, given the dimension of the shift, the observed market by itself doesn’t carry enough information for the appropriate revenue reconciliation.

The use of Ramsey prices with load profile is able to quantify prices "second best". However the implementation of the traditional Ramsey model does not guarantee the optimization of the system loading.

Hence, the problem consists in finding an efficient tariff computation approach, which simultaneously guarantees revenue reconciliation and incorporates the network optimization. Adopting Ramsey prices as an economic signal in the price mechanisms of the TOU type [4] represents a solution to the problem. The TOU type price mechanisms optimize the system loading as a first aspect of efficiency. Ramsey prices, on their turn, besides guaranteeing the utilities’ economic sustainability, maximize consumer surplus, as a second aspect of efficiency.

In this way, this paper considers the traditional Ramsey price model which maximizes consumer surplus. Moreover, it includes the peak/off-peak price ratio of each voltage level obtained from TOU as addition constraints.

MARKET EMULATION

In order to solve the maximization problem of the consumer surplus the relations between the consumption and associated prices must be defined, that is, the demand function [5]. For the problem in question, the demand functions for each tariff at any voltage level must be measured, as well for each time of the day.

Thus, the price-elasticity of the energy demand must be known in order to establish these demand functions. Regarding that these data is not usually available, one may use its linearization near a known operation point [6]. Moreover, since there is not enough data available for a wide range of price and consumption, this paper makes the assumption that the demand curve is isoelastic. Besides that, the elasticity of energy prices was obtained from econometric equations defined to forecast energy consumption [7].

The elasticity was obtained from studies conducted by Brazilian Secretariat for Economic Monitoring [8]. The values identified are presented in Table I.

<table>
<thead>
<tr>
<th>Elasticity</th>
<th>Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.545</td>
<td>Industrial</td>
</tr>
<tr>
<td>-0.174</td>
<td>Commercial</td>
</tr>
<tr>
<td>-0.146</td>
<td>Residential</td>
</tr>
</tbody>
</table>

Once the elasticities for each consumer sector is defined, and considering that at least one consumption-price point is known, that is, defined by the current tariffs and demand (represented by typical load curves), it is possible to establish all the necessary demand functions. For a consumption class with the load profile described in Figure 1 and submitted to the price system in Figure 2, the demand functions calculated for the time 1 would be established according to the curves presented in Figure 3.
Figure 3 presents two different functional forms representing the demand of energy at hour 1: linear and power. Both were computed from the consumption-price point (89.7; 0.13) and from the industrial loads typical elasticity (-0.545) [2].

One can see from Figure 3 that depending on the functional form chosen, if there are significant variations on the tariffs, there will be a displacement between the demand curves described. As mentioned before, this paper makes the assumption that elasticities are constant; therefore the results here will be based on the power functional form.

Once elected a functional form for each hour, one must establish the load behavior model. The following hypotheses have been considered:

1. There is no idle capacity in the system [9];
2. The maximum demand in a 24-hour period is restricted to the historical maximum;
3. The maximum energy consumption capacity is limited to the continuous use of the maximum demand possible;
4. The minimum demand in a 24-hour period is restricted to the historic registers;
5. The hourly signal on power tariff\(^2\) leads to load modulation, but does not change the total energy consumption [9];
6. The energy tariff variation leads to the change in energy consumption, changing the load consumption profile;
7. The maximum increase in the tariff is limited to 20 times the value of current one.

Once these hypotheses have been considered, it is possible to estimate both the consumer unit surplus as well as the expected revenues after a new set of tariffs is applied in the market. If the demand curve at time \(h\) may be explained by the function:

\[
D_h(T) = a \ast T^{-b}
\]  

(1)

Then the consumer surplus at time \(h\) is given by:

\[
CS_h(T) = \int \limits_{T_{min}}^{T_{max}} D_h(T) dT
\]  

(2)

For the revenue calculation one must observe how the consumption is charged. If the tariff charges only on the energy consumption (MWh), the revenue will be obtained by multiplying the tariff for time \(h\) by the energy consumed in the same hour; that is:

\[
R_h(T) = D_h(T) \ast T
\]  

(3)

Nonetheless, if the tariff charges the power as well (kW), one must observe the specific rules for the computation of the revenue that are define by the regulator.

