PROVISION OF GENERATION RESERVES AS AN ANCILLARY SERVICE IN THE BRAZILIAN SYSTEM

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Abstract - This paper deals with the possibility of the supply of generation reserve be considered an ancillary service in the Brazilian system. The hydroelectric nature of the generating units, the energy market design and the Independent System Operator (ISO) rules for reserves are taken into account. Important aspects such as reserve types, reserve requirements, reserve allocation are addressed in order to form the basis for establishing the future market. The proposed method for reserve procurement and reserve selling is based on the Rational Buyer's method and includes several important features. The computational algorithm used to find the solution is fast enough to be adequate for a system with two hundred generators bidding for the one-hour ahead market.

Keywords: generation reserves, ancillary services, reserve types, reserve requirements, reserve allocation, procurement methods.

1 INTRODUCTION

A common aspect shared by the various designs of restructured electricity markets around the world is the designation of an independent system operator that is responsible for the secure operation of the electric power system. Ancillary services (AS) are additional services required to produce stable and reliable electricity supply to meet the need of the real-time electricity market. Ancillary service procurement is a major operational function in the de-regulated electricity market. A survey on 12 U.S. electric utilities showed that the cost of ancillary services ranges from 5 to 25% of generation and transmission costs, with an average of 10% [1]. The service of providing generation reserve is one of the most important ancillary services. It is responsible for 44% of the total AS costs while losses account for 30% [1].

2 TYPES OF GENERATION RESERVES

The types of reserves and their precise definition can vary from system to system. In California, four types of ancillary services have been defined as follows:

1. Regulation: Service provided by generating units that can respond to the ISO's Automatic Generation Control (AGC) in either an upward or a downward direction to match the real-time demands and resources. Since the procurement of downward regulation is separated from other upward ancillary services at ISO, the term regulation is referred as to upward regulation only.

2. Spinning Reserve: Reserve capability available within 10 minutes from on-line generating capacity and/or imports.

3. Non-Spinning Reserve: Reserve capability available within 10 minutes from off-line generation capacity, interruptible load, and/or imports.

4. Replacement Reserve: Reserve capability available within 60 minutes from on-line or off-line generating capacity, interruptible load, and/or imports.

The Brazilian ISO defined that the operational generation reserve is composed of four parts according to their objective [2]:

R1 - Primary Reserve: Reserve to be used for primary frequency control by the action of the speed governor of several generating units. The ISO established no criteria for the reserve utilisation as the primary frequency control is automated. However, it establishes that all generating units are to operate with unblocked speed governors and with its speed droop adjusted to 5%.

R2 - Secondary Reserve: Reserve to be used for secondary frequency and tie line power flow control. It is necessary to allow the secondary control to bring frequency and interface flows to, respectively, the nominal and the programmed values after instantaneous and short term load variations. It is a spinning reserve allocated in generating units under Automatic Generation Control inside the Control Area.

R3 - Tertiary Reserve: Reserve to be used to cover generating unit outages and other unforeseen limitations caused by equipment failures including the generator's transformer.

The value of R3 is based on the calculation of the necessary probabilistic reserve for the entire interconnected system. It considers the utilisation diversity of reserves R1 and R2 in the event of forced outage of any generating unit and the accepted risk level established in the operation planning stage.

Reserve R3 is a spinning reserve allocated in generating units under AGC inside the Control Area. It may be allocated in other generating units in case of operational constraints.

R4 - Quaternary Reserve: Reserve to be used to recompose reserves R3 in case of a long lasting generator outage.

It is a characteristic of each Control Area since it is composed with the available resources, such as interruptible loads, pumping loads, maintenance rescheduling of generating units, expensive thermal generation.

3 RESERVE REQUIREMENTS

The ISOs typically use different procedures to calculate their requirements for the four services purchased in the AS markets, i.e., regulation, spinning and non-spinning reserves and replacement reserves. Fundamentally, the demand for AS is primarily a function of the total system load. There is no established ex-ante formula for the regulation service. Except the size of the load, the rate of load change during morning and evening ramp influences the demand for regulation. Under some conditions, such as schedules that may not be operationally feasible given their unit commitment constraints, the demand for regulation increases since units rely on the real time market to make up the difference. Typically, the demand for regulation averages between 2 to 3% for most hours but it may increase to between 7 to 8% during morning or evening hours when the load rapidly increases or decreases [3].

