Demand Response: a survey on Challenges and Opportunities

Francesco Gianelloni[1], Lorrane Câmara[2], Andre Leite[3], João Felippe Cury Marinho Mathias[4]

[1] *UFRJ - GESEL, Av. Pasteur 250, Rio de Janeiro, Brazil, francesco.zubiria@ppge.ie.ufrj.br*
[2] *UFRJ - GESEL, Av. Pasteur 250, Rio de Janeiro, Brazil, lorrane.camara@pped.ie.ufrj.br*
[3] *UFSC, Av. R. Eng. Agronômico Andrei Cristian Ferreira, Florianópolis, Brazil, andre.ls.leite@gmail.com*
[4] *UFRJ - GESEL, Av. Pasteur 250, Rio de Janeiro, Brazil, mathias@ie.ufrj.br*

SESSION: "Scientific session"

ABSTRACT

Higher efficiency and reliability of the electric system are important goals to be achieved. The increasing growth and importance of intermittent renewable energy sources and its massive incorporation into the electricity grid, given the efforts to diversify the energy mix and reduce the carbon emissions, bring new challenges to the sector, such as the need of higher levels of flexibility. In this context, demand-side flexibility measures come to light as a way of improving system reliability and, at the same time, defer the need for investments in the expansion of distribution and transmission grids, reducing the demand for additional generation capacity and allowing the shave of peak demand, resulting in a reduction of electricity costs. Among these measures, demand response figures as one of great importance. It is based on electricity consumers' capability to respond to price signals, increasing the consumers' role in ensuring system security in a cost effective way.

The objective of this article is to examine some of the main challenges and opportunities for enabling demand response programs, taking some lessons from the international experience. An additional effort is to focus on Brazilian case. The methodology consists of bibliographic and documental review, with the analysis of challenges and opportunities, followed by an investigation of demand response programs in Brazil. This paper was developed under the framework of a project supported by the ANEEL's R&D Program. It was found that technological requirements of demand response can be a great obstacle, as observed in some of the European countries cost-benefit analysis and in the Brazilian case. The Brazilian experience is by all means only incipient and takes advantage of a small part of the full demand response potential, but even in this condition, shows some positive results in efficiency.

KEYWORDS: Demand Side Management; Demand Response; Smart Grids; Demand Flexibility; Dynamic Pricing

1. INTRODUCTION

In almost every market, demand and supply conditions determine the price, which, as a result, allows equalization of quantities in both sides. Consumers demand and producers supply certain quantities according to the current price. A perturbation in demand or supply conditions is communicated to the market through changes in quantities and, in the case of inexistent price rigidities, results in a new price level which *clears* the market given the supply and demand conditions. In short, it allows demand and supply equalization. This mechanism, in competitive markets, is very efficient from resources allocation point of view (Varian, 1996). However, in electricity markets, tariffs usually (the price) have a certain degree of rigidity; in other words, their adjustment for a new level is delayed in a certain amount of time, which that depends on certain institutional, technological and market niche conditions. Electricity tariffs usually reflect the variable costs incurred in the last period before the adjustment. So, if during the last period through which the price was fixed, the costs raised (in face of a higher demand, or higher fuel prices for example) in comparison to the previous period, the current price will reflect this raise in costs and elevate in relation to the previous.

Notwithstanding, the demand and supply of electricity must always be the same in order to ensure that all consumers receive the demanded electricity, task that is assigned by the system operator. Supply conditions (costs and availability) of electricity are subject to variability, since some of the generation technologies depend on stochastic and intermittent natural conditions. In a scenario of decarbonization and serious insertion of renewable energy sources in the power mix, this variability of supply becomes even more significant (Ambec and Crampes, 2015). From the consumers point of view, their demand have seasonal and hourly variations, since it also depends on natural conditions to which they react (temperatures changes during the year) or conditions inherently related to the intra-day schedules (like business hours).

