International Journal of Pure and Applied Mathematics
Volume 118 No. 24 2018
ISSN: 1314-3395 (on-line version)
url: http://www.acadpubl.eu/hub/
Special Issue
http://www.acadpubl.eu/hub/

A review on reserve markets and pricing of spinning reserve in restructured electricity market

J.KRISHNA KISHORE, B.V.SANKARA RAM
Research Scholar, Professor,
JNTUH, Hyderabad.
Faculty,QISCET,Ongole
KISHOREJAMPANI@GMIL.COM

May 2, 2018

Abstract

Ancillary Services are essential in maintaining reliable and secure operation power system in any restructured competitive electricity market. Procurement of ancillary services is important and must take into consideration for effective use of the capacity . The spinning reserve is one of the import ancillary services that. must be provided efficiently. This paper presents a detailed OPF-based formulation for pricing spinning reserve using MATLAB. The proposed methodology is applied to a typical 6 unit system which demonstrates the effectiveness of joint dispatch of energy and reserve over sequential dispatch

***Key Words*:**Joint dispatch, Sequential dispatch, Ancillary services.

1 Introduction

The operation of the power systems is naturally stochastic since all the main components e.g. power generation and load is dynamic with respect to time. All the Independent system operators (ISOS) are using forecasting tools regarding the available power production and load demand in order to plan efficient operation of the power system. But, during the real time operation several deviations may occur either in generation side or in the demand side. Therefore, the improvement of efficient economic and technical tools able to handle the imbalance of supply and demand should always be considered[1]. One of the key ingredients in the restructured electricity market for secure and reliable operation of the power system are the Ancillary Services (A/S), which are used to restore or keep the systems characteristics i.e. frequency and voltage within their nominal values. Therefore, Ancillary Services take part a vital role in the electricity market and their procurement mechanism is important for the reliable, secure and economic operation of the power system. Spinning reserve is one of the important ancillary service that could be provided with in the minimum time to keep the frequency within the limits .Spinning reserve is defined as the generation capacity that that is on-line but unloaded and that can respond within 10 minutes to compensate for transmission or generation outages. At present, there are two main types of reserve markets schemes. In the first type of market design the procurement of ancillary services is through sequential auction. In the second type, simultaneous energy and reserves capacity auction is performed.

Sequential optimization - where resources are used first to satisfy the load within the energy market, remaining resources used secondarily to satisfy the reserve requirements. Joint optimization - where the bids and offers in the energy reserve markets are evaluated at the same time, satisfying both the total demand and the reserve requirements in such a way that the economic gain from trade for all participants is maximized by taking advantage of the relative differences in energy and reserve offers[2].

Reserve Procurement Mechanism

In order to procure economical reserves in power systems, the ISO needs to use all facilities to prepare sufficient reserves. These are associated with the least possible price to supply secure and reliable electric. To achieve these goals, the ISO must consider system reserve capability with regard to all participants potentials, including generators, curtailable loads and their maximum contribution.

The ISO should also apply advanced techniques to dispatch energy and reserves considering either cost-based and/or market-based pricing methodologies to clear the optimum price for energy and reserves. As shown in Figure 1, in the reserve procurement mechanism the ISO is dealing with several different issues including physical and economical considerations.

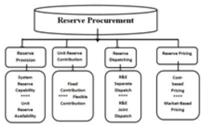

Figure 1: Structure of reserve procurement

System reserve capability, unit availability and unit maximum reserve contribution are physical aspects, while dispatching methods and pricing mechanisms are both physical and economical aspects. The main idea of using ED or OPF for reserves provision is to capture the most economic reserve capacity dispatching, incorporating all possible physical and economical restrictions. Such restrictions are reliability and security constraints.

2 Reserve Market mechanism in some Power Markets

2.1 Reserve markets in UK

In any system, the system frequency is to be maintained within acceptable range. Reserves are required in circumstances when actual demand more than forecast or breakdown of plant occurs.

2.1.1 Mandatory Frequency Response

The minute by minute system frequency is managed through the self-balancing actions of generators and suppliers and the offer/bid acceptances by the NGC(National Grid Company). All large generators have to capable of contributing to second-by-second frequency control, which is mandatory by the Grid Code and conditions for connection to the transmission network. Each associated unit have a 4% governor droop characteristic. Prices are cost-reflective to reflect inefficiency, and wear & tear costs related with service provision.

2.1.2 Commercial Ancillary Services

Commercial Frequency Response measures are entered into when both the System Operator and the provider see a technical or commercial benefit in doing so and are freely negotiated between the parties both in terms of contract from and price. While generators, through mandatory services, provide continuous system frequency control, occasional frequency control requirements are largely met by changing demand through commercial contracts. NGC is always intense to contract for commercial services by volume to obviate the need to use the generally more expensive obligatory services. The demand can participate if it is prepared to be interrupted for 30 minutes several times a week, triggered by LF relay within second for primary response and 30 seconds for secondary response; payments are based on the relay setting in MWh at contract price. Fast Reserve is the quick and consistent delivery of active power provided as improved output from generation or a drop in consumption from demand sources, following receipt of an electronic dispatch instruction from the National Grid. Active power delivery must start within 2 minutes of the dispatch instruction at a delivery rate in excess of 25MW/minute, and the reserve energy should be sustainable for a minimum of 15 minutes. Standing Reserve: at certain times of the day NGC needs extra power in the form of either generation or demand reduction to be able to deal with actual demand being greater than forecasted demand and plant breakdowns. This requirement is met from synchronized and non-synchronized sources. NGC procures the non-synchronized condition by contracting for Standing Reserve, provided by a range of providers including generating units, demand reduction and independent generating plant[3].

