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doi:10.15199/48.2015.03.33

A New Proposal for Demand Response Program and Its Impacts on the Spot Price in the Brazilian Electricity Market

***Abstract**. The growth of electricity demand in the Brazilian system is high. This is due to the growing economy featuring most of the developing countries. However, its installed capacity cannot keep the pace of such a demand growth. This has led to some problems like the saturation of the system transmission and generation components during peak periods, as well as problems such as reduced system security and the inability to maintain low energy prices during peak periods. This paper presents a new proposal for the demand response program and an analysis of how are its impacts on the spot price within the electricity market.*

Streszczenie.** W artykule przedstawiono program umożliwiający analizę odpowiedzi systemu energetycznego na przykładzie sieci w Brazylii. Program umożliwia wykrywanie nasycenia systemu jak również zagrożenia bezpieczeństwa. **Program do analizy odpowiedzi systemu energetycznego na przykładzie sieci energetycznej w Brazylii.

Keywords: demand response, energy market, spot price, volatility.
Słowa kluczowe: system energetyczny, sieci przesyłowe, analiza systemu.

Introduction

The Brazilian energy mix is somewhat peculiar as the country is one of the biggest producers of hydroelectric power in the world. As a result, it has been possible to develop an interconnected system capable of exploiting advantageously the different hydrological conditions found throughout the country, thereby enabling energy exchange among the various regions of the system. The Brazilian interconnected system is made up of four distinct subsystems, as shown in Figure 1 [1].

Fig.1. Electrical subsystems in the interconnected Brazilian system

The operating costs of the hydroelectric plants are low as they mainly incur in maintenance costs. Fuel does not need to be purchased to dispatch the generated energy. The operating costs of thermoelectric plants are, however, intimately linked to the power generated and the type of fuel employed. As such, the hydroelectric generation remains currently as the most competitive dispatch source. Nevertheless, the future risk of low water levels in reservoirs has to be accounted into the operating program and, with that in mind, part of the thermoelectric park will be dispatched on the basis of the perceived necessity. By doing so, the risk of future shortfalls in hydroelectric supply, can be minimized [2].

The Brazilian spot price (PLD) is calculated from the power stations dispatch programs, and corresponds to the system's marginal operating cost. This price marks out the differences between generation (or consumption) and contracts in the spot market. Therefore, the spot price is calculated by assessing the current and future levels of water stored in the reservoirs, fuel costs of thermoelectric plants, the optimum proportion of hydraulic and thermic generation, as well as the interchange among the subsystems, always taking into account what can be considered as acceptable risk to the system [3].

The search for better safety margins of electrical supply has led to demand response programs to become increasingly attractive, as these programs can increase the system capacity by indirectly promoting an increase of resource to the system.

Demand Response

Demand response is when a consumer makes an adjustment in their consumption profile in response to some stimulus. So, demand response can be defined as some form of payment incentive to induce the consumer to reduce the consumption during periods in which prices are high, or when the reliability of the system is at risk. A demand response policy may result in three types of end-user responses.

The first one, known as load shedding, is simply when reduced consumption occurs during the system's peak times, when prices are at their highest, without imposing changes in the use pattern of other periods. This measure will cause a momentary loss of comfort to the end-user. An example of this type of response would be temporary alterations in thermostat, heater or air-conditioning settings [4].

A second type of response, called load shifting, occurs when consumers respond to high prices by moving their consumption from peak to off-peak periods. An example would be the off-peak use of washing machines, tumble driers or pool pumps [4].

The third form of response is when the consumer generates his/her own electricity. This requires the use of distributed generation. Consumers derive little or no change in the pattern of their energy consumption from local generation. However, this generation will supply more capacity to the system, as the system sees the consumer as having reduced their consumption [4].

Demand Response Impacts on Electrical Energy Markets

The demand curve of those consumers who do not feel short-term price swings is a vertical line, that is to say, demand is inelastic. When consumers experience short-term price swings the demand curve becomes sloped and the demand becomes elastic. The different demand curves can be seen in Figure 2.

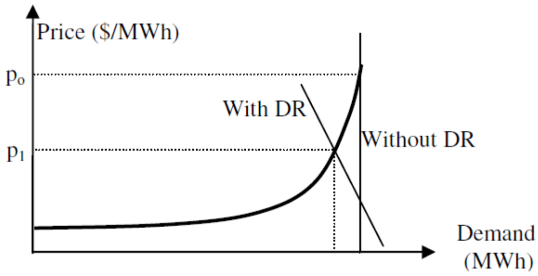

Fig.2. Simplified Effect of DR on short-term electricity prices [5].