The main problem with the price rigidity is its incapability of communicating these changes during a period of price rigidity that only operates a unique tariff. This results in a demand that is “blind” to these conditions, and acts inflexible, precluding, for instance, consumers with flexible demand capacity to consume during lower prices periods, which are characterized by good supply conditions and a lower demand. Another inherent consequence of such a rigid tariff system is the turmoil caused by these characteristics during peak demand periods, when the supply’s reliability and safety are jeopardized in face of simultaneous adverse natural conditions. A financial compensation (lower than the costs of system blackout) from the energy retailers to those willing to reduce or even cut their consumption to zero in those critical periods could be a reasonable and efficient way of increasing the electric sector supply reliability. This last is classified as an ancillary service.

Both of the above glimpsed alternatives, the more dynamic tariff in opposition to the very rigid tariff, and the possibility of an instantaneous demand response (financially compensated) in face of adverse supply conditions (conditions pre-determined), are part of what is known in the economic literature as Demand Response (DR), since they result in responses from the demand side. In FERC’s definition: “Changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.” (FERC *apud* MIT, 2011, p.147)

The objective of this article is to examine some of the mains challenges and opportunities for enabling demand response programs, taking some lessons from the international experience. An additional effort is to focus on Brazilian case, whose electric system comes from a very different background but is facing the same challenges of an ever increasing role of intermittent and stochastic renewable sources in the electricity generation matrix, just like the European and North American countries.

2. OPPORTUNITIES

One of the greatest motivations for enabling demand response mechanisms relies on its capability of reducing costs, through more efficient consumption choices. More dynamic tariffs and lower or incentivized voluntary demand curtailment have as a consequence what came to be known as *peak shaving*. Peak shaving is the result of a reduced demand during usually higher demand periods (peak periods). Since consumers charged with dynamic tariffs are aware of the higher costs of these peak demand periods through higher tariffs, they will tend to shift their load to other ones, with lower tariffs. If this temporal shift in load does not alter the overall period electricity consumption, then the result is called *load shifting*. If it does alter, in a way that consumption in other periods do not compensate the consume reduction during peak demand periods, then the result is called *load shed.* Electricity generation marginal costs tend to be crescent, since dispatch ordering criteria is customarily based on merit (lower costs first), which means that the total cost is a convex function of the demand. So if the total electricity consumption is the same for two different periods, the period with less variability (or fewer/lower peaks) will be the less expensive[1]. Considering that load shifting is in itself a consequence of a better management aiming costs reduction and that load shedding will only happen voluntarily (financially inactivated, with economic based incentives), it is easy to conclude that there must be a cost reduction.

With an ever increasing insertion of renewable energy in a large number of countries power mix, intermittency and stochastic behavior from part of the supply side can jeopardize the electrical system stability or even its supplying capability for a given time (Ambec and Crampes, 2015). Wind plants, for example, are subject to very high generating oscillations, exerting high stress over the supply and demand balance, as illustrated by Fig. 1:

