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Optimal generation scheduling strategy for profit maximization of genco in deregulated power system

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Abstract : *A GA based optimal generation scheduling strategy is developed to solve the profit maximization problem for GENCO in the day ahead market. It is a multi objective formulation that includes the forecasted demand, forecasted market clearing price, startup cost and profit functions, besides the generating limits and demand constraints. The proposed GA approach is investigated on three unit and ten unit test systems and numerical results are tabulated. This results shows that this method effectively maximize the GENCO's profit and compared with that of a traditional methods.*

Keywords: *Electricity power market, Generation scheduling, Genetic algorithm, spinning reserve, GENC Profit.*

NOMENCLATURE

PF	Total profit of GENCO's
RV	Total revenue of GENCO's
TC	Total generation cost of GENCO's
P_{it}	Real power output of the i^{th} generator at an hour of t
$P_i(t)$	Real power output of i^{th} Generator
$P_D(t)$	Forecasted system demand during hour t
$P_i^{max}(t)$	Maximum generation limit of i^{th} generator during hour of t
$P_i^{min}(t)$	Minimum generation limit of i^{th} generator during hour of t
SP_t	Forecasted market price at hour of t
T	Number of time Periods considered
N	No of generating units
a_i, b_i, c_i	Cost co-efficient of the i^{th} generator
GENCO	Generation Company
TRANSCO	Transmission Company
DISCO	Distribution Company
ISO	Independent system operator
PX	Power exchange
NGC	National Grid Company
$R_i(t)$	Reserve i^{th} generating unit during hour of t
SR *(t)*	Spinning reserve during hour of t
PM	Proposed Method
U_{it}	Unit status

I. INTRODUCTION

The restructuring of electricity has changed the role of traditional entities in a vertically integrated utility and created new entities that can function independently. The new entities are GENCO, TRANSO, and DISCO. The main objective of the introduction of competition in the electricity supply industry is to increase efficiency in the production and distribution of electricity, providing better choice to market participants, while maintaining the security and reliability of supply. The fundamental idea behind this is the commercial separation of electric energy as a product from its transmission as a service, the ultimate goal being to protect the interest of the consumers [1]. At the same time, the utilities must also be kept in business by ensuring sufficient revenue recovery that would meet their targeted profit levels.

In the paper [2] and [3] the deregulated environment, generation, transmission and retail services are unbundled also provided by a distinct entity. The main entities involved in the provision of transmission services are Independent System Operator (ISO) and Transmission Companies (TRANSCOs). Generating Companies (GENCOs) and Distribution Companies (DISCOS) are the main users of transmission services. Most of the restructured models have wholesale power pools or Power Exchanges (PX) and Scheduling Coordinators (SCs). The electricity market [4] can trade through a centralized market, bilateral contracts, or both. Not only should a competitive electricity market be efficient, meaning that it either operates at or very close to its optimal operating point, it should also be price – driven, therefore requiring the existence of a fair, transparent and open price-setting mechanism. The factors that favor market efficiency include the number of participants and the information exchange mechanisms - in an efficient market, all participants have sufficient information about the prices, supply and demand.

The review is to promote competition by facilitating entry and exit from the electricity market, thus increasing its efficiency and providing greater choice to market participants, while maintaining the operation of a secure and reliable system. Among the principals of the new arrangements are to abandon the current centralized [5] scheduling and pricing mechanisms, to minimize central administration and increase participation from the demand side, and to give market participants the ability to freely negotiate their sales and purchases , based on the level of risk they are able and willing to accept . Trades could be arranged a few years in advance via the use of forwards or futures contracts or through short-term screen –based power exchanges. Participation in the market would be entirely voluntary, with terms negotiated between the parties involved. The settling of trades would be left to the market participants, while the balance of supply and demand would be achieved through a separate balancing mechanism.

A host of solution techniques such as integer programming, dynamic programming, lagrangian relaxation and simulation techniques are available to solve optimal generation scheduling problem [6-8]. Researchers also presented a review on deterministic, meta-heuristic and hybrid approaches of generation scheduling in both regulated and deregulated power markets. All the above methods have their own advantages and also disadvantages. [8-14]

The objective of this paper is to develop a genetic algorithm based optimal generation scheduling and the constrains handled are power balance, unit capacity limits. The method is simple and execution time is less when compared with other conventional methods. The proposed method is applied on two test system to illustrate its performance and the results are presented.

