Energy Market and Active Power Reserve Market Modeling in Competitive Electricity Markets to Reduce the Cost of Electricity with Considering the Increasing of Network's Load

Ramin Ghoraba, Power & Water University of Technology, Iran
Mohammad Taghi Ameli, Power & Water University of Technology, Iran
Eng.electronic@gmail.com , mtameli@yahoo.com

Abstract

By notice to the stochastic altering of electricity load in operating power system network, amount of production and transmission capacity is considered as reserve power. In competitive electricity markets, needed power for the reserve network will be purchased from the ancillary service market. In this market, producing units (generators) announce their offers to the market that are including amount of power, power prices and ready prices. Meanwhile buyers (loads) announce their bids to the market that are including amount of power and power prices. Meantime independent system operator (ISO) buys his needed power for reserve from this market. Energy market and reserve market implementation is possible with simultaneous method and serial method.

Choosing each of the mentioned methods related to the type of market and other conditions. In this paper energy market and active power reserve market are simulated in two formations as serial and simultaneous for uniform pricing system.

In each method, limitation of transferring power through the lines base on available transfer capacity (ATC) is considered alongside the other constraints in energy market and active power reserve market. Then during network overload, economic dispatch is accomplished between winner units in reserve market by using a linear optimization problem, and needed power supply from these units by minimum cost. Finally, our proposed methods are implemented on IEEE 39-bus test system and the results are analyzed.

Introduction

In traditional systems, the operating of electricity networks was done by an integrated entity which was often-governmental structure. In this system, supply the needed reserve for electricity networks was not overly complicated. But with restructuring in electric industry, there was some complexity. In restructured system, the manufacturing part will participate in the market, as an independent identity and so cannot be pre-determined portion of each participating units to provide reserve. To resolve this problem, the market has been launched as an active power reserve market. In this market, generators announce their offers to the market that is including the steps of price and MW.

Then by implementation of market, portion of each participating generators in the market is determined. In this perspective, confrontation between the energy market and active power reserve market provides a variety of issues. Different strategies are presented in different references for optimal performance in the reserve market alongside energy market. The presented work in [1] predicted the required reserve in a competitive electricity market. At the mentioned work, a predictive reserve requirements engine is designed by combining artificial neural networks and real genetic Algorithm. LM (Levenberg–Marquadt) algorithm is used for training. The presented method in [2] used CPSO (Constraint Particle Swarm Optimization) algorithm for optimal dispatch between the generators in the energy market and reserve market. Presented work in [3] used the method's that show simultaneously optimizing energy market and the secondary reserve market. At the mentioned work, only simultaneous implementation method for the energy market and active power reserve market is formulated and GAMS software has been used to solve it. A method is presented in [4] for reserve market price rating according to the ready price. [5] Determined pricing strategy in Chile reserve market by following to the contrast between reserve market and energy market. A type of unit commitment is presented in [6] based on the optimizing of the producing companies' profits. In this reference the constraints related to the System required reserve in design issue has been considered. A method is presented in [7] based on the system optimal power flow for optimal providing required energy and reserve for network. In our work, serial and simultaneous implementation of energy market and reserve market are formulated and compared with together.

Design Issue

In energy market, generators and loads announce their offers and their bids to the market that are including the steps of price and power, but in reserve market just generators announce their offers to the market. Energy market and reserve market may run in serial method or in simultaneous method, and problem’s formulation in each state is different.

Simultaneous Implementation Method

In this method, energy market and reserve market is performed simultaneously. Mathematical definition of the problem should involve all constraints concerned with energy market, reserve market and network. All of implied constraints simultaneously at this section are as the mentioned in the bellow:

- Limitation of power that produced by generators:
  By following this constraint, generators producing power should be in allowed range. Base on what mentioned in above, the won reserve by a generator on the market should be producible. Meantime this constraint is defined as follows:

$$PG_i^{min} \leq PG_i + PR_i \leq PG_i^{max} \quad (1)$$

Where:

PG_i^{min}: is the minimum power can be produced by the i^{th} generator
PG_i^{max}: is the maximum power can be produced by the i^{th} generator

PG_i: is total won power by i^{th} generator in energy market and is calculated as follows:

$$PG_i = \sum_k pg_{i,k} \quad (2)$$

Where:
$pg_{i,k}$: is won power by i^{th} generator in energy market related to the k^{th} proposed step

PR_i: is total won power by i^{th} generator in energy market and is calculated as follows:

$$PR_i = \sum_k pr_{i,k} \quad (3)$$

Where:
$pr_{i,k}$: is won power by i^{th} generator in reserve market related to the k^{th} proposed step

- Loads suggested steps limitation:
  Won power by each load must be situated in suggested steps range. This constraint considered as follows:

$$0 \leq pl_{i,k} \leq pl_{i,k}^{max} \quad (4)$$

Where:
$pl_{i,k}$: is won power by i^{th} load in energy market related to the k^{th} proposed step

$pl_{i,k}^{max}$: is the power in i^{th} load in the energy market related to the k^{th} proposed step

- Generators suggested steps limitation:

$$0 \leq pg_{i,k} \leq pg_{i,k}^{max} \quad (5)$$

Where:
$pg_{i,k}^{max}$: is the power in i^{th} generator in the energy market related to the k^{th} proposed step

- Reserve steps limitation:

$$0 \leq pr_{i,k} \leq pr_{i,k}^{max} \quad (6)$$

Where:

$pr_{i,k}^{max}$: is the power in i^{th} load in the reserve market related to the k^{th} proposed step

- Limitation of transferring power through the lines:
  During the implementation of market, limitation of transferring power through the lines should be considered. Otherwise, the market result may causes to reject the network constraints. For considering the limitation of transferring power through the lines, the following equation is used:

$$|f_{ij} + \Delta f_{ij} \leq f_{ij}^{max}| \quad (7)$$

Where:

f_{ij}: is transferring power from the line between bus *i* and bus *j*

Δf_{ij}: is the power variation in network lines, while all of the network loads increase rarely as required reserve

f_{ij} and Δf_{ij} are obtained from the DC power flow.

- Constraints related to DC power flow:

$$f_{ij} = \frac{1}{Xij}(\theta_i - \theta_j) \quad (8)$$

$$PG_i - PL_i = \sum_j \frac{1}{Xij}(\theta_i - \theta_j) \quad (9)$$

- Objective function:
  In this issue, the main purpose in energy market is to increase the social welfare. In addition, the main purpose in reserve market is to reduce the reserve cost. According to these points, objective function is defined as follows:

$$obj = max\left\{\left[\sum_j \sum_k cl_{jk} \cdot pl_{jk} - \sum_i \sum_k cg_{ik} \cdot pg_{ik}\right] - \left[\sum_i \sum_k (cr_{ik} \cdot pr_{ik} + co_k \cdot Rf_i\right]\right\} \quad (10)$$

Where:

i: is introduced generator
j: is introduced load
k: is introduced proposed step
Rf_i: is a binary parameter.

If it is one that shows the i^{th} generator has won in reserve market and if it is zero that shows the i^{th} generator has not won in reserve.

ck: is loads suggested prices in energy market
cg: is generators suggested prices in energy market
cr : is generators suggested prices in reserve market
co: is the ready price

Expressed relations in above, shows the simultaneous implementation of energy market and reserve market in the form of an optimization problem.

Serial Implementation Method

In this case, the energy market is run first, and then run the reserve market. The constraints considered in this section are very similar to simultaneous method.