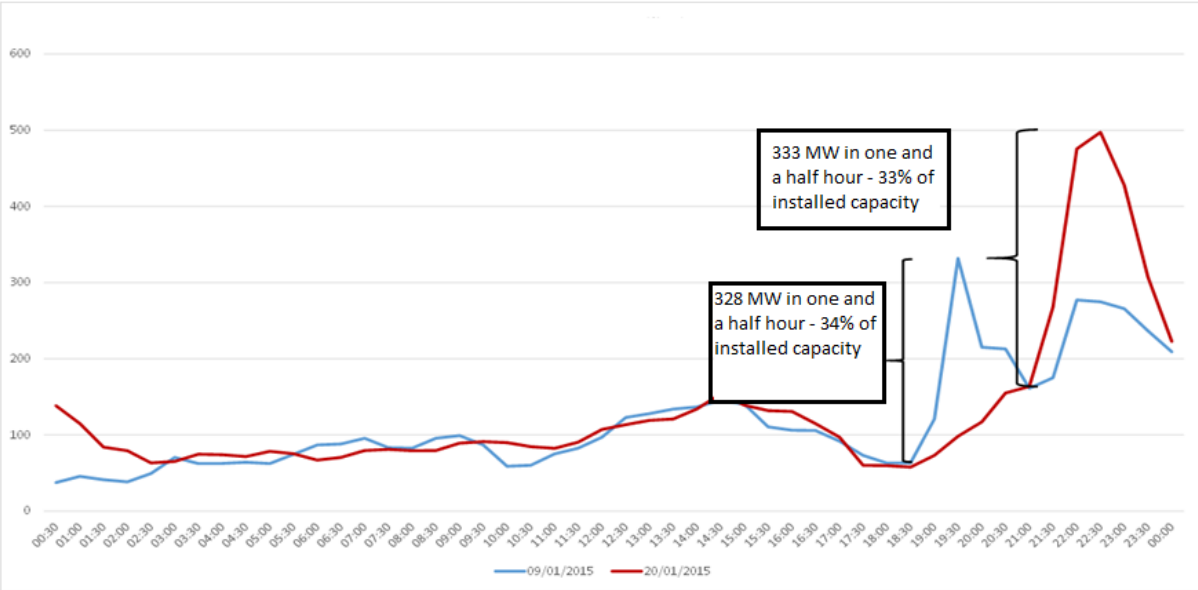

Figure 1: A Brazilian wind plant intermittent profile. Days: 09/01/2015 and 20/01/2015. Source: ONS – Brazil's system operator

Another motivation, according to Sheikhi Fini et al (2013), quoted by Poudineh and Jamasb (2013), can be identified in the opportunity of postponement in grids investments. Since peak shaving results in a more stable demand, grids can operate with less idle capacity and the current grid installations might be able to work without the need for upgrades and reinforcements for the next few years. Fig. 2 illustrates the case with a British example:

Figure 2: Estimated costs of grid reinforcements in Great Britain, with and without (business as usual) demand response, for different heat pumps and electric vehicles penetration levels. Source: G Strbac et al (2010), Benefits of Advanced Smart Metering for Demand Response based Control of Distribution Networks

[1] By the Fundamental Theorem of Calculus $F'(x) = f(x)$. Since F'is increasing, F is convex. If $w = x + x$ and F is convex, then $\int_0^x f(x) < \int_x^w f(x)$. So we conclude that $\int_0^w f(x) = \int_0^x f(x) + \int_x^w f(x) > \int_0^x f(x) + \int_0^x f(x) = 2\int_0^x f(x)$. In short: $F(w) > 2F(x)$. Either x and w can be considered as the consumption of a period, as long as equal periods have equal consumptions, with F representing the total cost function in a given period and f the marginal cost function. This result can be extended analogously for a larger number of sub-periods.

	Without DR programs	With DR programs
Penetration Level	Total Investment (£bn)	Total Investment (£bn)
10%	5.1	2.2
25%	13.0	4.7
50%	25.5	11.1
75%	33.8	18.7
100%	38.8	22.2

Fig. 2 shows different investment scenarios for grids reinforcement in Great Britain, taking in consideration possible heat pumps and electric cars penetration levels, both considered great drivers for increased electricity consumption. It is possible to observe that as the penetration level raises, demand response's absolute contribution increases, but its relative contribution, taken as a proportion of avoided investments, falls.

The same reasoning can be used to explain the postponing over generation capacity investments permitted by a more stable demand, cutting off the necessity of operating with a large number of plants that remains most of the time on an idle stance, acting in emergency. In addition to that, a capacity market with DR participation, where DR can act as a "generating investment substitute", offering services that have the same effect on a demand-supply balance, makes even clearer this opportunity.

It is important to note that in order for achieving all demand response potential, securing all the opportunities, not only prices must update more rapidly, in order to incentivize demand response, but ancillary and capacity markets must also act together. There are technical and regulatory requirements that must be attended for the purpose of enjoying all DR benefits. The section bellow addresses these requirements and challenges.

3. CHALLENGES

3.1. Technological Challenges

It is impossible to achieve Demand Response without certain technological requirements. The most important of them is the smart meter. Smart meters allow more dynamical tariffs, and in some cases, real time tariffs, with hourly updates. Smart meters can be seen as Demand Response enablers (Cambridge Economic Policy Associates Ltd, Tpa Solutions & Imperial College London, 2014). They also grant fast response in electricity demand, allowing even automation of electrical demand reduction or curtailment, when certain conditions are met. These actions are even more efficient when smart meters are combined with smart electronics, like smart air conditioners or heaters that react to price signals, reducing demand intensity. Aside from smart meters, there is a need for other investments in equipment for data retention, communication in general, and reporting infrastructure to work in assistance with the meters which are indispensable (Hurley et al, 2013). Professionals must be hired in order to keep an informational structure, which also results in increased costs.