The main benefits are the reduction in short-term price and the avoided generation cost, both of which can be seen in Figure 3. The configuration of optimum dispatch is done in such a way that the generating units with lowest generation prices ($/MWh) generate on the basis of economic merit. Short-term price is defined based on the demand curve. Should the market not possess a demand response policy, the short-term price will be the intersection between the generation curve and the demand curve D. Whenever the demand response is present, the short-term market price will be the value obtained from the generation curve and the demand curve D_{DR}. Reduced demand results in the demand curve shifting to the left causing a fall in the spot price. Moreover, the generation cost, represented by the area above the generation curve between lines D_{DR} and D, was avoided. The fact that more expensive thermal plants were not dispatched represents a system saving that is passed on to all agents.

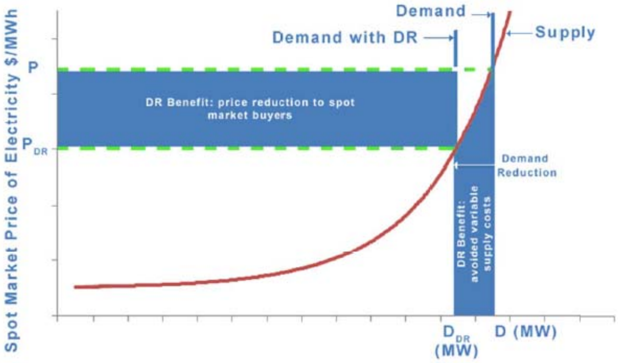

Fig.3. Impact of DR on short-term price [4].

Short-term price is usually less volatile when demand response programs are present. This is largely affected by the greater load curve planned followed by an increase in the system's available capacity [6].

Demand response also leads to a delay in the investment of new transmission lines and generation units. When demand response programs are in place, transmission lines do not get overloaded. In other words, the program supplies more capacity to the system. Constraints on the system mean that short-term price goes up. If demand response reduces electrical constraints on the transmission lines, there is a downward impact on short-term prices [4].

Price Formation Models Used in Brazil

Because Brazil has a predominantly hydroelectric system, the complexity of price formation and operation models is greater than that of other systems. In thermoelectric systems, price formation is generally performed on a daily basis, without considering past operating results and without worrying about future supply risks.

The operation of hydroelectric systems and, consequently, the formation of spot price are time-linked, as the model has to consider current operational impacts on future scenarios. Furthermore, the results of past operations impact directly on present results.

The main characteristics of the operation of a hydrothermal system are: (i) relationship between present decision and future consequences (Figure 5); (ii) interdependence of hydroelectric plant reservoirs: (iii) impossibility of perfectly predicting future inflows, making it an essentially stochastic problem; (iv) the large number of reservoirs in existence and the need for multiperiod optimization; (v) implicit non-linearities due to the role of future thermoelectric operating costs and the energy production role of the hydroelectric plants; (vi) water stored in the reservoirs of hydroelectric plants has an indirect value associated with the thermoelectric fuel saving opportunity that it offers; (vii) the water in these reservoirs offer multiple possibilities of use (sailing, flood control, irrigation, water supply and sanitation), along with the generative dispatch of multiperiod optimization of reservoirs [7].

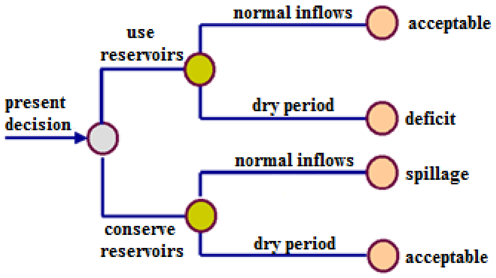

Fig.4. Decision making process for hydrothermic systems [7].

Medium-term operational planning is defined for a five year planning horizon, on a monthly basis. This problem resolution at this stage determines the total thermal and hydraulic generation and the expected marginal operating cost values, for any period within this time frame.

The five year time frame was chosen on the basis of the longest ever dry spell, which occurred in the south west in the first half of the 1950s [7,8].

In the short-term the planning horizon considered is from 2 to 6 months, on a weekly basis. In this stage, both the plants and main transmission lines are viewed in greater detail [8].

Where daily planning is concerned, the system is inspected at intervals of half an hour, with a time frame of a week. The system is comprehensively inspected, taking into account all electrical bus bars of interest and the hydraulic restrictions, as well as making detailed representations of the generating units [8].