Implementation of Energy Market

Constraints considered are as follows:

- Limitation of power that produced by generators:
  By following this constraint, generators producing power should be in allowed range.
  Base on what mentioned in above, the won reserve by a generator on the market should be producible. Meantime this constraint is defined as follows:

$$PG_i^{min} \leq PG_i \leq PG_i^{max} \qquad (11)$$

- Loads suggested steps limitation:

$$0 \leq pl_{i,k} \leq pl_{i,k}^{max} \qquad (12)$$

- Generators suggested steps limitation:

$$0 \leq pg_{i,k} \leq pg_{i,k}^{max} \qquad (13)$$

- Limitation of transferring power through the lines:

$$|f_{ij} \leq f_{ij}^{max}| \qquad (14)$$

- Constraints concerned with DC power flow:

$$f_{ij} = \frac{1}{Xij}(\theta_i - \theta_j) \qquad (15)$$

$$PG_i - PL_i = \sum_j \frac{1}{Xij}(\theta_i - \theta_j) \qquad (16)$$

- Objective function:

In this issue, the main purpose in energy market is to increase the social welfare and defined as:

$$obj = max\left\{\sum_j \sum_k cl_{jk}.pl_{jk} - \sum_i \sum_k cg_{ik}.pg_{ik}\right\} \qquad (17)$$

Expressed relations in above, indicate the implementation of energy market in the form of an optimization problem.

Implementation of Reserve Market

Reserve market is implemented after energy market and this subject has lead to change reserve market constraints a little. Constraints related to this section are as follows:

- Generators suggested steps limitation:

$$0 \le pr_{i,k} \le pr_{i,k}^{max} \qquad (18)$$

- Providing the required reserve constraint:

$$\sum_k pr_{i,k} = Res \qquad (19)$$

- Limitation of transferring power through the lines:
In implementation of reserve market, the remaining capacity of the lines should be put into the issue's simulation as form of constraints. If the purchased reserve is used, overload should not occur in network lines. This constraint can be considered as follows:

$$|\Delta f_{i,j}| \le ATC_{ij} \qquad (20)$$

In this formula, *ATC* is available transfer capacity and defined as:

$$ATC_{ij} = f_{ij}^{max} - f_{ij} - fm_{ij} \qquad (21)$$

In this formula, fm_{ij} is lines security margin and is placed in issue in order to maintain line security and prevent complete filling line capacity.

- Limitation of reserve can be produced by the generators:

$$max\{0, PG_i^{min} - PG_i\} \le Pr_i \le PG_i^{max} - PG_i \qquad (22)$$

This constraint makes won power by each generator in the reserve market, be in range of remaining capacity of the production.

- Objective function:
  Main purpose of objective function in this section is to reduce the reserve cost and defined as follows:

$$obj = min\left\{\sum_{i}\sum_{k}(cr_{ik}.pr_{ik} + co_{k}.Rf_{i}\right\} \quad (23)$$

Contingency Simulation in the Network

After implementation of energy market and reserve market, in case of sudden load increasing or sudden production decreasing in the network, network operating will be done from the won units in the reserve market, and lack of desired production is provided with the lowest cost. In this paper, the contingency has been applied as a sudden load increasing. In this regard, some of the constraints must be respected. This problem is defined in the form of an optimization problem, that is bounded to the network security constraints and participating units in the market. Different parts of this optimization problem are as follows:

- Limitation of power production in generators
- Supply shortage in load constraint
- Limitation of transferring power through the lines
- Limitation on the use of purchased reserve

Figure 1 shows the flowchart for serial method in energy market implementation and reserve market implementation with considering the contingency.

Figure 2 shows the flowchart for simultaneous method in energy market implementation and reserve market implementation with considering the contingency.