2.2 Reserve Markets in the USA

2.2.1 California Markets

In California the CAISO (California Independent System Operator) is responsible for ancillary service procurement to make sure that adequate ancillary services are available to preserve the reliability of CAISO grid. Ancillary services requirements, recognized by CAISO, may be self-provided by each SC(Scheduling Coordinator) those not self-provided must be competitively acquired by contracts for long term, day ahead, hour ahead, or real time basis. The CAISO is responsible for obtaining or monitoring the acquisition of spinning reserve and other ancillary services. The ISO determines a MCCP(Market Clearing Capacity Price) for each of ancillary service, where successful bidders into each of these markets may or may not in fact be called upon to provide energy. If these units are asked to provide real-time energy, suppliers to the replacement, spin and non spin reserve markets are paid the imbalance energy price for any energy that they may provide. This payment is in additional payment to the capacity payment they get for making their capacity offered to the ISO.

2.2.2 New York Markets

The NYISO (New York Independent System Operator) is responsible for ancillary service procurement through an ancillary service market. The markets managed by the NYISO comprise energy, installed capacity, transmission congestion contracts, and ancillary services. NYISOs A.S markets include T.M.S.R (ten-minute spinning reserves), T.M.N.S.R.(ten-minute non-spinning reserves), thirty-minute non-spinning reserves, and regulation. To ensure the security of the electric system, the NYISO obtains reserves through the NYISO administered ancillary services market. The operating reserves requisite in New York are both ten minute reserves and thirty minute reserves. The entire ten-minute reserve capacity equal to the largest contingency that may occur in the system; half of that amount must be spinning reserve and half can be non-spinning. Thirty-minute reserves available in an amount equal to 50% of total ten-minute reserves. The total reserves therefore required, ten-minute plus thirty-minute, equals 1.5 times the largest single contingency that may occur in the system.

2.2.3 PJM markets

PJM implemented some synchronized A/S markets in 2001 to co-optimize the supply of energy, regulation, and operating reserves. These include DAM(Day-Ahead Energy Market),RTM(Real-Time Energy Market), Forward Regulation Market, Forward Synchronized Reserve Market, and Forward Day-Ahead Scheduling Reserve

Market. Both generation and demand resources are allowed to tie in each A/S market. Load-serving entities are indebted to take share of the PJM A/S requirement in any of three ways: self-scheduling the entitys own resources; mutual contracts to purchase services from other parties; and purchasing services from the A/S markets. The share of obligation is determined on the basis of the entitys total load in the PJM RTO. In the PJM regulation market, resource owners also submit specific offers for regulation capability and regulation performance. PJM minimizes the RTO dispatch profile and forecasts LMPs to calculate an hourly regulation market clearing price, regulation market performance clearing price (RMPCP), and regulation market capability clearing price. For each hour, RMCP is the total of RMPCP and RMCCP.

3 Problem formulation-Joint energy and reserve dispatch (JERD)

The JERD deals with allocating the system demand for energy and spinning reserve among the existing generators such that all equality and inequality constraints are satisfied and the total operating cost is optimized. In addition to the normal operating constraints the ramp-rate constraints are to be considered.

i)The objective of the JERD is given as

$$minC_r = \sum_{i=1}^{N} [F(P_i) + G(R_i)] \tag{1}$$

F(Pi), G(Ri) are the energy and reserve costs of the ith unit.

The energy price is assumed to be quadratic and the spinning reserve price is assumed to be linear. The energy and spinning reserve costs can be expressed by (2) &(3) respectively.

$$F(P_i) = a_i(P_i^2) + b_i(P_i) + c_i \tag{2}$$

Where ai ,bi,ci are cost coefficients of generator i.

$$G(R_i) = d_i \times (R_i) \tag{3}$$

Where d_i is the reserve price of i^{th}generator.

ii) Unit energy capacity constraints

$$P_i^{min} \leq P_i \leq P_i^{max} \quad (4)$$

Here$P_i^{min}$and $P_i^{max}$are unit operating limits
iii) Unit reserve capacity constraints

$$0 \leq R_i \leq R_i^{max} \quad (5)$$

R_i^{max} is the specified reserve limit
iv)Tie-line capacity constraints given as

$$T_i^{min} \leq T_i \leq T_i^{max} \quad (6)$$

T_i^{min}, T_i^{max} are tie line limits
Where d_i is the reserve price of i th generator.
v)) Load flow constraints:
The load flow constraints are as follows

$$\sum_{i=1}^{N} P_i - \sum_{i=1}^{N} P_{Di} - P_{Loss} = 0 \quad (7)$$

$$\sum_{i=1}^{N} Q_i - \sum_{i=1}^{N} Q_{Di} - Q_{Loss} = 0 \quad (8)$$

Where

$$P_{Loss} = \sum_{i=1}^{N} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i) \quad (9)$$

$$Q_{Loss} = \sum_{i=1}^{N} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i) \quad (10)$$