II. PROBLEM FORMULATION

The proposed GA is formulated as an optimization problem that maximizes [14] the GENCO's profit as

$$\text{Maximize } PF = RV - TC \tag{2.1}$$

$$Max\ PF_{it} = \sum_{i=1}^{N} \sum_{t=1}^{T} P_{it}.SP_t.U_{it} - (C_{it}(P_{it}) + ST_{it})U_{it} \tag{2.2}$$

where, $i = 1, 2 \ldots N$ & $t = 1, 2 \ldots. T$

The equation (2.2) represents the GENCO's profit, which is the difference between the revenue (based on the forecasted market price of electricity) and the cost of power generation. The total cost $F_i(P_i(t))$ includes the start-up, shut-down and operating costs of a unit. However, we could also present the startup cost as a function of cost (dollars) instead of fuel.

$$C_{it}(P_{it}) = a_i P_i^2 + b_i P_i + c_i \quad \$/h \tag{2.3}$$

a_i, b_i, c_i are the i^{th} GENCO's cost parameters which are included in the GENCO's offer parameters. The objective is to maximize profit while satisfying the constraints on the demand, Generating unit limits and unit output and ramp up or down time of unit.

Subject to constraints…

(i) GENCO's demand constraint

$$\sum_{t=1}^{N} P_i(t)\ U_{it} \le P_D(t) \tag{2.4}$$

This inequality constraint shows that the total power generated by a GENCO should be less than or equal to the forecasted system demand. It is to be emphasized that a GENCO is not responsible for supplying the system demand which is the ISO's responsibility. A GENCO will supply a portion of the demand that maximizes its profit which will be determined by the optimization problem.

(ii) Generating Unit Limits

$$P_i^{min}(t) \le Pi(t) \le P_i^{max}(t) \tag{2.5}$$

The power generated for each unit must be within a certain range represented by its minimum power output (P_i^{min}) and its capacity (P_i^{max}).

(iii) Spinning reserve

To ensure that the power system can recover from an unplanned contingency, a pre-specified amount of operating reserves for the system needs to be maintained. This system operating requirement is then converted into corresponding individual contributions from each of the generators supplying energy to a given power system. The relationship of the MW output of a generating unit to its operating-reserve obligation can be represented in the following manner.

$$\sum_{i=1}^{N} R_i(t)U_{it} \leq SR(t) \tag{2.6}$$

III. SOLUTION METHODOLOGY

Genetic Algorithm

Genetic Algorithm (GA) is an optimization technique based on the Natural evolution process. They are a very general algorithm [15] and so will work well in any search space. A first step of GA is the creation of initial population and the size is determined by experimentation. The second step is that of Evaluation wherein the variables are read and decoded and function values are evaluated. The third step is Reproduction where in the weaker members are replaced by stronger based on fitness values. Crossover is performed in the fourth step to produce offspring's. Mutation is performed in the fifth step so that parent selection and cross over operations do not lead to identical individuals.

In this study, the value of the objective functions (profit) is used to designate the fitness function. To evaluate the total profit of a GA string the optimal value of loading for each committed GENCO needs to be determined by solving different (one at each hour) power calculation sub-problems whereby we try to maximize the profit for the particular string. This is based on the feasible and operating range of the control variables. The first population is randomly initialized. Here population size is 20; initially many individual solutions are randomly generated to form an initial population. The population size depends on the nature of the problem, but typically contains several hundreds or thousands of possible solutions. Traditionally, the population is generated randomly, covering the entire range of possible solutions (the *search space*). Occasionally, the solutions may be "seeded" in areas where optimal solutions are likely to be found. Reproduction is the process in which individuals are copied according to their profit function.

