The impact of time-of-use electricity tariffs for Brazilian residential consumers using smart meter real data

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Abstract - In 2011, the Brazilian Electricity Regulatory Agency (ANEEL) approved a new tariff structure for distribution services, the White Tariff, a time-varying tariff modality for retail consumers connected to low-voltage distribution grids. The aim of this paper is to demonstrate existing distortions in White Tariffs established by ANEEL for two Brazilian distribution utilities: Ampla and Coelce. Furthermore, through the analysis of the consumption profiles of residential customers located in these two companies, this paper reveals that those distortions can provide differentiated signals for similar consumers’ profile and also distinct revenue impacts for both distribution utilities. The real data came from electronic meters with mass memory. These measurements were carried out through specific devices that provide not only the total consumption but also its breakdown considering the relevant electric equipment existing in each analyzed household. As a result, taking into account the studied samples, 66.67% of Ampla’s clients would benefit from the new tariff compared to 98.33% of Coelce’s, which would lead to loss revenue of 1.96% for Ampla and 7.73% for Coelce.

1. Introduction

The implementation of Smart Grid can be considered the main instrument of the current modernization in the electric power sector. Smart Grids are able to monitor and manage, using advanced digital meter technology. In this way, it enables active actions among them, sending real time information as consumption, and quality of service.

Smart meters, a technological evolution of electronic meters, are essential smart grid components. Besides providing additional information for utilities and consumers, it presents the possibility to offer different tariff options, such as hourly rates, for example, as the advanced meters can record customers consumption in real time [1].

With the information provided by the smart meter and an appropriate tariff policy, it will be possible to promote change in the electricity consumption behavior - the ultimate concept of demand response, since the consumer can manage their energy use in order to obtain the lowest cost.
This paper aims to show the application impacts of time-of-use tariffs for Brazilian residential consumers using smart meter real data.

2. Time-varying Tariff

Tariff is an effective tool for modifying agent consumption patterns, so an optimized tariff structure is essential to ensure a more efficient system operation. The use of electricity varies over time and the capacity of the equipment which makes up the electrical system is determined by the maximum use of electrical energy per unit of time, even if it occurs only during certain hours of the day.

The peak load demand, which occurs when there is a high concurrent use, imposes risk and cost to the electrical system because it occurs only a few hours of the year [2]. In this way, a consumer that increases its consumption in periods of high load on distribution systems contributes to the system expansion needs. In addition, peak load is usually supplied by fossil fuels and/or energy stored in hydroelectric reservoirs, resulting in increase of emissions and environmental impacts.

An alternative to hire additional infrastructure to maintain a secure balance between generation and demand of electricity is the implementation of Demand Response mechanisms, which can be defined as a change in the electricity utilization by end users in relation to their usual consumption, in response to changes in energy prices that encourage the reduction of use in periods of high energy costs [2]. These mechanisms are feasible only with smart grid and smart meter implementation.

The application of time-varying tariffs that signal to customers the different costs of energy supply contributes, therefore, to a more optimized use of the electric system infrastructure, as it encourages consumers to use the energy outside the peak hours. Among the benefits this type of tariff are increase of generation capacity and network, reduction of the overall costs of the electric system, fairer price in retail market since there is more correspondence between the costs each consumer imputes to the system and the value at which energy is charged. As a result, there are the following consequences: customer energy bill reductions, improvement of customer service (automatic billing, less theft of energy, quality of energy etc.), favoring the expansion of renewable and intermittent distributed generation (such as solar and wind), and possibility to introduce electric vehicles in the market. Besides it also involves possible greenhouse gases (GHG) emissions reductions [3].

Aiming at sending time-varying economic signals to retail electricity consumers and optimizing the use of the distribution network, the Brazilian Electricity Regulatory Agency (ANEEL) approved the creation of a time-varying tariff modality for retail consumers connected to low-voltage distribution grids, the White Tariff, with R$/kWh tariffs that vary according to the time of day [4].

In Brazil, low voltage consumers are charged via supply tariffs, basing exclusively on energy consumption, in R$/kWh. The White Tariff will be an alternative to the existing Conventional Tariff, a flat tariff (no differentiation over different periods within a day) that is currently applied to all consumers [4]. This new tariff modality is conditioned to the substitution of the current electromechanical metering by smart meter, which the first model was approved by the Brazilian National Institute of Metrology, Quality and Technology (INMETRO) in 2016.