The main challenge is not the existence of the technology itself, but the costs of its implementation. Smart meters costs are very significant and can result in increased electricity tariffs, since the investment has to be amortized. Given this, a cost-benefit analysis has to be made, in order to decide if a smart meters rollout is an economical based decision and how much of the rollout must be executed (a partial rollout might be the best decision).

Fig. 3 shows the cost-benefit analysis for a large number of countries in European Union, in the case of a rollout reaching at least 80% of the homes in the country and most of the main big consumers:

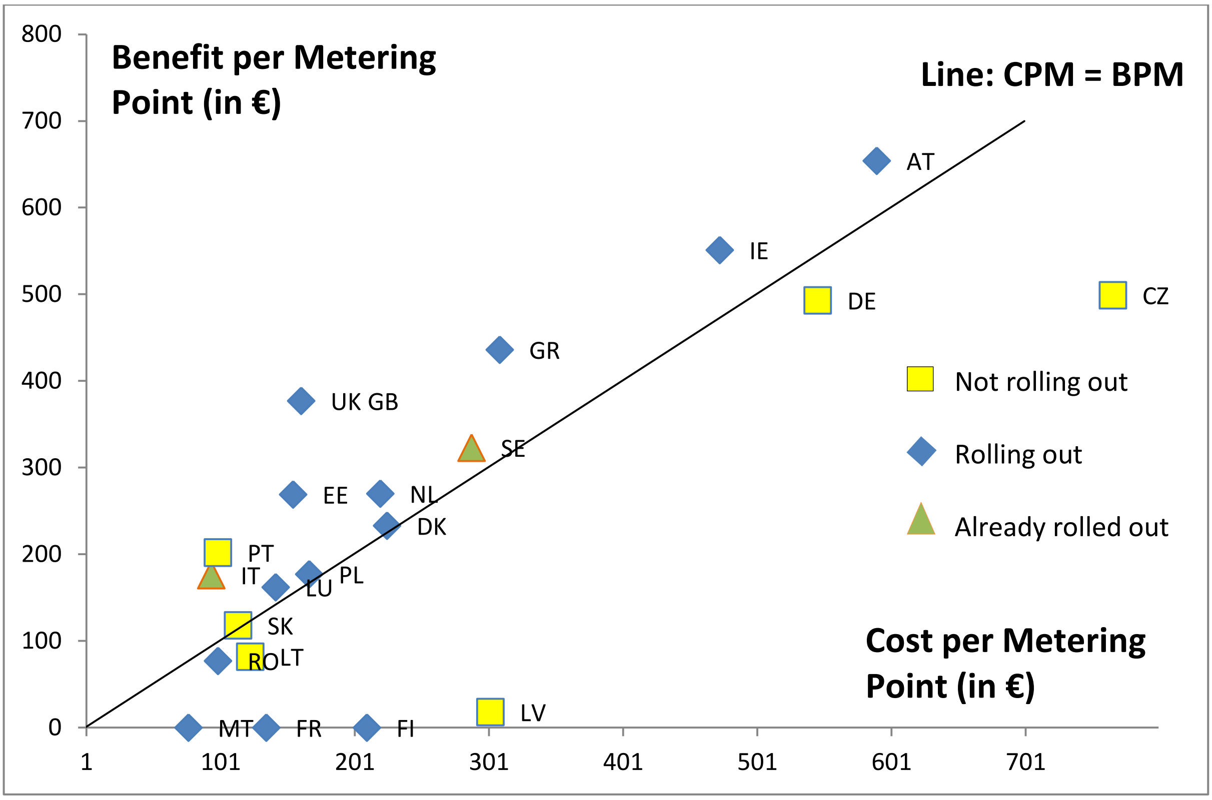

Figure 3: Summary of costs against benefits in countries in the European Union. *Source: EC SWD (2014) 189 Cost-benefit analyses & state of play of smart metering deployment in the EU-27*

There is no data for Malta, France and Finland benefits estimation, but their smart meters rollouts are in execution. The benefits include faster detection and restoration of service, contraction of energy loses and theft, DR gains, such as power saving and peak load shaving, considering also postponed investments in grid reinforcement. It is possible to observe that for most countries, the estimated benefits overcome the estimated costs. Considering that technologies costs tend to decrease over time and that the participation of renewable energy is growing in most European countries power mix, as a result of an effort of decarbonization lead by the *Renewables Directives*, we expect that future cost-benefit analysis will recommend smart meters rollouts, since the benefits will grow with a more intermittent electricity generating matrix. In Brazil, the same reasons apply, so it must follow a similar trend.