Where
N: Number of buses of the network
P_i, Q_i : Supply of active and reactive power at i^{th} bus
P_{Di}, Q_{Di}: Active and reactive demand at i^{th} bus
$V_i = |V_i|\angle\delta_i$: Voltage phasor at bus i
$Y_{ij}\angle\theta_{ij}$: The j^{th} element of admittance matrix
vi)Unit capacity constraints:

The sun of real power dispatch and spinning reserve allocation must be less than units maximum capacity. This can be expressed as follows

$$P_i + R_i \leq P_{imax} \tag{11}$$

$$P_i \leq P_{imin} \tag{12}$$

P_{imax}, P_{imin} are maximum and minimum generating capacities of generator i respectively

4 SIMULATION AND RESULTS

Here the system demand is assumed to be 1040 MW, and the reserve requirement is 100 MW. The energy bidding blocks and SR bidding blocks in associated with the unit RR capability and MW generation capacity are shown in Table 1. Two different scenarios sequential dispatch (SQD) and Joint dispatch (JERD) are implemented. To find the optimal generation and reserve allocation & to find the market clearing price for energy and reserve, a Linear Programming method by using MATLAB Programming is applied. The energy and reserve dispatch results are shown in Tables 2. The energy clearing price, reserve clearing price and total energy and reserve prices are shown in Table 3.

Table.1 Six unit test system data

Unit	Energy Offer						Ancillary Service offer		Ramp Rate MW/min	MW Limit
	Band 1		Band 2		Band 3		Band 1			
	MW	Price	MW	Price	MW	Price	MW	Price		
1	5	13	7	23	5	27	5	1.5	5	17
2	80	14	60	26	60	28	20	3	5	200
3	70	11	15	22	15	25	10	2.5	7	100
4	400	12	60	21	60	24	50	2.75	10	520
5	200	15	40	17	40	23	50	3.5	10	280
6	50	12	30	27	30	29	20	1.25	5	110

Table.2 Energy and Reserve dispatch results.

Unit	Sequential dispatch			Joint dispatch		
	P_G	SR	Total	P_G	SR	Total
1	12	5	17	12	5	17
2	158	15	173	133	20	153
3	90	10	100	90	10	100
4	470	50	520	475	45	520
5	230	0	230	280	0	280
6	80	20	100	50	20	70

Table.3 Energy and Reserve costs.

Case	Energy cost ($/hr)	Reserve cost ($/hr)	Total Cost ($/hr)	Energy market clearing Price ($/MWhr)	Reserve market clearing Price ($/MWhr)
Sequential dispatch	15855	240	16095	28	3
Joint dispatch	15569	241.25	15810.25	26	3

It is observed from the results that Joint dispatch may provide an improvement in coordination of energy and reserve dispatch. The most secure and economic solution can be achieved through this approach.

5 CONCLUSION

The study on a competitive market for spinning power services in deregulated electricity systems have attempted in this paper.. This paper makes a review on the various ancillary spinning reserve markets in the world. In this paper the co-optimization of energy and spinning reserve is discussed. Here Gencos could share their total generation capacity in two markets so as to take advantage of their profits.

References

[1] Stefanos Delikaraoglou and Yi Ding. Report-Development of simultaneous energy and reserve dispatch model and cor-

responding pricing mechanism, technical report DTU CET March 2012.

[2] M.Rashidinejad,Y.H.Song,M.H.Javidi, Contingency reserve pricing via a joint energy and reserve dispatching problem,Energy Conversation and Management,Vol.43,2002,pp.537-548.

[3] Y.H. Song, and X.F. Wang, Operation of market-oriented power systems, Springer Publications, 2004. www.nationalgridinfo.co.uk

[4] Pal, Kirti, Laxmi Srivastava, and Manjaree Pandit. "Static/dynamic optimal dispatch of energy and reserve using recurrent differential evolution", IET Generation Transmission &Distribution, 2013.

[5] Tong Wu, G. Angelidis, Z. Alaywan, A.D.Papalexopoulos. "Regional ancillary services procurement in simultaneous energy/reserve markets", IEEE PES Power Systems Conference and Exposition, 2004.

[6] Chun-Lung Chen. "Optimal generation and reserve dispatch in a multi-area competitive market using a

[7] hybrid direct search method",Energy Conversion and Management, 2005. Kankar Bhattacharya, Math H.J. Bollen, Jaap E. Daalder, Operation of restructured power systems, Kluwer Academic Publishers,2011.

[8] B. Kirby, Ancillary Services: Technical and Commercial Insights,2007, http://www.consultkirby.com/Publications.html

[9] Xingwang Ma, David Sun, Energy and Ancillary Service Dispatch in a Competitive Pool, IEEE Power Engineering Review, 1998,PP.54-46.