3. Metering

In most of the countries, the classic electromechanical meter is still the main way of measuring energy consumption in residences and small businesses. This traditional electricity meters show consumption in kWh, record consumption cumulatively and are read manually. In some places,
monthly the supplier sends a meter reader to each residence in order to read the meter, in others, monthly billing is based on a consumption estimate and a correction, if necessary, is done when the reading is done, therefore with a delay. Tariffs are based on a unit (kWh) rate, independent of time of use.

Electronic meters can have multiple functionalities. Interval meters are electronic meters that have the ability to record electricity consumption on frequent intervals, usually 15 or 30 minute intervals, which are able innovative pricing schemes to retail electricity customers, as more complex time-varying rates, for example. Smart meters can be equipped with communications technology that allows the supplier read the meter remotely.

Communications technology improves functionalities allowing greater interaction between the players in the chain. Two-way communications systems enable innovative services for the customer and options for the supplier as remote connection and disconnection, loss of supply detection and communication to the supplier, ability to interface with load control technology.

The most recent evolution of the smart meter is based on the introduction of bidirectional capabilities from two different points of view: communication and also energy. Therefore, these meters also have the capability to record electricity that is imported from the grid as well as electricity that is exported to the grid, allowing for the measurement of energy production from micro-generators (photovoltaic, for example).

The European Parliament, in the 2012/27/EC directive, defined a smart metering system as “an electronic system that can measure energy consumption, providing more information than a conventional meter, and can transmit and receive data using a form of electronic communication”.

The benefits of smart metering can be divided into two main categories:

(i) Operational benefits: The avoided cost of meter reading is one of the most significant operational benefits. Non-technical loss reduction, as losses due to theft, can also be an important benefit as well as better outage detection that can reduce field visits. It can be possible to reduce technical losses with more complete and frequent data from nodes and networks. Furthermore, accurate billing also improve the efficiency of metering services reducing the frequency of customer complaints and savings in re-issuing bills. Moreover, utilities can use the big variety of data generated from measurements to make a variety os forecasts using predictive analysis, which can enabling them to take proactive action [5].

(ii) Demand response benefits: Smart meters are able to offer customers more choice of payments, to provide additional consumption information and to facilitate micro-generation installation. The smart meters can act as a platform for automated forms of demand response by connecting with smart appliances, such as the smart thermostat, to control loads directly. Direct load control and time-varying prices can move consumption from peak to off-peak periods.

However, demand response impacts of smart metering depend on the tariffs offered by suppliers, the number of customers that opt to the new tariffs and/or load control and the availability of customer to respond to new tariffs and change use habits, contributing to energy efficiency of the energy system. In addition, smart meters may remove the cost to customers of installing additional metering equipment to link the microgeneration units to the grid.

Metering service consists of several activities that do not necessarily have to be carried out by a single party: (i) meter provision (supplying metering equipment); (ii) meter operation (installation, operation and maintenance); and (iii) meter reading and data processing. Traditionally, meters have been owned and activities have been undertaken by network operators but in some countries there is
competition in metering [5]. And, in the last decade, most countries have committed to adopt changes in technology to enable them to meet targets on sustainability and ensure security of energy supply [6].

In the European Union, the 2006 Energy Services Directive (2006/32/EC) requires Member States to “ensure that, in so far as it is technically possible, financially reasonable and proportionate in relation to the potential energy savings, final customers for electricity, natural gas, district heating and/or cooling and domestic hot water are provided with competitively priced individual meters that accurately reflect the final customer's actual energy consumption and that provide information on actual time of use” [7]. Also, smart metering is one of the most relevant tools in promoting more responsive demand in the context of improving security of supply and reducing CO2 emissions.

