Optimal Dispatch of Generation, Spinning Reserve and Load under Competitive Environment Using Genetic Algorithm

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Abstract- This paper presents an application of Genetic Algorithm (GA) for determining Generation, Spinning Reserves and Load, simultaneously. The objective is to minimize Generation, Load Shedding and Reserve costs while maximizing consumers' benefits. In electricity market environment, generating units are allowed to bid their energy and capacity to energy markets as where as to ancillary service markets simultaneously. This paper considers the load elasticity implying the demand side as an active participant in the electricity market. It is also shown that load management considering interruptible loads can help the Independent System Operator to preserve the spinning reserve within its standard margins during contingencies.

Keywords- Genetic Algorithm, Load shedding, Spinning Reserve, Load Management, Electricity Market.

I. INTRODUCTION

In recent years, Deregulation in power systems has resulted significant changes in power system operation and planning. The fundamental goal of the deregulation is to expand competition among electricity energy suppliers, to provide the electricity consumers more choices, to increase the efficiency of power industry and to improve the social welfare.

Although the reform has brought many benefits, the power system has been forced to run closely near its security margins in many cases [1]. To ensure the required degree of security, Power system operator should be able to manage security problems caused by contingencies through various methods. One is to provide sufficient Ancillary Services. Due to the fact that the penalty of loosing supply in competitive electricity market is very high, utilities are in a position to ensure about their supply reliability and security. Ancillary Services are very important in controlling and therefore supporting the security of power system.

Power system security is referred to, as the ability of a power system to withstand a set of contingencies. The optimal system security is calculated based on pricing incentives as participants contribute to generation and reserve allocation for maximizing their own revenues [2].

Spinning reserve (SR) is a measure of a power systems ability to increase generation under certain contingencies such as loss of generation, line outage or sudden load increase [3]. It is one of the most important ancillary services and is a kind of operating reserve which is synchronized to the system and is able to respond immediately to serve load. Thus it is necessary to pay enough attention to it in management and operation of the market. Therefore establishing an efficient market structure for spinning reserve services has become crucial.

Interruptible loads have also been recognized as one of the ancillary services, particularly, as a contingency reserve service. It has found more important role in competitive system operation, because, the operation margin available to ISO reduces when the competition increases [4].

Load Shedding is defined as the set of controls, which results in a decrease of load in the power system in order to reach a new equilibrium state. Different techniques have been proposed to solve the load shedding problem in either the dynamic or steady state cases [5].

Reducing the price that is paid by consumers can be one of the objectives of introducing electricity markets. However, Consumers have very little influence on the design of these electricity markets. Possibly, as a consequence of this lack of representation, most electricity markets do not treat consumers as a genuine participant capable of making rational decisions but simply as a load that needs to be served under all conditions. Over the last ten years, wholesale electricity markets have become quite sophisticated and have been fairly successful. However, active participation in these markets by the demand-side remains minimal. Retail electricity markets have been much less successful than wholesale markets and rarely give consumers the opportunity to buy electrical energy at spot prices. "Recent experience in California made painfully clear that introducing competition on the supply side while shielding the demand from liberalized prices seriously distorts the market" [6].

This paper investigates the economic dispatch problem under a competitive environment in which load elasticity is considered and spinning reserve and load shedding are known as ancillary services.

II. PROBLEM FORMULATION

The objective is to minimize Generation, Reserve and Load Shedding costs while maximizing consumers' benefits. The objective function can be expressed mathematically as:

$$Min \sum_{i=1}^{G} \alpha_i C_i P_i + \sum_{m=1}^{SH} C_{lsh,m} P_{lsh,m} - \sum_{l=1}^{L} C_{load,l} P_{load,l} + \sum_{i=1}^{G} \beta_i C_{reserve,i} P_{reserve,i}$$

Where variables are defined as follows:

G : Number of generation

SH : Number of load shedding variables in each area (each area consists of one load shedding variable.)