Despite being accepted and used in other countries, typical load profiles to forecast or project DISCOs revenues are not commonly used in Brazil where the observed market is the reference [9]. This approach assumes an inelastic market, and is widely used in Latin America, even though it is contradictory to the results verified in other studies [8], [10].

The approach proposed in this paper introduces elasticity in the tariff computation, allowing a better estimate of the real load behavior facing a tariff signal.

**COMPARATIVE ANALYSIS**

Simulations were conducted in order to verify the feasibility of the proposed model. Data from a medium-sized DISCO were used. This company’s distribution system is composed of 5 voltage levels where the load profiles are represented by 49 typical consumption curves and the network profiles by 33 typical transformation curves.

For each typical consumer profile, the price elasticity was adopted according Table I. The ideal procedure would be to represent the different economic activities by considering also the prices to which these activities were submitted. The greater and more diversified the consumer profiles are the smaller the error of the modeling will be.

In order to check the accuracy of load curves to explain the DISCO revenue, the difference between the revenues obtained by the reference and estimated market is 0.64%, considering that the load curves initially are inelastic. These results suggest that the load is well characterized and one can use the typical curves to emulate DISCO revenue.

In order to compare the proposed model and the present one, three situations were considered:

1. Standard tariffs, demand completely inelastic;
2. Standard tariffs, elasticity lower than 1;
3. Optimized tariffs (Ramsey prices considering TOU constraints), elasticity lower than 1.

The first case, as previously mentioned, was used only to check the capacity of model to reproduce the actual regulator’s procedure. In the second case, it is possible to estimate the DISCO’s market response due to the standard regulator’s tariff computation. It is verified that a reduction of 7.1% on the tariff level would imply only a reduction of 2.4% in the total revenue.

The load response to the third case would imply an effective reduction of 7.1% in the total revenue, reaching the equilibrium point established in the tariff revision process.

Exactly as in the previous case, the expected regulatory revenue would be obtained by considering the different load responses at each voltage level and consumption class, reducing 0.39% in the total supplied energy.

As for the total surplus, the use of the proposed model in relation to the present method, showed an increase of US$ 32 million, or an increase of 0.5% in the total expected surplus. Despite the variation of this aspect not being so significant, it
is worth mentioning that this distributor’s market is predominantly of low voltage (69% of the total load) and, if the predominant elasticity in the analyzed market is lower, the differences between the revenue reconciliation methods, concerning total surplus, tends to drop.

**COMPARATIVE ANALYSIS**

The inclusion of elasticity-price in the tariff calculation procedures has been observed in a large number of monopolistic activities precification.

The frailty of this proposal lies on the identification of load elasticities compared to the energy prices. Consumer’s behavior must be assessed from a demand function that relates the price and energy consumption. Establishing this relation is not trivial because electrical energy is a continuous consumed product, and is charged in different ways (peak energy, off-peak, power demand, etc.). The elasticity, obtained through the demand function, is a traditional form of measuring consumption reaction to each of the elements of the tariff.

In an ideal environment, it would be necessary to undergo a preliminary experiment about the consumer’s behavior with significant samples of each sub-market to which the new tariffs could be applied. Obviously, it is a costly and slow solution to estimate elasticities. Alternatively, as an example of what was described in this paper, specific projects could be developed so as to try to make use of the number of researches already accomplished for other countries, in a number of contexts and thus evaluate the best estimates that would adjust to the Brazilian market.

The preliminary results obtained show that the proposal of including elasticity in the present tariff calculation procedures is promising. Despite not presenting high increments in the total surplus, the described process permits the regulator to achieve regulatory balance point more precisely besides quantifying the possible load response compared to tariff signals. This quantification would permit the use of tariffs as a load management element, optimizing the distribution system loading by using the price periods. Therefore, making TOU tariffs more versatile would optimize the loading of the electricity distribution system.

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**REFERENCES**