In simple GA, strings are selected in the mating pool by Simple Roulette wheel selection. The following two schemes are applied for the selection of parents so that the string with large values of fitness is copied more into the mating pool. Besides standard single point crossover, another crossover operation has been used in this work. According to this scheme; one randomly chosen GENCO in one population is exchanged with the status of same unit in other population. Crossover operator creates new chromosomes from randomly selected chromosomes from mating pool. The crossover operator is carried out according to a rate of crossover. In this study crossover rate is defined as 0.8 and the type of crossover is scattered. Our approach is as follow: Two chromosomes are selected from mating pool as parents, randomly. A number is selected from interval (0, 1) randomly and uniformly. If random number is less than crossover rate then crossover operator create two new chromosomes as child from parents, else parents will be copied in child chromosomes cell by cell. After selection and crossover, you now have a new population full of individuals. Some are directly copied, and others are produced by crossover. In order to ensure that the individuals are not all exactly the same, you allow for a small chance of mutation. You loop through all the alleles of all the individuals, and if that allele is selected for mutation, you can either change it by a small amount or replace it with a new value. The probability of mutation is usually between 1 and 2 tenths of a percent. A visual for mutation is shown below. As you can easily see, mutation is fairly simple. You just change the selected alleles based on what you feel is necessary and move on. Mutation is, however, vital to ensuring genetic diversity within the population. In mutation operator is used to form the new strings. So it must return to first step for fitness calculation. Mutation rate is considered as 0.2 and the type is Gaussian.

IV. SIMULATION AND RESULTS

The proposed methodology is tested to evaluate its accuracy on 3 unit 12 hour system and 10 unit 24 hour system [9] using MATLAB. The unit data for 3 unit 12 hour system, 10 unit 24 hour system and forecasted demand and spot price for these system are given in tables I, II, V and VI. Initial status in these tables indicates the status of generator of concerned unit before starting the scheduling hour. GA parameters setting are shown in table III.

Case 1; In this case, three generating units system is considered. The results obtained by the proposed method are compared with the results of conventional method. The solution of the PM for the 3 unit 12 hour system including the Revenue, Total generation cost, and PM profit are given in the table IV. The graphical representation of fuel costs, revenue costs and profits of three unit system are shown fig - 2

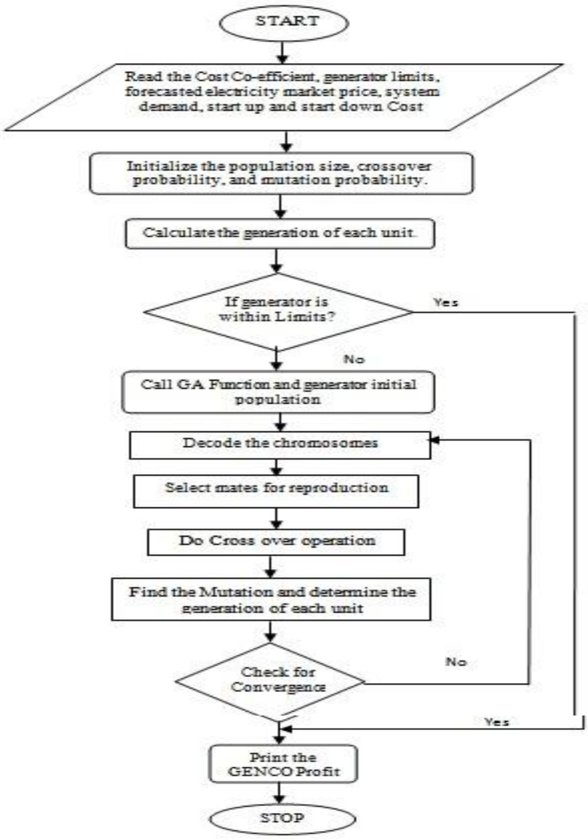

Fig-1 Flow chart of the proposed method

V. UNIT DATA FOR THREE UNIT SYSTEM

TABLE-I

	Unit 1	Unit 2	Unit 3
P_{max} (MW)	600	400	200
P_{min} (MW)	100	100	50
a ($/h)	500	300	100
b ($/MWh)	10	8	6
c ($/MW^{2}h)	0.002	0.0025	0.005
Min Up time (h)	3	3	3
Min down time (h)	3	3	3
Startup cost ($)	450	400	300
Initial status (h)	-3	3	3

FORECASTED DEMAND AND SPOT PRICE FOR THREE UNIT 12 HOUR SYSTEM

TABLE-II

Hour (h)	Forcased demand (MV)	Forecasted Market Price ($/MWh)	Forecasted Reserve (MW)
1	170	10.55	20
2	250	10.35	25
3	400	9.00	40
4	520	9.45	55
5	700	10.00	70
6	1050	11.25	95
7	1100	11.30	100
8	800	10.65	80
9	650	10.35	65