The ISO's requirement for operating reserves (spinning and non-spinning) is the greatest of i) the largest generating unit outage, or ii) 5% of the load served by hydroelectric resources plus 7% of the load served by other resources within the Control Area. Loads served by firm imports do not contribute to the operating reserve demand whereas interruptible imports and on-call exports must be supported by 100% operating reserves. Even though in most cases the operating reserve demand can be met by 50-50% split between spinning and non-spinning reserves, under some conditions the ISO may opt to increase to spin portion to more than 50% [3].

The demand for replacement reserves is determined based on the need to restore the dispatched operating reserves within sixty minutes to its scheduled set point. Other factors influencing the demand of replacement reserves are the anticipated shortfall between scheduled demand and the ISO's load forecast and patterns of generation and transmission outages. In this sense, replacement reserves can be considered a short-term generation adequacy product instead of an insurance policy that is used only in contingencies.

An important characteristic of reserves, as distinct from financial options, is that they are procured not based on any dynamic hedging strategy but based on pre-set reliability standards defined by NERC and WSCC that relate the reserve requirement to overall generation [3].

The Brazilian ISO defines that the value of R1 is 1% of the Control Area generation (RPG). It is to be allocated inside the Control Area k. If possible, each Control Area should distribute the value of R1 among all units with unblocked speed governors. Therefore, the Primary Reserve is given by:

$$R1_k = 0.01 \ RPG_k$$

where RPG_k is also the Control Area load + exports - imports.

The Brazilian ISO defines that the value of R2 is 2,5% of the Control Area generation (RPG) plus 1,5% of its own load (CP) allocated inside the Area k, i.e.:

$$R2_k = 0.025 \ RPG_k + 0.015 \ CP_k$$

The Brazilian ISO defines that the value of $R3_S$ is equal to the difference between the probabilistic reserve recommended to the entire system (RTP_S) minus (R1 + R2). The RTPs calculation may be found in [4].

The reserve $R3_S$ is to be prorated among the Control Areas according to their RPG and to their largest generating unit. The reserve R3 for each Control Area k is given by:

$$R3_k = \frac{MM_k \cdot RPG_k}{\sum_{i=1}^{n} (MM_i \cdot RPG_i)} \cdot R3_S$$

where:

$R3_k$: R3 to be provided by Control Area k

$R3_i$: R3 to be provided by Control Area i

$R3_S$: R3 necessary for the interconnected system

MM_k: Largest generating unit of Control Area k

MM_i: Largest generating unit of Control Area i

4 RESERVE ALLOCATION

Control Area is an electric system bounded by measurements in its interconnections. It controls its own generation to keep interchange schedule with other control areas and to help frequency regulation – as defined by NERC (1995) [5]. Control Area is a part of the system where its Control Centre is responsible for controlling frequency and power interchange through the AGC - as defined by the Brazilian ISO [2]. Control Area is a part of the system where its generating units are able to cope with its load variation [6].

According to the above definitions for Control Area, all types of reserves are to be allocated inside the Control Area. This is easy to be done provided there are enough resources available. However, there is a certain peculiarity for reserve R1. Suppose, for instance, a small load increase within Control Area k. Frequency would come down and the automatic primary frequency control of the entire system would act through the unblocked speed governor of several generating units. In other words, part of the reserve R1 of generating units belonging to other Control Areas different from Control Area k where the load increase took place would be used. Primary frequency control would alter interconnection power flows and increase the flows to the Control Area k.

Secondary frequency and tie line control would come into action (time constant larger than the primary control one). Reserves of type R2 are used. In order to restore tie-line flows to the original values it is necessary to increase generation inside Control Area k. Therefore, reserve R2 must be allocated inside Control Area k. Otherwise, it would not be able to cope with load variations inside itself. And this goes against the Control Area definition.

The reserve allocation among generator agents inside a Control Area would be responsibility of the Area Control Centre. Although 90% plus of the Brazilian generation is hydroelectric, power dispatch is done based on the generation cost for each generating unit. Therefore, reserve distribution inside a Control Area is to be done after the power generation dispatch. Reserves would be allocated in generating units partially dispatched and /or on units not dispatched.

If units with no generation were called to supply reserve they would have to generate the minimum amount of power say, to avoid physical damage such as cavitation in hydraulic turbines. Owing to the fact that energy is paid according to the Market Clearing Price, i.e. the price of the most expensive unit, the price of energy would go up. As some generators would have to lower their output, thus loosing the opportunity to sell energy, the corresponding reserve would be paid by the opportunity cost which would be equal to the energy cost. Thus, the price of reserves would also go up.

Transmission constraints may also have the same effect on the energy and reserve prices.