L : Number of loads

α_i : Binary variable denoting selection of a generating unit in electricity market (α_i =1 indicates that generator i participates in electricity market and α_i =0 denotes that generator i does not participates in electricity market.)

C_i : Cost of generator i ($/MW)

P_i : Generation of generator i (MW)

$C_{lsh,m}$: Cost of load interruption in area m ($/MW)

$P_{lsh,m}$: Load shedding in area m (MW)

$C_{load,l}$: Load price of load l ($/MW)

$P_{load,l}$: Load of consumer l (MW)

β_i : Binary variable denoting selection of a unit as a spinning reserve (β_i =1 indicates that generator i participates in reserve market and β_i =0 denotes that generator i does not participates in reserve market.)

$C_{reserve,i}$: Cost of spinning reserve of generator i ($/MW)

$P_{reserve,i}$: Reserve of generator i (MW)

A relation between α_i and β_i has been considered such that:

If α_i =0 then β_i=0 & If α_i =1 then β_i=0 or 1

This means that if a unit does not participate in energy market; it is not allowed to take part in spinning reserve market and if a unit has been accepted in energy market it can (or can not) participate in reserve market based on availability of extra energy.

A. Equality Constraints:

$$\sum_{i=1}^{G} \alpha_i P_i + \sum_{m=1}^{SH} P_{lsh,m} - \sum_{l=1}^{L} P_{load,l} = 0$$

$$\sum_{i=1}^{G} \beta_i P_{reserve,i} = 1800 (about\ 10\%\ of\ Total\ Load)$$

which are generation-load balance and reserve equality constraints, respectively.

B. Inequality Constraints

$$\alpha_i P_i^{\min} \le \alpha_i P_i \le \alpha_i P_i^{\max}$$

$$0 \le P_{lsh,m} \le P_{lsh,m}^{\max}$$

$$0 \le P_{load,l} \le P_{load,l}^{\max}$$

$$-P_{line}^{\max} \le P_{Line} \le P_{line}^{\max}$$

$$\beta_i P_{reserve,i} + \alpha_i P_i \le \alpha_i P_i^{\max}$$

Where:

$P_i^{\min}$: Minimum generation limit of generator i

$P_i^{\max}$: Maximum generation limit of generator i

$P_{lsh,m}^{\max}$: Maximum allowed load shedding in each area which equals the load of that area

$P_{load,l}^{\max}$: Maximum load in each area

P_{Line} : Line flow of each interface

$P_{line}^{\max}$: Maximum Line flow of each interface

III. GENETIC ALGORITHM OPTIMIZATION APPROACH

The introduction of genetic algorithm can be traced back to John Holland's work in 70's [7]. GA is a blind search technique using stochastic operations based on the mechanics of the survival of the fitness. It also works with a population of individuals rather than single point. GA has many advantages over the traditional techniques, such as, fewer mathematical requirements, greater flexibility of implementation, global searching, etc. one of the most useful advantages of GA is that it does not require the problem to be convex or differentiable as many traditional optimization methods do.

Generally GA starts with a set of initial solutions, called the initial population, which is randomly selected from the feasible solution space. Each member of population is called "Chromosome" that represents a possible solution of the objective function. Each

Chromosome evolves to get the final solution through operations such as Elitism, Crossover and Mutation.

A "Fitness Function" is allocated to each Chromosome which represents the objective function of the problem and penalties (Penalties are considered when the constraints are not met). Based on the fitness of each Chromosome of a population two Chromosomes with minimum fitness values are selected and directly represent in the next population (Elitism). In each Population two Chromosomes (parents) are selected randomly (based on fitness values), the children are then generated from the parents in the process of Crossover by complimenting the children at selected bit positions. Mutation is then applied on some of Chromosomes to generate variety of children. The solution is improved through careful choice of population and the number of generations. This should lead to the possibility of convergence to a global optimum [8].

IV. SIMULATION RESULTS

Simulations are carried out using a test system adapted from reference No. 9. It consists of 11 areas and 18 interfaces Fig. 1.