It is anticipated that almost 800 million smart meters would have been installed globally by 2020. While Europe leads the penetration rate – growing from 15% in 2010 to 85% in 2020. When the rollout is complete, China would see the largest install base with over 435 million meters followed by the United States with 135 million meters [6]. Although the deployment of smart meters is happening worldwide, utilities are focused on different benefits from them. For North American utilities, for example, the priorities are support outage management and increasing grid reliability. In contrast, European utilities are much more focused on consumer-related capabilities and meeting regulatory mandates [8], including reduction of greenhouse gases (GHG). According to the European Commission, member states have committed to deploy 200 million smart meters by 2020 (Electric Directive 2009/72/EC). This implies that more than 70% of end-users will be covered by smart grid technology. In 2013, the total number of installed smart meters was estimated at 61 million, mainly as the result of large rollouts in Italy, Sweden, Finland, and Denmark. [9]

Starting in 2001, Italy has been the first case of deployment of smart metering systems on large scale in Europe: in 2016 more than 35 million customers have their smart meter installed and working. Now Italy is preparing a new upgrade in the technology of smart meters which will enable greater efficiency in the supply chain and allow customers to benefit of new innovative services. [10]

Advanced meters are the predominant metering technology installed and operational throughout the United States. According to the Energy Information Administration (EIA) 2014 data, 58.5 million advanced meters were operational nationwide out of a total of 144.3 million meters, indicating a 40.6 percent penetration rate [12]. Deployments are projected to reach 70 million smart meters by the end of 2016 and 90 million by 2020. More than 30 electric companies in the United States have fully deployed smart meters. [11]

China has become the world’s largest market for smart electricity meters because of several initiatives by the Chinese national government. The installed base of smart meters in China is expected to grow from 139 million units in 2012 to 377 million units by 2020, reaching 74% market penetration. [6]

4. Methodology
The data presented in this paper come from a Research and Development Project (R&D) lead by Pontifical Catholic University of Rio de Janeiro (PUC-Rio) with customers from two distribution utilities in Brazil: Ampla and Coelce.

Regarding the measurement, two types of electronic meters were used: one that measured the total consumption of homes called SAGA 2000 and the other, Powersave meter, specifically
designed for the project, consists of intelligent sockets individually installed in household appliances. Both meters have an important property of mass storage in all measurements done.

A sample of residential customers of each utility was extracted, using information provided by them. It was measured the appliances that had a greater representation in the overall household consumption (using Powersave meter). The other devices, including the lighting system, “other uses”, were obtained by the difference between the total load curve and the sum of the load curve of the meter, being used 240 measurements (120 of each electricity distribution utility). The meters remained in the homes for nine consecutive days between the months of July and November of 2012 and recorded the energy consumption in intervals of 15 minutes, storing and recording them in their mass memory. These measurements provided information for the daily load curve and monthly electricity consumption.

5. Results
It was observed, in the current situation and considering the analyzed samples, the revenue of Ampla, which has the highest tariff, is 23.27% above that of Coelce, although consumption is only 8.15% higher. Considering a compulsory migration for the White Tariff by all consumers studied, 66.67% of consumers would benefit in Ampla area and 98.33% in Coelce, simply from adopting the new tariff without changing their consumption behaviors and, therefore, without bringing any benefit to the electric system. At the same time the revenues of both distribution utilities would be reduced: Ampla in 1.96% and Coelce in 7.73%. Taking into account only the benefited consumers, as the White Tariff indeed consists of a voluntary, opt-in time-varying tariff modality, Ampla’s loss would increase to 2.78% and that of Coelce, 7.81%, increasing the financial imbalance of the distribution companies.

By simulating one company’s market using the other’s tariff, it is possible to conclude that, in addition to the tariff distinction, there is a differentiation, albeit minor, in the way the energy is used throughout the day. When the load curves of the measured equipment consumptions are analyzed, it is observed that the equipment has different weights in the electrical system peak:

![Figure 1: Load Curve registered in Ampla and Coelce](image)

6. Conclusion
The expansion of deployment of smart meters is taking place worldwide as one of the most relevant tool in promoting more responsive demand in the context of improving security of supply and reducing CO2 emissions.
Following this tendency, Brazilian Electricity Regulatory Agency (ANEEL) approved the creation of a time-varying tariff modality for retail consumers connected to low-voltage distribution grids, the White Tariff.

However, the study concludes that the migration to the White Tariff, as it is established, would not bring immediate benefits to the electric system, since many consumers would benefit without any change of electricity consumption behavior.

In addition, it was found that the White Tariff did not provide the same incentives to the two distribution companies, compromising the equality criterion of benefits and duties. Therefore, in the way the White Tariff is defined, it would bring greater losses to one company than the other.

Time-varying tariff main objective is to benefit the system with greater security and reliability and also postpone expansion investments. Therefore, it is necessary to consider if a two-part tariff would be more objective in order to send economic signals to retail electricity consumers, since the White Tariff reflects only the energy consumption not taking in account the demand.

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