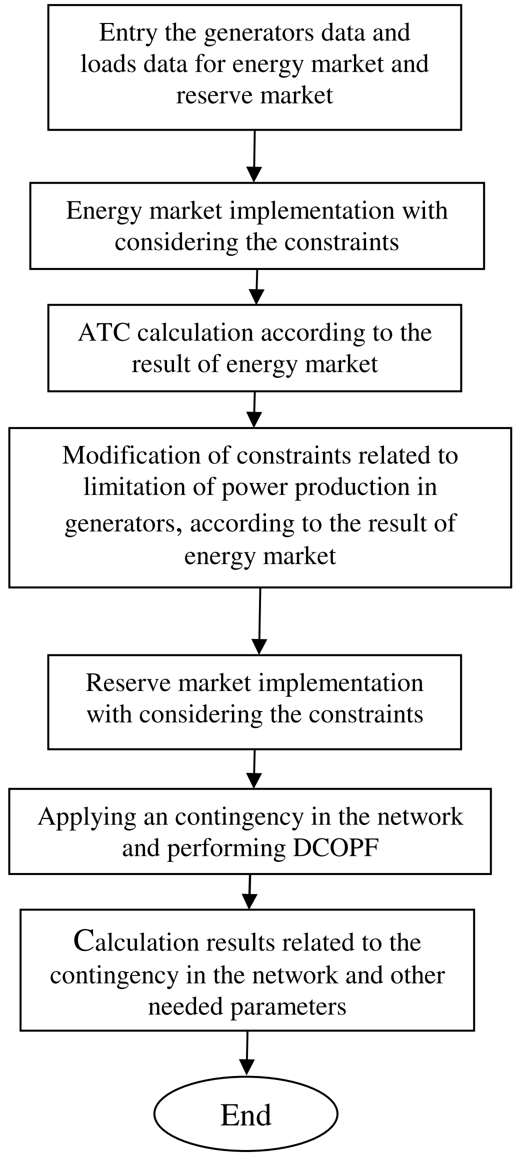

Figure 1: Flowchart for serial method

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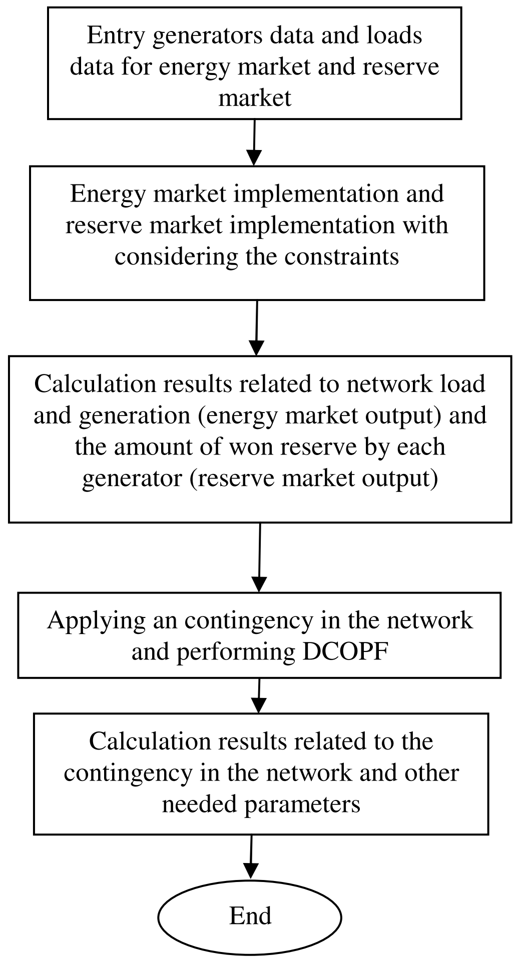

Figure 2: Flowchart for simultaneous method

Case Study

IEEE 39-bus test system for case study has been used. Figure 3 shows the single line diagram of the IEEE 39-bus test system. Table 1 and table 2 show the information about proposed energy market and reserve market for generators and loads.