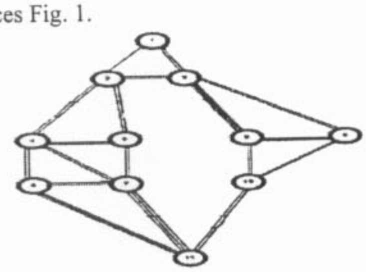

Fig. 1. Test System

Each area contains three generators and one load. Table 1. shows the price of generation and reserve. Each load is divided into two loads; high and low priced loads (90% of area load is high priced and 10% of it is low priced). Table 2. shows load and load shedding prices.

TABLE 1
Generation and Reserve Prices ($/Mw)

area	Generation prices			Reserve prices		
	Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3
1	16.5	19.5	22.5	1.65	1.95	2.25
2	18	20.5	23	1.8	2.05	2.3
3	8	11	14	0.8	1.1	1.4
4	16.5	20	23.5	1.65	2	2.35
5	10	13	15.5	1	1.3	1.55
6	9.5	12.5	15.5	0.95	1.25	1.55
7	10	13.5	15	1	1.35	1.5
8	16	18.5	21	1.6	1.85	2.1
9	14	17	20	1.4	1.7	2
10	10.5	12.5	16	1.05	1.25	1.6
11	17.5	21.5	24	1.75	2.15	2.4

Total generation and load of the network are 22030 MW and 19730 MW respectively. In Tables 3, 4 and 5 each unit's upper and lower generation limits, area loads and flow limit of each interface are shown. Two different cases have been considered in our investigation which are follow:

1) Normal State (No Contingency):

The simulation results for this case are shown in Tables 6, 7 and 8. As it was expected while there is no contingency; the amount of load shedding is Zero.

TABLE 2
Load and Load Shedding Prices ($/Mw)

area	Load Prices		Load Shedding Prices
	High	Low	
1	165	30	495
2	180	30.5	540
3	80	31	240
4	165	31.5	495
5	100	29	300
6	95	29.5	285
7	100	32	300
8	160	34	480
9	140	32.5	420
10	105	33	315
11	175	30	525

TABLE 3
Generation Upper and Lower Limits (Mw)

area	Generation Upperlimit			Generation Lowerlimit		
	Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3
1	637.5	1087.5	1162.5	212.5	362.5	387.5
2	300	350	450	100	116.6	150
3	400	500	600	133.3	166.6	200
4	300	400	500	100	133.3	166.6
5	1032.5	1182.5	1332.5	344.1	394.1	444.1
6	300	400	500	100	133.3	166.6
7	1032.5	1182.5	1332.5	344.1	394.1	444.1
8	400	500	600	133.3	166.6	200
9	1032.5	1182.5	1332.5	344.1	394.1	444.1
10	200	300	400	66.6	100	133.3
11	350	350	400	116.6	116.6	133.3

TABLE 4
Area Loads (Mw)

area	Loads	
	High Priced	Low Priced
1	243.99	27.11
2	2333.4	259.27
3	2729.4	303.27
4	2066.8	229.6
5	243.99	27.11
6	2346.4	260.71
7	513.99	57.11
8	2927.4	325.27
9	513.99	57.11
10	1716.3	190.7
11	2121.3	235.7

TABLE 5
Flow Limits (Mw)

Interface	From	To	Number of Circuits	Flow Limit
1	1	2	1	500
2	1	3	2	800
3	2	3	2	250
4	2	4	2	2000
5	2	5	2	1000
6	3	8	4	1000
7	3	9	2	400
8	4	5	2	2000
9	4	6	2	1000
10	4	7	2	2000
11	5	7	2	1333.33
12	6	7	2	2000
13	6	11	3	1500
14	7	11	3	1200
15	8	10	2	800
16	8	9	3	1000
17	9	10	2	500
18	10	11	2	500