3.2. Regulatory Challenges

A large number of challenges from the regulation side can be pointed out. First of all, there are regulatory practices that may difficult the implementation of smart meters. It is possible that excessively high or unclear technical standards prevent smart meter rollouts. A good example of technical standards barriers is the Brazilian case, which will be analyzed subsequently. Even when it is legal, lack of incentives to its implementation can become a barrier if a cost-benefit analysis results in a small margin. Another difficulty can arise from a regulatory framework that does not provide clear incentives and/or a proper remuneration for the services provided by consumers engaged in DR programs. An even stronger regulatory barrier is the possible restriction on DR participation, by restricting aggregators, with a large number of small and technologically restricted consumers, from participate and engage, or by restricting types of services (Hurley et al, 2013).

As mentioned before, regulation is responsible for the allowance or not, of ancillary services and capacity markets that have DR as a tool, through adequate institutions and laws. So proper regulation, in order to permit DR from a variety of consumers in capacity markets and ancillary services is a must, in countries that expect to take serious advantages of Demand Response programs.

4. BRAZILIAN EXPERIENCE

Brazilian power sector consists of a hydrothermal system based on the intensive exploration of the hydro potential, complemented by thermal generation from different sources (Castro et al. 2010). Current installed capacity is predominantly compounded by hydro power plants, representing 67.7% of the total capacity, which corresponds to approximately 90 GW (BRASIL, 2015). An important characteristic of Brazilian power sector is the presence of huge water reservoirs, which have played the role of regularizing hydro based energy supply along the year, reducing the risk and uncertainty associated to affluences seasonality. These reservoirs have had, for a long time, a multi-annual profile. However, in the last few years this scenario has being changing. In face of a fast demand growth, associated to restrictions to the construction of new hydro plants with big water storage capacity (social and environmental restrictions associated to topographic features of remaining capacity), the reservoirs are losing their regularization capacity. The already contracted hydro capacity expansion until 2019 totalize almost 19 GW, from which 99% consists on water flow power plants and the remaining 1% is represented by a single plant with water reservoir, which has 135 MW of installed capacity (BRASIL, 2015).

Furthermore, a strong increase of renewable energy resources, like wind and solar, is projected to the next few years. Wind power capacity, for example, will reach 8,5 GW by the end of 2015 (BRASIL, 2015). Concomitantly, mini and microgeneration, mostly from photovoltaic panels, will become a very relevant source in the coming years.

As a consequence of this scenario of increasing participation of hydro power plants without reservoirs, as well as wind and photovoltaic plants, energy sources characterized by the stochastic and intermittent profile, Brazilian electric system faces higher risks, uncertainty, variability and unpredictability levels related to energy supply. These factors impose to the System Operator a challenge to ensure electricity supply reliability, real time equilibrium between supply and demand, and, even more, to ensure the supply of peak demand.

This scenario results in a higher demand for cost efficient flexibility sources, and, although Brazilian experience with demand response programs is still incipient, as will be shown below, demand response represents an alternative of system flexibility, which tends to come into light in a near future.

4.1. Hourly Fee

In 1988, Brazil initiated the application of demand reaction programs based on time of use tariffs (TOU), with the creation of time-of-day/seasonal (horoseasonal) tariffs. This tariff structure encompass the hourly signaling (peak time tariff and out of peak tariff) and the seasonal signaling (wet and dry periods), and it is applied to medium and high tensions consumers. The hourly fee consists on a binomial tariff, with a price component applicable to electricity consumption (KWh) and another one to power demand (KW). (ANEEL, 2010)

Even though the intermittency and stochastic factors were not the addressed problems in 1988, since they reflect a contemporary conjectural problem, the hourly fee represented a first step in the way of a more dynamic tariff, allowing reduction of time lags in cost transmission through tariffs.