Another important factor concerning reserve allocation is the ramping constraint of each generating unit. It has to be taking into account the capacity of changing the unit output in MW per minute.

5 SETTING THE BRAZILIAN MARKET

It is necessary to establish a reserve market. The market agent should procure reserves from the generator agents according to the necessity established by the ISO. The acquired reserves should be sold to distribution agents and to industrial consumers (with and without own generation).

Generator agents should declare on an hourly basis its reserve capacity. The price of each MW for each kind of reserve could be established freely by the generator agents or by the market agent based on the declared costs by the generator agents.

The market agent should have the obligation of buying the reserve amounts defined by the ISO at minimum price. The agent should sell the reserves at the same price.

Based on the definition and the amount required for each reserve established by the Brazilian ISO, the following points could be inferred.

1. The total reserves R1 and R2 may be defined as percentages of the system load. Using the amounts defined by the ISO, the value of system reserves R1 + R2 is 5% of the system load. In this sense, the values of reserves should follow the load values in each hour level. Therefore, the reserve service should be procured on an hourly basis or on the time of each load level, if different from the hour.

2. Reserves R1 and R2 should be procured together, although in different quantities (and prices). That is because there is no way to use one or another independently. This leads to the conclusion the users of R1 are necessarily the users of R2 and vice-versa.

3. The same reasoning applies to reserves R3 and R4, taking into account that R4 may be considered the reserve of R3. Therefore, the users of R3 are also users of R4 and vice-versa.

4. Reserve R3 does not need to be spinning reserve entirely. Quick-start units may be used for the purpose of this kind of reserve. The ISO should define the maximum time that could elapse between the notice that the reserve will be used and the full amount of power output procured. Typically, this time is 10 min for the spinning and non-spinning parts of reserve R3.

5. Users of reserves R1, R2, R3 and R4 are the distribution agents, and the large industrial consumers without own generation.

6. The supply agents for R1, R2, R3 e R4 are to be remunerated as a function of the MW.h i.e., the amount of the procured reserve in MW multiplied by the time of reserve availability in hours.

7. Independent power producers (IPPs) who are consumers as well should inform the ISO about their generation, load (if any), and the generating units forced outage rate. If they have load, they should pay for reserves R1 and R2 as any other consumer because they are connected to the grid and benefit from system frequency regulation.

8. Industrial consumers with generation and reserves may not need to buy R3 and R4. However, that is not likely to occur because it is supposed to be cheaper to buy those reserves in the system market than to provide them.

9. The reserve amounts for the distribution companies, the independent power producers and the large industrial consumers, are determined by the ISO and are proportional to their loads.

Although some argue that market participants should have the option of either self-providing AS or purchasing them from the market agent, it is clear from the above points that it is not the case for the Brazilian market for generation reserves.

6 METHODS OF PROCUREMENT

The rules which govern the California ISO ancillary service market are defined as follows [7]:

1. Multiple Bids: A resource can submit bids to any or all of the four different ancillary service markets with different capacity and price. However, a resource can only submit one bid of capacity and price to a specific market.

2. Quality Order: The service quality order is predetermined as regulation, spin reserve, non-spin reserve and replacement reserve. The requirement for service in higher quality market has to be met before meeting that in a lower quality market.

3. Lower Bids ln: In each ancillary service market, the bid is accepted from the lowest bid price to the highest bid price until the requirement for service in this market is met. The price of the last accepted bid sets the Market Clearing Price (MCP) for that market. All bids with a price lower than the MCP has to be accepted. All bids accepted are paid at the MCP in the market instead of their bid prices.

4. Partial Selection: For the bid that sets the MCP a portion of the available capacity can be accepted in case excess supply exists. If more than one bid sets the MCP, the accepted bids will be prorated based on their available capacity.

5. Capacity Constraint: A resource may have bids accepted in more than one ancillary service markets. However, the total accepted capacity from the resource can not exceed its total available capacity considering its operating limit and energy schedule.

6. Ramping Constraint: The capacity accepted for an ancillary service market has to satisfy the ramping requirement of the specific market. In California ISO, the ramping times of 30, 10, 10, and 60 minutes are used for regulation, spin, non-spin, and replacement markets, respectively.

The method of procurement called Sequential method procures the ancillary service exactly following the market rules described above. Details of how the Sequential method works are given in [7, 8].

This market design results in the lowest possible cost for procuring AS individually for each market. However, it does not necessarily minimise the overall cost of procuring all AS. One way to address these problems is to implement a simultaneous AS auction with downward substitution for the different reserves. The objective function could be the minimisation of procurement cost. This method is called Rational Buyer's method and details of how it works are given in [7, 8].