The NEWAVE model is used for medium-term purposes, while the DECOMP model is used for short-term periods. The daily programming model is called DESSEM and is currently undergoing a process of validation. These models have been developed by the Centre for Electrical Energy Research (CEPEL). CEPEL works for the Electrical Systems National Operator (ONS) for operational programming, and also by the Electrical Energy Commercialization Chamber (CCEE) for spot price formation.

The shorter the temporal discretization of the model, the greater the level of modelling thoroughness of the system components. The models evincing higher levels of temporal discretization feed those with lower levels with their data output. That is to say, NEWAVE data output serves to feed part of the DECOMP input data: the same relation holds between DECOMP and DESSEM.

Proposed Demand Response Program

Analyses of the literature and current regulations of various markets suggest that demand response programs based on reduced load supply show great promise. However, there is currently no such demand response program of this type in the Brazilian electrical market.

In the Brazilian case, a good way of applying a demand response program, based on supply reduction, would be by means of a short-term mechanism in which some consumers inform the ONS beforehand as to their load reduction availability for certain months. Also, the financial value associated with that reduction is informed. A flowchart showing this mechanism is presented in Figure 5.

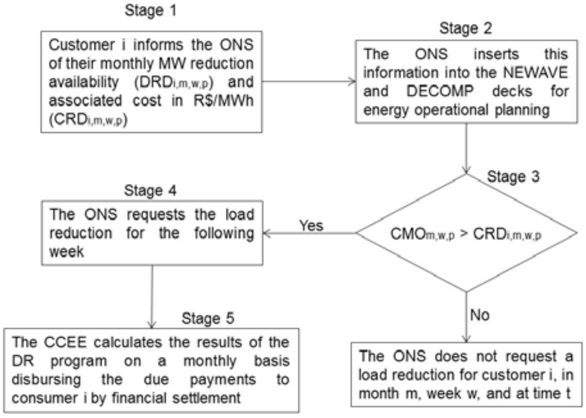

Fig.5. Rules of the proposed demand response program.

Stage 1: ONS proposes a timetable where consumer i, participant in the DR program, states, at year Y, its monthly demand response availability by time period, ($DRD_{i,m,w,p}$), in MW. This is done for a period of five years (from Y+1 to Y+6, with their respective associated costs ($CRD_{i,m,w,p}$), in R$/MWh). The values of $DRD_{i,m,w,p}$ and $CRD_{i,m,w,p}$ for the first year (Y+1) will be assumed to be obligations of the participant, whilst for the last four years (from Y+2 to Y+6) they will be considered for the purposes of future price projection. Before starting the second year of operation (Y+2), consumer i will be able to review the values that had been presented for the period from Y+2 to Y+6 and must also make known their $DRD_{i,m,w,p}$ and $CRD_{i,m,w,p}$ for year Y+7.

Stage 2: The $DRD_{i,m,w,p}$ and $CRD_{i,m,w,p}$ values must be entered into the NEWAVE and DECOMP decks so that the DR program is available as a system resource for operational planning purposes. The methodology proposed by [9] will be used to operationalize this stage. So, the $DRD_{i,m,w,p}$ and $CRD_{i,m,w,p}$ values of each i consumer are added to the models by inserting virtual thermic plants into the input data. The $DRD_{i,m,w,p}$ value will correspond to the value of the thermal plant's physical guarantee whilst the value of $CRD_{i,m,w,p}$ will correspond to the value of the plant's generative value in R$/MWh (CVU) [9].

Stage 3: When the marginal cost of operation calculated by the NEWAVE and DECOMP models is higher than that of the $CRD_{i,m,w,p}$ of an i participating consumer, the model will inform to the system about the necessity of participation by this consumer by means of its load reduction. As such, the virtual thermic dispatch that represents the reduced i load will take place (and physically, the i consumer will have its load reduced) [9].

Stage 4: The models are run before the start of the operative week and the results made available on Friday as the operative week starts on a Saturday. Should the models indicate the participation need of the i consumer in the operation of the system, the operator (ONS) will inform the consumer about the load reduction obligation.

Stage 5: In the event that consumer i is told to reduce its load, and this load reduction obligation is met, they will be remunerated. However, should they fail to meet the target it will be penalized.