In the tariff review cycle of 2011, however, it was extinguished the seasonal signal of the tariff structure, given that was outdated and couldn’t well reflect the costs and power sector conditions any more. At the same time, ANEEL creates a new tariff modality called White Tariff, applicable to low tension consumer and inspired on the Hourly Fee.

Studies prove the effective industrial consumer’s response to the tariffs with hourly signalizations, as can be seen in the Fig. 4:

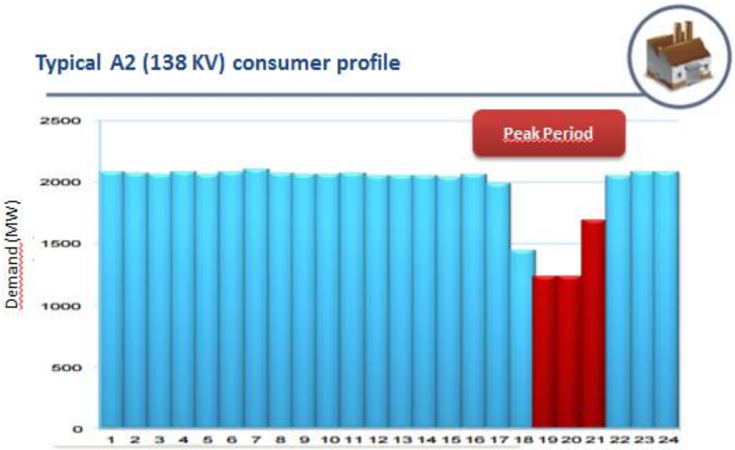

Figure 4: A typical A2 (138KV) consumer profile. Source: ANEEL

The graphic above represents the reduced consumption of a typical high tension consumer, during peak time. Since this is a typical consumer, a large number of high tension consumers behave this way, resulting in a load shifting movement, reducing overall generation costs and reducing operational risks during the peak period.

4.2. White Tariff

The White Tariff is a kind of Time of Use tariff, designed to be applied to the lower tension consumers, including residential, commercial and rural consumers, with voltage electricity supplying lower than 2.300 volts (Santos et al., 2014). The adherence is facultative, and it communicates consumers about the electric energy price according to the day and hour of consumption. The White Tariff is a monomial tariff (R$/MWh), as it is solely based on the amount of energy consumed. It is composed by three "tariff ranks": peak, which consists of three straight hours, usually between 18h and 21h; intermediate, which consists of the immediate previous hour and the subsequent hour of peak time; and out of peak, which consists of the remaining hours (ANEEL, 2015). According to the National Electric Power Agency (ANEEL), White Tariff was created with the main purpose of offering to lower tension consumers a higher variety of tariff modalities, in order to obtain, by their own choice, positive effects to the system through temporal load shifting. According to ANEEL (2010), hourly fees aim to reduce the gap between price and marginal cost of marginal consume meeting and, thus, induce demand shift from periods when the grid is crowded to others when the grid works with idle capacity. Meanwhile, an issue that comes into light is how much the residential demand will vary in response to electricity price variations, in other words, what is the price elasticity of residential demand. This parameter is crucial to the effectiveness of White Tariff.

The White Tariff can be seen as a first reaction to the forecasted and lately established new scenario, with loss of regulation capacity through reservoirs management and a more significant role of renewable, intermittent and stochastic, sources of electricity.

The Normative Resolution 502/2012 by ANEEL stablished 2014 March as the deadline for smart meters installation for those that adhered to the White Tariff, as distribution companies' responsibility. However, in 2014 February, ANEEL postponed the White Tariff execution date in face of the unavailability of smart meters certificated by INMETRO, according to the technical criteria defined by NR 502, on the market (Santos et al., 2014). As mentioned earlier in this article, one of the main barriers for white tariff (a more dynamic tariff) implementation is the need for smart meters installation. By now, the deadline to White tariff implementation is still opened. As observed in the "challenges" section, technical requirements can become a remarkable obstacle, which in the Brazilian case, until now, has acted as an impediment. As far as we know, no cost-benefit analysis of smart meters was carried in Brazil, but as facts have shown, it is to be expected that, if it was carried, a positive cost-benefit analysis would be an improbable scenario.