In California the four ancillary services are procured on an hourly basis in both the day-ahead and hour-ahead markets.

Since the California ISO went into operation on March 31, 1998, ancillary service procurement has been a major function in the day-to-day market operation. The costs of ancillary service procurement comprised 48% of the total ISO market costs during the first year of operation. A sequential method had been used at the California ISO to procure ancillary services because of its strict consistence with the ancillary service market roles and relatively easy implementation. The first year operation experience showed that this method did not achieve market efficiency and was prone to price spike. During the heat wave of July 1998, the ancillary service price was soaring up to US$ 9999 per MWh for a few hours, comparing with a normal price range of US$ 5 to US$ 10 per MWh. The California ISO Board of Governors had to impose a price cap of US$ 500 per MWh, which later was reduced to US$ 250. To improve the market efficiency and prevent price spikes, the California ISO embarked an ambitious effort to redesign the ancillary service market. As a major component of the redesign effort, the Rational Buyer's algorithm has been put on production since August 18, 1999. The real-time operation results show that the Rational Buyer's algorithm is practically feasible and has improved the market efficiency [7].

7 BUYING AND SELLING IN THE BRAZILIAN MARKET

A possible design for the Brazilian reserve market has to take into account the hydroelectric nature of the generating units, the energy market design and the ISO rules for reserves.

The proposed market design is based on the Rational Buyer's method, which includes the following features for reserve procurement:

1. The service quality order is predetermined as R2, R1, R3 and R4. The requirement for service in higher quality market has to be met before meeting that in a lower quality market.
2. The bid is accepted from the lowest bid price to the highest bid price until the requirement for service in the market is met. The price of the last accepted bid sets the MCP for that market.
3. Each generating agent bids for the four reserves at the same time (amount and price).
4. Higher quality offers may be used for lower quality demand (the rollover option).
5. The overall procurement cost is minimised constrained by features 1 and 2 above.
6. If the demand is greater than the offer for one type of reserve, higher quality surplus reserves are used to cover the deficit.

The "Rational Seller" method includes:

1. The buy-and-sell market agent is neutral; i.e. the revenue is always equal to the procurement cost (no uplifts or other adjustments).
2. The procurement cost savings achieved using the Rational Buyer's method instead of using the Sequential method is distributed among the reserve buyers in such a way that the price for each reserve is always smaller than the price which would be paid under the Sequential method.
3. Reserve buyers of only R1 and R2 are dealt with fairly: they affect only the prices of R1 and R2 and they participate only partially on the procurement cost savings.

Features 1, 2 and 3 above are explained as follows. The most typical pricing rule is to set the price of each reserve type equal to the procurement price of that type. Under this pricing rule, buyers of a reserve type, say Spinning reserves, may end up paying more if Spinning Reserves is also used for Non-Spinning reserves, thus raising the MCP for Spinning reserves. Note, under this pricing rule, the market agent may not be revenue neutral and may need an uplift charge to make up the revenue shortfall [3].

It is proposed that the selling price should be based on the MCPs of the Sequential method. The savings obtained by using the Rational Buyer's method when procuring reserves should be distributed among the four markets. This is achieved by using a reduction factor applied to the MCPs of the Sequential method. The factor is equal to the total reserve cost acquired according to the Rational Buyer's method divided by the cost of the Sequential method. Such procedure guarantees that the income is always equal to the revenue and thus there is no need of further adjustments.

The following example illustrates the idea. Table 1 shows the reserve requirements for each distribution agent of a Control Area in MW for each reserve type, as imposed by the ISO (see Section 5). Table 2 shows the generation agents bids in MW, $/MW for each reserve type, as well as their maximum reserve capacity. It is the responsibility of the market agent to buy the reserve requirements of Table 1 using the offers of Table 2. Applying the Rational Buyer's method the market agent buys as shown in Table 3 – the accepted bids in MW and the MCP in $/MW for each type of reserve. The highest quality reserve R2 (not R1) is entirely bought in the R2 market, of course, as there is no rollover option to the highest quality reserve. In order to avoid the speculation of generator agents 1, 2 and 3 for the market of R3 and of generator agents 1, 2 and 5 for the market of R4, 800 MW of higher quality R1 is acquired. The R1 requirement was only 64 MW.

Table 4 shows the amount in MW bought in each market and the corresponding MCP in $/MW. The total expenditure was $ 6,051,39. If the buying had been made according to the Sequential method the total spending would had been $ 8,486.20. These two values indicate that the cost has been reduced to 71.3%. Reserves are sold to the distribution agents using the MCPs of the Sequential method multiplied by 0.713, as shown in Table 4.