10	330	11.20	35
11	400	10.75	40
12	550	10.60	55

GA PARAMETERS SETTING
TABLE-III

Population size	20
Crossover Probability	0.80
Mutation probability	0.2
Elitism	2
No. of Generations	500

SIMULATION RESULTS FOR THREE UNIT 12 HOUR SYSTEM
TABLE- IV

Hour (h)	Power Demand (MW)	Revenue ($/MWh)	Total generation cost ($/h)	Profit ($)	
				Conventional method	Proposed method
1	170	2635.55	2064.50	126.5	540.00
2	250	3225.00	2706.25	352.9	520.00
3	400	4945.55	4145.50	103.6	320.00
4	720	5558.65	5257.10	303.1	394.00
5	700	7441.12	7000.00	-363.2	206.00
6	1050	11812.50	10805.00	1017.8	1352.00
7	1100	12430.50	11400.00	1040.9	1385.00
8	800	8506.20	7987.20	548.4	986.00
9	650	7082.12	6429.90	308.1	812.00
10	330	3696.00	3182.25	91.1	815.00
11	400	4303.64	3849.40	159.7	802.00
12	550	5832.48	5035.50	359.9	925.00
			Total profit	**4048.80**	**9057.00**

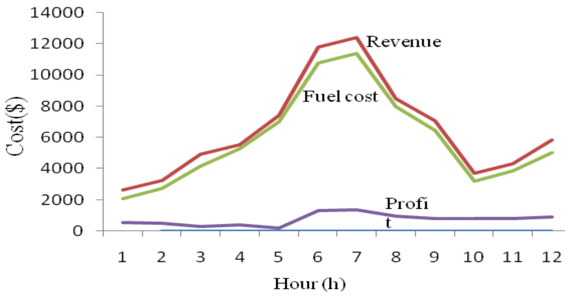

Fig -2 Revenue, Fuel cost and profit for the Three unit 12 hour system

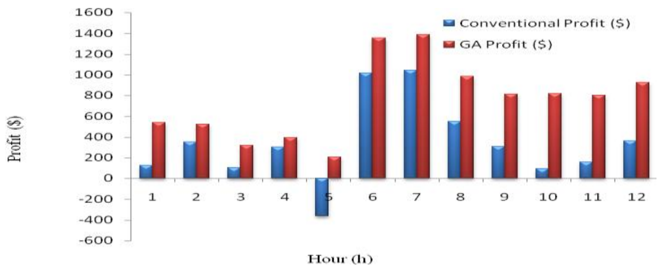

Fig -3 Comparison of profits with proposed and conventional method for three unit 12 hour system

Case 2; In this case, 10 units, 24 hour system is considered. The results obtained by the proposed method are compared with the results of conventional method. The solution of the PM for the 10 units 24 hour system including the Revenue, Total generation cost, and PM profit are given in the table VII. The graphical representation of fuel costs, revenue costs and profits of ten unit 24 hour system are shown fig-4.

Unit Data For Ten Unit System
Table-V

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
P_{max}	455	455	130	130	162
P_{min}	150	150	20	20	25
a	0.00048	0.00031	0.20200	0.00211	0.00398
b	16.19	17.26	16.60	16.50	19.70
c	1000	970	700	680	450
Min up	8	8	5	5	6
Min down	8	8	5	5	6
ST	4500	5000	550	560	900
Initial	8	8	-5	-5	-6
	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
P_{max}	80	85	55	55	55
P_{min}	20	25	10	10	10
A	0.20712	0.00079	0.20413	0.00222	0.00173
B	22.26	27.74	25.92	27.27	27.79
C	370	480	660	665	670
Min up	3	3	1	1	1
Min down	3	3	1	1	1
ST	170	260	30	30	30
Initial	-3	-3	-1	-1	-1