4.3. Tariff Flags System

The most recent Brazilian experience with demand response is the Tariff Flags System, and it was created in order to mitigate the risks associated do the hydro crisis Brazil is facing. It is also known that Brazilian power sector is strongly based on hydro power plants, and counts on a Centralized System Operator that determines the dispatch according to an optimization computer model called NEWAVE. One of the main outputs of this model is the CMO (Marginal Operation Cost), which basically represents the opportunity cost of water, in terms of other available sources. The CMO reflects, mainly, the current and forecasted hydrology conditions. So, in situations of unfavorable hydrology, the CMO reaches high levels. Based on the CMO the ONS (National System Operator) determines the dispatch of the system plants, according to the merit order. This marginal cost also has a great impact on the short term electricity market, through its influence on the PLD (Settlement Prices for the Differences), that is the short term price, and also reflects hydrology conditions, tending to be in the minimum when the system faces good hydrology and can reach the maximum in situations of unfavorable hydrology (Castro et al., 2014). Another important characteristic of Brazilian system is associated to the energy market, which is not a day ahead market, like in Europe, but a long term contracts market, in which consumers need to contract 100% of their demand. The dispatch, otherwise, has no relation with the energy contracted, what results in a high volume of differences to be liquidated by the PLD on a monthly basis (Castro e Brandão, 2015). This decoupling between contracts and dispatch represents a high financial risk to the agents, who are constantly exposed to an energy price with high volatility. It is also important to highlight that the costs incurred by distributors in energy purchasing are passed on to the consumer with a big delay, what lead the system to an even more difficult situation.

With Tariff Flags System there is a better cost signalization, giving the consumer the chance to adapt his demand, as well as inducing a demand reduction, reliving the system. The Tariff Flags aim to signalize consumers about the real power generation conditions, which is dependent on hydrological conditions and the need to dispatch thermal plants. Their purpose is to reduce the adjusting delay between electricity costs and the price charged from the consumers. Given this, it is expected that the consumers will respond to the supply costs variations. In other words, it acts as a DR program, in the definition sense, but its authenticity is questioned, since it is a compulsory system.

This system can be seen as a strong reaction to a very adverse conjectural problem, originated with a very unfavorable hydric condition, resulting in the intense use of thermal energy plants that were not designed to work for such a long period and had as a consequence a calamitous (and very exceptional) rise in electricity costs. Since hydric conditions can change, and these changes are difficult to forecast, keeping the tariffs elevated with the possibility of reduction after every month results in flexibility gain.

The Tariff Flags System is applied by all distribution companies connected to the National Integrated System – SIN, so it is compulsory to all captive final consumers. The green flag is turned on during the months in which the variable cost per unit (VCU) from the last dispatched power plant is below R$ 200/MWh. In this case, the default tariff is charged. The yellow flag, otherwise, is powered during the months when the VCU is equal or above R$ 200/MWh and below the maximum PLD (Differential Liquidity Price), currently at R$ 388,48/MWh. The default tariff raises R$ 0,025/kWh. Finally, the red flag is turned on during the months when the VCU is equal or above the maximum PLD. The default tariff raises R$ 0,045/kWh. It is by all means a compulsory method, applied to all captive consumers. It is important to highlight that, since the implementation of this system, red flag is triggered (ANEEL, 2015).

5. CONCLUSIONS

Demand response programs can be considered as new and recent alternatives, allowed by technological advances, to deal with a more complex, diversified and intermittent electricity generation matrix, which are becoming a trend worldwide, due to a decarbonization effort, aiming to reduce the global warming progress. The opportunities and motivations that propel research, pilot programs and innovative regulation are: the overall cost reduction, achievable through peak shaving, either by load shed or load shifting and also deferment of grid and generation investments. Gains in reliability, with the participation of DR in ancillary services and capacity markets can be added to these. However, there are challenges to be faced, such as regulation and technical requirements currently acting as barriers to DR implementation. Technical requirements can be achieved if cost-benefits analysis shows good results, as it has already shown in a large number of European countries. Innovations on the regulatory side are mandatory in order to achieve full DR programs advantages.