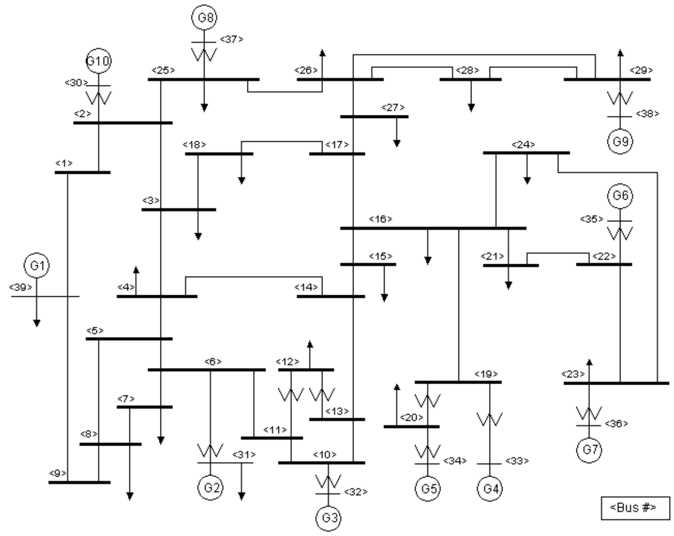

Figure 3: Single line diagram of the IEEE 39-bus test system

Table 1: Generators information

Bus number	Energy Market				Reserve Market				
	Step No:	Step one	Step two	Step three	Ready Price	Step No:	Step one	Step two	Step three
30	(MW)	100	100	50	100	(MW)	20	20	20
	($/Mwh)	33	45	60		($/Mwh)	10	12	15
31	(MW)	100	50	50	100	(MW)	20	20	20
	($/Mwh)	55	65	75		($/Mwh)	13	14.5	17
32	(MW)	300	300	100	100	(MW)	60	60	50
	($/Mwh)	29	40	65		($/Mwh)	13	14	16
33	(MW)	400	200	200	100	(MW)	50	50	50
	($/Mwh)	26	34	55		($/Mwh)	14	16	17
34	(MW)	100	50	50	100	(MW)	50	50	50
	($/Mwh)	50	60	70		($/Mwh)	10	12	14
35	(MW)	200	200	150	100	(MW)	100	100	60
	($/Mwh)	35	40	75		($/Mwh)	14	16.5	18
36	(MW)	250	250	250	100	(MW)	50	50	50
	($/Mwh)	30	35	55		($/Mwh)	13	14	16.5
37	(MW)	250	150	100	100	(MW)	100	60	60
	($/Mwh)	25	35	58		($/Mwh)	12	14	15.5
38	(MW)	400	400	100	100	(MW)	100	100	50
	($/Mwh)	50	60	65		($/Mwh)	14	14.5	16
39	(MW)	500	400	100	100	(MW)	80	50	50
	($/Mwh)	18	25	35		($/Mwh)	19	20	25

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Table 2: loads information

Bus number	Step No:	Step one	Step two	Step three	Bus number	Step No:	Step one	Step two	Step three
3	(MW)	200	100	100	23	(MW)	160	100	100
	($/Mwh)	65	55	45		($/Mwh)	78	66	50
4	(MW)	200	200	200	24	(MW)	135	100	80
	($/Mwh)	73	67	40		($/Mwh)	88	68	58
7	(MW)	250	200	200	25	(MW)	220	100	100
	($/Mwh)	95	45	40		($/Mwh)	74	65	45
8	(MW)	50	50	50	26	(MW)	230	150	100
	($/Mwh)	75	60	45		($/Mwh)	64	54	34
12	(MW)	200	100	100	27	(MW)	340	200	200
	($/Mwh)	60	55	35		($/Mwh)	66	43	33
15	(MW)	250	150	100	28	(MW)	250	150	100
	($/Mwh)	90	70	40		($/Mwh)	76	55	35
16	(MW)	200	200	200	29	(MW)	200	200	100
	($/Mwh)	70	63	33		($/Mwh)	67	57	47
18	(MW)	150	150	100	30	(MW)	140	200	200
	($/Mwh)	65	45	40		($/Mwh)	65	50	45
20	(MW)	250	200	100	31	(MW)	500	400	250
	($/Mwh)	83	73	34		($/Mwh)	85	75	45
21	(MW)	120	80	80	32	(MW)			
	($/Mwh)	65	55	45		($/Mwh)			

In table1, the first row shows the information about the power suggested steps and second row shows the price of each step. Table 3 shows the required information for needed reserve and load increasing.

Table 3: Amount of load increasing

Bus number	The percent of load increasing
3	20%
4	20%
20	20%
24	20%
31	20%
39	20%
Reserve=15%	

Table 4 shows the result of serial implementation of market and simultaneous implementation of market.