TABLE 6
Generation and Reserve (Mw)

area	Generation			Reserve		
	Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3
1	629.4	1024.1	0	0	137.06	0
2	256.01	343.1	375.11	82.09	0	57.15
3	400	500	438	0	0	47.26
4	0	137.11	496.39	0	258	0
5	1030.15	1167.24	1024.21	0	0	899.06
6	0	400	339.14	0	0	0
7	1032.3	1182.25	1311.21	0	0	0
8	213.21	481.33	0	121.37	0	0
9	0	1023.31	0	0	0	0
10	194.16	256.22	311.2	0	198	0
11	342.21	342.11	376.01	0	0	0

TABLE 7
Load and Load Shedding (Mw)

area	Load		Load Shedding
	High	Low	
1	238.05	22.31	0
2	2329.02	17.03	0
3	2701.03	133.22	0
4	2066.06	5.13	0
5	242.16	11.21	0
6	2345.32	16.11	0
7	513.01	29.06	0
8	874.21	71.24	0
9	23.34	33.26	0
10	1713.22	119.01	0
11	2115.4	7.05	0

TABLE 8
Line Flows (Mw)

Interface	From	To	Number of Circuits	Line Flow
1	1	2	1	-59.34
2	1	3	2	893.69
3	2	3	2	154.47
4	2	4	2	-551.69
5	2	5	2	-1021.96
6	3	8	4	-237.84
7	3	9	2	-210.25
8	4	5	2	-1492.22
9	4	6	2	326.29
10	4	7	2	-823.46
11	5	7	2	445.84
12	6	7	2	-1476.04
13	6	11	3	308.03
14	7	11	3	1130.04
15	8	10	2	-287.78
16	8	9	3	247.03
17	9	10	2	452.68
18	10	11	2	-371.94

2) State with contingency:

In this case the outage of one line of interconnection between area 1 and 3 (1 and 3 interconnection has 2 lines) has been investigated. The results show that for satisfying the line flow limits and reserve limits load shedding has occurred. The results are shown in Tables 9, 10 and 11.

TABLE 9
Generation and Reserve (Mw)

area	Generation			Reserve		
	Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3
1	0	512.01	0	0	1733.41	0
2	255.11	0	0	0	0	0
3	0	0	0	0	0	0
4	0	253.28	0	0	0	0
5	1031.4	1182.3	1150.3	0	0	0
6	0	383.4	347.28	0	0	0
7	1031.3	1181.3	1330.3	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	299.37	0	0	0	0	0
11	0	323.3	398.12	0	26.41	0

TABLE 10
Load and Load Shedding (Mw)

area	Load		Load Shedding
	High	Low	
1	127.07	20.11	0
2	2175.4	256.36	1024
3	23.27	101.3	0
4	2066.2	162.29	0
5	241.41	8.22	0
6	2103.37	39.23	0
7	513.02	6.18	0
8	383.25	12.2	0
9	423.38	23.04	0
10	139.28	36.25	0
11	2121.17	8.12	0

TABLE 11
Line Flows (Mw)

Interface	From	To	Number of Circuits	Line Flow
1	1	2	1	87
2	1	3	2	311.1
3	2	3	2	150.94
4	2	4	2	-261.33
5	2	5	2	-955.2
6	3	8	4	241.32
7	3	9	2	96.14
8	4	5	2	-1649.08
9	4	6	2	296.5
10	4	7	2	-883.95
11	5	7	2	510.09
12	6	7	2	-1476.96
13	6	11	3	361.54
14	7	11	3	1172.98
15	8	10	2	-0.96
16	8	9	3	-153.17
17	9	10	2	-95.25
18	10	11	2	-124.57

V. CONCLUSION

Ancillary service market should be properly investigated and developed. In this Paper, the authors have presented an algorithm for determining Generation, Load, Reserve and Load Shedding simultaneously. It is considered only those units that participate in energy market are allowed to be considered in reserve market. In the proposed market, market participants are required to submit both energy and reserve bids at the same time to ISO.

It is observed that the market competitiveness is enhanced while the social welfare is improved. Furthermore, considering the demand side as a participant of the electricity market will announce more choices for the electricity consumers.

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ISSN 1813-419X