The short analysis of the Brazilian experience on demand side flexibility programs lead us to conclude that the evolution of the electricity generating park in Brazil will require greater flexibility of the system, and demand side policy must be considered as an important alternative. However, the Brazilian Demand Response experiences are still incipient. The Tariff Flags system, for example, is not a genuine demand response program. Demand response in Brazil has been focused on great consumers. The White Tariff is unable to be implemented due to an inexistent smart meter rollout, reflecting the strength of such obstacle in the way of demand response enabling. Finally, there are uncertainties about the price-elasticity of the demand from residential consumers of electricity, which proposes another challenge to a full smart meter rollout.

REFERENCES

Agência Nacional De Energia Elétrica – ANEEL "*Resolução Normativa nº 502/2012*" Disponível em: < http://www.aneel.gov.br/cedoc/ren2012502.pdf> Acesso em: 27/12/2015

Agência Nacional De Energia Elétrica - ANEEL. Procedimentos de Regulação Tarifária, submódulo 7.1: Procedimentos Gerais, de 15 de novembro de 2015.

Ambec & Crampes. (2015) Decarbonizing electricity generation with intermittent sources of energy. Toulouse School of Economics Working Paper nº 603.

ANEEL. (2010). Nota Técnica nº 362/2010-SRE-SRD/ANEEL, de 06 de dezembro de 2010.

ANEEL. (2014). Resolução Normativa Nº 502/2014. Regulamenta sistemas de medição de energia elétrica de unidades consumidoras do Grupo B.

ANEEL. (2015). Nota Técnica nº 355/2015-SGT/ANEEL, de 23 de dezembro de 2015.

BRASIL. (2015). Ministério de Minas e Energia. Empresa de Pesquisa Energética. *Plano Decenal de Expansão de Energia 2024.* Brasília: MME/EPE.

Cambridge Economic Policy Associates Ltd, Tpa Solutions & Imperial College London. (2014). *Demand Side Flexibility*: *The Potential Benefits and State Of Play in the European Union.* Final Report for ACER, Final Version.

Castro, N. J. d. et al. (2010). Considerações sobre a Ampliação da Geração Complementar ao Parque Hídrico Brasileiro. Rio de Janeiro: UFRJ/IE/GESEL, Textos de Discussão do Setor Elétrico n 15.

Castro, N. J. d. et al. (2014). A Formação do preço da energia Elétrica: Experiências internacionais e o modelo brasileiro. Rio de Janeiro: UFRJ/IE/GESEL, Textos de Discussão do Setor Elétrico n 62.

Castro, N; Brandão, R. (2015). Modelo de Comercialização de Energia: Reflexões para Aperfeiçoamentos. Rio de Janeiro: UFRJ/IE/GESEL, Relatório Técnico.

EC SWD. (2014). 189 Cost-benefit analyses & state of play of smart metering deployment in the EU-27. Retrieved from: http://eurlex.europa.eu/legalcontent/EN/TXT/?qid=1403084595595&uri=SWD:2014:189:FIN

G Strbac et al. (2010). Benefits of Advanced Smart Metering for Demand Response based Control of Distribution Networks. Summary Report 2.0. Imperial College London. (pp. 37)

Hurley, Doug; Peterson, Paul; Whited, Melissa. (2013). Demand Response as a Power System Resource: Program Designs, Performance and Lessons Learned in the United States. Brussels: Rap Publications.

MIT (Massachusetts Institute of Technology) (2011), "The Future of the Electric Grid". Retrieved from: http://mitei.mit.edu/system/files/Electric_Grid_Full_Report.pdf.

ONS – Operadora Nacional do Sistema. (2015). Francisco José Arteiro de Oliveira's Power Point Presentation. Francisco José Arteiro de Oliveira is Planning and Operation Scheduling Director in ONS .

Poudineh & Jamasb. (2013) Distributed Generation, Storage, Demand Response, and Energy Efficiency as Alternatives to Grid Capacity Enhancement. Cambridge Working Paper in Economics nº 1356.

Sheikhi Fini, A., Parsa Moghaddam, M., And Sheikh-El-Eslami, M.K. (2013). An investigation on the impacts of regulatory support schemes on distributed energy resource expansion planning. Renewable Energy. nº 53

Varian, Hal R. (1996). *Microeconomia: princípios básicos.* (5ªed.). Rio de Janeiro: Campus