The value to be received for the fulfillment of such DR consumer obligations, known as participating consumer demand response remuneration payment for the m month (PRC_DR_m) shall be calculated according to (1):

$$(1)\quad PRC\_DR_m = \sum_{w}^{n}\sum_{p}^{3} DRDE_{i,m,w,p}.CRD_{i,m,w,p}$$

for the condition:

$$(2)\quad 0 \le DRDE_{i,m,w,p} \le DRDS_{i,m,w,p}$$

where: w – operative week, m – month, p – period of load, n – number of operative weeks in the m month, PRC_DR_m – value to receive from the i consumer for participating in the DR program (R$), $DRDE_{i,m,w,p}$ – reduced value effected by the i consumer, $DRDS_{i,m,w,p}$ – value of the reduction requested by consumer i.

In the event of non-compliance with the consumer's DR program obligations (dubbed participation penalty for the m month, PEN_DR_m), the value to be paid must be calculated according to Equation (3):

$$(3)\quad PEN\_DR_m = \sum_{w}^{n}\sum_{p}^{3}\left(DRDS_{i,m,w,p} - DRDE_{i,m,w,p}\right).PLD_{m,w,p}$$

where: PEN_DR_m – amount to be paid by the i consumer for non-compliance with the DR program (R$), $PLD_{m,w,p}$ – PLD of the p period at w week of the mwmonth.

The amount to be disbursed to the DR program for the i consumer ($LIQ\_DR_{i,m}$) is given by Equation (4):

$$(4)\quad LIQ\_DR_{i,m} = PRC\_DR_m - PEN\_DR_m$$

Impacts of Proposed DR Program on Spot Price and the Electrical Energy System

By using the operating data supplied by ONS for December 2013 as a base the demand participation for the DR program was defined (by submarket), as shown in Table 1. No DR program participating load was defined for the N subsystem, as this subsystem is usually an energy exporter due to its generating power potential well in excess of the electrical energy load.

Table 1. Definition of DR Program Participation Load

Submarket	Load Dec 13 (MWavg)	Industrial Load (MWavg)	Industrial Load with Manageable Demand (MWavg)	Participant Load in the DR Program (MWavg)
SE/CO	38,499	15,785	5,682	900
S	10,999	4,510	1,623	300
NE	9,956	4,082	1,470	270

For the purposes of analyzing the impacts of a demand response program on the Brazilian short-term market two scenarios were defined in paper [9]. The load reduction availability prices in these scenarios were maintained in this work, with the DR program amounts being adapted accordingly. The DR program proposed by [9] merely anticipated reduction in the SE/CO submarket whilst this paper envisages reductions in the SE/CO, S and NE submarkets, as illustrated in Table 2.

Table 2. Scenario and Virtual Thermoelectrical Plant Definitions for DR Program Simulation

Scenario	Virtual Thermoelectrical Plant	Availability (MW)	Associated Cost for Load Reduction (R$/MWh)
Scenario 1	UTV1-SE	900	R$ 100.00
	UTV1-S	300	R$ 100.00
	UTV1-NE	270	R$ 100.00
Scenario 2	UTV1-SE	300	R$ 130.00
	UTV2-SE	300	R$ 150.00
	UTV3-SE	300	R$ 200.00
	UTV1-S	100	R$ 130.00
	UTV2-S	100	R$ 150.00
	UTV3-S	100	R$ 200.00
	UTV1-NE	90	R$ 130.00
	UTV2-NE	90	R$ 150.00
	UTV3-NE	90	R$ 200.00

The impacts of the demand response program, by time period and scenario during the NEWAVE study time frame, on the average annual PLDs (spot prices), for the SE/CO submarket are presented in Table 3. The base case scenario is that in which the DR program is not applied. Similar results were calculated for the S, NE and N subsystems.

Table 3. DR Impact on Spot Price as Calculated by NEWAVE for the SE/CO submarket (values in R$/MWh)

Case (SE/CO)	Period	2014	2015	2016
Base	Peak	273.80	193.72	147.17
	Inter	273.73	193.55	147.04
	Off-peak	273.33	192.17	146.50
Scenario 1	Peak	200.77	141.67	109.63
	Inter	200.64	141.52	109.52
	Off-peak	200.06	140.78	108.76
Scenario 2	Peak	209.79	145.14	114.64
	Inter	209.66	144.96	114.54
	Off-peak	208.52	143.70	113.66

The spot price reduction was significant across all time periods and submarkets throughout the study. With the implementation of the demand response program, NEWAVE looks to future months and identifies possible load reductions as an increase in system capacity. The expanded capacity identified by the model causes the water opportunity cost to fall, as well as reduces the necessary dispatch due to the load reduction which results in lower prices.