Table 4: Serial implementation and simultaneous implementation of market

	Serial method	simultaneous Method
Energy cost ($)	329490	321692
Reserve cost after Contingency ($)	8928	5229
Total cost ($)	338418	326921
Energy market clearnig price ($/Mwh)	63	63.14
Reserve market clearnig price ($/Mwh)	31	18

In the next section, the comparison between simultaneous mode and serial mode is done.

Comparison of results

Simulation results shows, the energy market clearing price in the energy market in serial method is less than the energy market clearing price in simultaneous method. Also, the total power exchanged in energy market in serial method is more than the total power exchanged in simultaneous method. This issue shows, the serial method has better performance in energy market in compared with the simultaneous method. On the other hand, the reserve market clearing price in simultaneous method and the required cost for supplying the load increasing in network are less than the serial method. This shows, the serial implementation of reserve market has better performance than the simultaneous implementation. The reason for this is that in serial implementation of reserve market cannot be seen the reserve market offers. This causes, generators with low energy market price come to their maximum production capacity and if, their reserve market price is appropriate, they do not have the ability to produce. Therefore, units that are more expensive remain for the reserve market. But in the simultaneous method, the reserve market prices are seen in the energy market. Therefore, cheaper generators are selected for the reserve market. And this causes, reserve market price come down in this method. Finally we can say, the serial method is better for networks that have good reliability and often have little load variations. Simultaneous method will have a better efficiency at reducing costs in the networks that have loads with unpredictable severe changes and constantly need to use the purchased reserve. The following Figure (Figure 4) shows the graphs related to the market clearing in both methods. As can be seen, in both cases the market has cleared at a point other than the point of intersection of supply and demand curve. This is because of power limitation in network lines. Market clearing in point of intersection of two curves is causing the overload on some lines. And this has caused, the market be cleared at a point other than the point of intersection of two curves. To fix this problem, Should be increased the capacity of the critical lines.

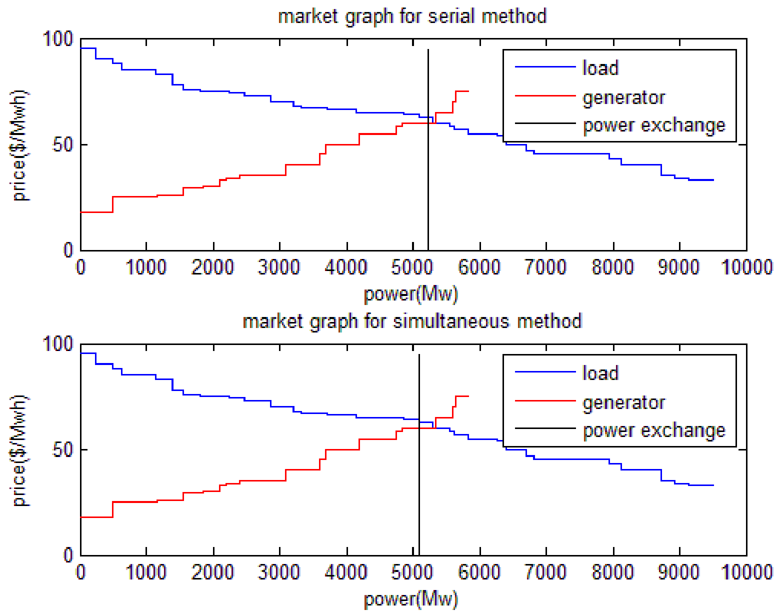

Figure 4: Market graph for serial and simultaneous methods

Conclusion

In this paper, serial implementation method and simultaneous implementation method are presented for the implementation of energy market and reserve market. The methods are defined in the form of optimization problems and are used in a case study on the IEEE 39-bus test system. Results from case study shows that the serial method has better performance in energy market and the market price will be less. Also, the simultaneous method has better performance in the reserve market. Finally, serial method is more suitable in networks that have a high reliability. And Simultaneous method has better performance in networks that have low reliability and purchased reserve should be used regularly.

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