A paper from the CAISO personnel [7], states that their Rational Buyer's algorithm tries to overcome the possible offer shortage in a certain market in relation to the reserve requirements by using the surplus of higher quality reserves. Due to reasons not explained in [7], the algorithm is not always successful even if there is enough surplus of higher quality reserve to cover the deficit of a lower quality reserve. The program used in the numerical example is always successful in doing so.

The computational algorithm used to find the solution was written in Mathlab 6.0. When 200 hundred generators are bidding in the four markets the program takes 118 seconds using a microcomputer AMD 1 GHz with 512 MB RAM.

8 CONCLUSIONS

The service of providing generation reserve is one of the most important ancillary services. This paper dealt with a possible design for the Brazilian reserve market taking into account the hydroelectric nature of the generating units, the energy market design and the ISO rules for reserves.

Important aspects such as reserve types, reserve requirements, reserve allocation were addressed in order to form the basis for establishing the market.

The proposed method for reserve procurement and reserve selling is based on the Rational Buyer's method, which includes the following features:

1. Each generating agent bids for the four reserves at the same time (amount and price).

2. Higher quality offers may be used for lower quality demand (the rollover option).

3. The overall procurement cost is minimised, considering that the requirement for higher quality reserve has to be met before the lower quality one and that the bid is accepted from the lowest bid price to the highest bid price until the requirement for reserve in the market is met.

4. If the demand is greater than the offer for one type of reserve, higher quality surplus reserves are used to cover the deficit.

5. The buy-and-sell market agent is neutral; i.e. the revenue is always equal to the procurement cost.

6. The procurement cost savings achieved using the Rational Buyer's method instead of using the Sequential method is distributed among the reserve buyers in such a way that the price for each reserve is always smaller than the price which would be paid under the Sequential method.

7. Reserve buyers of only R1 and R2 are dealt with fairly: they affect only the prices of R1 and R2 and they participate only partially on the procurement cost savings.

8. The algorithm used is such that offer shortage of one kind of reserve is always compensated with reserve of higher quality, provided there are surplus of the latter, of course.

9. The computational algorithm used to find the solution is fast and adequate for a system with two hundred generators bidding in the market.

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Distribution Agent Number	Reserve Types			
	R1	R2	R3	R4
	MW	MW	MW	MW
1	58	149	650	650
2	6	62	7	7
Control Area Requirement	64	211	657	657

Table 1: Reserve requirements for each distribution agent in MW as defined by the ISO for each reserve type

Generator Agent Number	Reserve Types								Maximum Capacity
	R1		R2		R3		R4		
	MW	$/MW	MW	$/MW	MW	$/MW	MW	$/MW	MW
1	150	0,99	100	30	200	10,50	300	4,80	350
2	250	0,95	200	29	350	11,00	400	4,75	450
3	300	12,00	250	25	350	10,00	450	0,005	480
4	100	0,90	--	--	150	0,03	150	0,900	160
5	300	0,92	200	26	400	0,05	400	5,000	440
6	200	0,91	150	23	250	0,02	250	0,006	300
7	100	0,96	--	--	150	0,01	150	0,004	190

Table 2: Generation reserves bids in MW and $/MW for each reserve type and maximum reserve capacity

Generator Agent Number	Reserve Types									
	R1		R2		R3		R4		Reserve Capacity	
	MW	MCP $/MW	MW	MCP $/MW	MW	MCP $/MW	MW	MCP $/MW	Sold	Spare
1	--	0,95	--	25	--	0,05	--	0,005	0	350
2	250		--		--		--		250	200
3	--		61		--		238		299	181
4	100		--		60		--		160	0
5	300		--		90		--		390	50
6	150		150		--		--		300	0
7	--		--		150		40		190	0

Table 3: Accepted bids in MW and the MCP in $/MW for each type of reserve using the Rational Buyer's method

Procedure →	Sequential Method MCPs $/MW	Rational Buyer's method		"Rational Seller's method"	
Reserve Types ↓		Amount MW	MCP $/MW	Amount MW	Price $/MW
R1	0.9	800	0.95	64	0.64178
R2	25.00	211	25.00	211	17.82715
R3	0.05	300	0.05	657	0.03565
R4	4.75	278	0.005	657	3.38716
Total Reserve Cost in $ →	8,486.20	6,051.39		6,051.39	

Table 4: MCPs of the Sequential method, MCPs of the Rational Buyer's method effectively used for buying and prices charged to the distribution agents