The evolution of average monthly spot prices under base case and the proposed scenarios are compared in Figure 6. The spot prices in scenarios 1 and 2 became lower than the base case for all months.

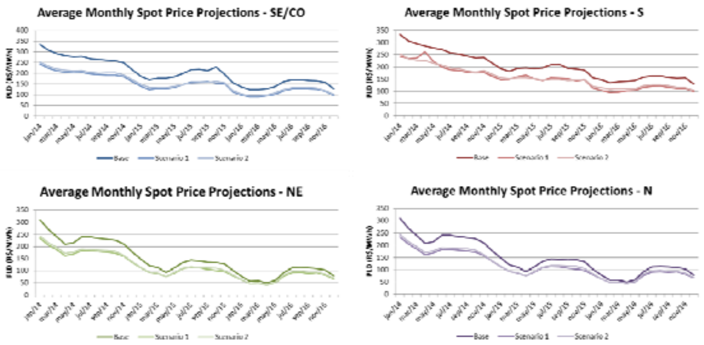

Fig.6. Comparison of monthly spot price evolution within the different study scenarios.

Table 4 shows price projection standard deviation, by scenario and subsystem, during the NEWAVE study time frame.

Table 4. Price Projection Standard Deviation by Scenario and Subsystem Within the NEWAVE Study Time Frame (values in R$/MWh)

Subsystem	Base	Scenario 1	Scenario 2
SE/CO	R$ 62.66	R$ 45.02	R$ 46.59
S	R$ 58.26	R$ 47.16	R$ 43.74
NE	R$ 72.66	R$ 52.92	R$ 55.18
N	R$ 74.15	R$ 53.81	R$ 56.55

The reduction in the spot price standard deviation across all submarkets in scenarios 1 and 2 points to a reduction in price volatility. The standard deviation variations when comparing the base case to scenarios 1 and 2 were -25.5% and -24.5%, respectively. These results were expected as the increased system capacity via demand response brings greater stability to the system operation. Furthermore, a reduced price range was observed in scenario 1 as the load reduction prices in this scenario were lower than those of scenario 2.

The graphs in Figure 7 present the percentage variations in prices in consecutive months (P_m/P_{m-1}). In the demand response scenario only subsystem S presented a greater range of variation.

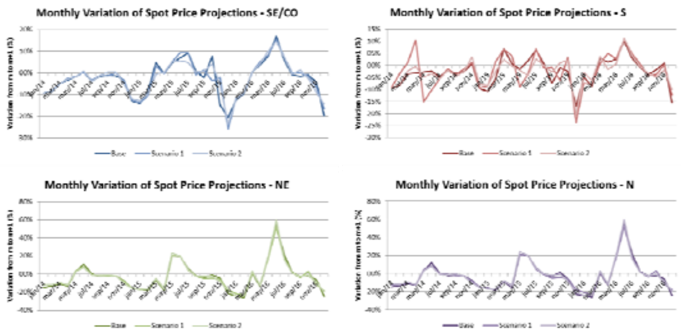

Fig.7. Percentage variation in spot price in consecutive months..

Table 5 shows the absolute average values for percentage variations in two consecutive months. For subsystems SE/CO, NE and N, the DR program resulted in reduced percentage volatility from month m-1 to month m. It can be noticed that although the DR program increased the spot price volatility from the standpoint of S percentage spot price variability, the introduction of reduced load supply reduced the breadth of price variation in this same subsystem, as presented in Table 4. This is translated into a lower risk for all the market participants.

Table 5. Spot Price Volatility for the Simulated Series With and Without the DR Program

Subsystem	Base	Scenario 1	Scenario 2
SE/CO	6.4%	6.0%	5.8%
S	4.8%	5.8%	4.3%
NE	11.8%	11.2%	11.5%
N	12.0%	11.3%	11.6%

Conclusion

This article presented a demand response program for the Brazilian electrical energy market. The program impacts were analyzed by comparing a base case, where no DR program was applied, to two scenarios in which the DR program was present and looking at the load shedding of part of the SE/CO, S and NE subsystems.

In the two scenarios where the DR program was implemented, a significant spot price reduction was apparent for the entire time frame of the study, as the program provided the system with greater capacity of supply.

It can be concluded that the demand response program reduced the spot price range across all submarkets.

Finally, the proposed DR program resulted in a reduction in spot price and an increase in the security of the system. Moreover, the suggested proposal showed a particular advantage for the Brazilian case, given that there is currently no reduced load-supply mechanism in its market.

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