Forecasted Demand And Spot Price For Ten Unit 24 Hour System
Table-Vi

Hour (h)	Forecasted Demand (MW)	Forecasted Reserve (MW)	Forecasted Market price ($/MWh)
1	700	70	22.15
2	750	75	22.00
3	850	85	23.10
4	950	95	23.65
5	1000	100	22.25
6	1100	110	22.95
7	1150	115	22.50
8	1200	120	22.15
9	1300	130	22.80
10	1400	140	29.35
11	1450	145	30.15
12	1500	150	31.65
13	1400	140	24.60
14	1300	130	24.50
15	1200	120	22.50
16	1050	105	22.30
17	1000	100	22.25
18	1100	110	22.05
19	1200	120	22.20
20	1400	140	22.65
21	1300	130	23.10
22	1100	110	22.95
23	900	90	22.75
24	800	80	22.55

SIMULATION RESULTS FOR TEN UNIT 24 HOUR SYSTEM

TABLE – VII

Hour (h)	Power Demand (MW)	Revenue ($/MWh)	Fuel cost ($/h)	Profit ($)	
				Conventional method	Proposed method
1	700	15520.505	13695	1822	1825.50
2	750	16516.50	14568	1946	1948.50
3	850	19654.63	16317	3333	3337.63
4	950	22489.96	18617	1647	3872.97
5	1000	22272.25	19629	629	2643.25
6	1100	25270.24	22261	697	1150.24
7	1150	25900.87	23098	3120	2802.87
8	1200	26606.58	23946	-34	2660.58
9	1300	29669.64	26273	3456	2396.64
10	1400	41131.09	28791	11982	12340.09
11	1450	43761.21	30624	11813	13137.21
12	1500	47522.47	32668	13658	15954.47
13	1400	34474.44	28801	5672	5693.44
14	1300	31881.85	26328	5666	5753.85
15	1200	27027.00	23946	2175	3181.00
16	1050	23438.41	20661	2410	2577.41
17	1000	22272.25	16629	-3334	873.25
18	1100	24279.25	22261	2376	2418.25
19	1200	26666.64	23964	2868	2902.64
20	1400	31741.71	28801	-5375	3240.71
21	1300	30060.03	26328	-241	3932.03
22	1100	25270.24	22261	2897	3009.24
23	900	20495.47	17194	3297	3301.47
24	800	18058.04	15441	2613	2717.04
			Total Profit	**75093**	**104670.33**

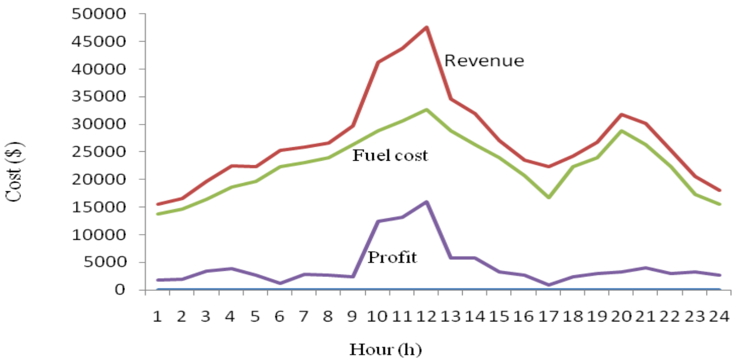

Fig-4 Revenue, Fuel cost and profit for the Ten unit 24 hour system

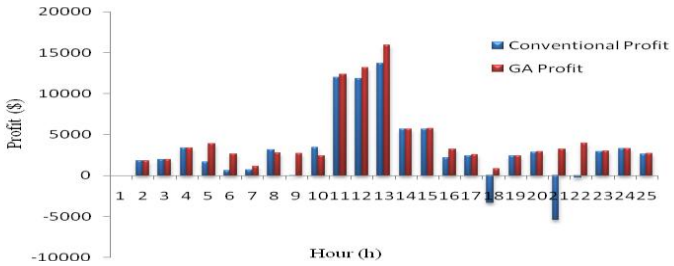

Fig-5 Comparison of profits with proposed and conventional method for ten unit 24 hour system

VI. Conclusions

The genetic algorithm has been applied to solve the Gencos profit maximization problem by considering the constraints such as generating limits and Gencos demand in the day ahead market. A multi objective profit maximization problem has been proposed based on some assumptions such as forecasted load and forecasted Market Clearing Price (MCP). Two different size systems are used to demonstrate the effectiveness of the proposed GA approach for GENCOs. The simulation results have been compared with the results obtained from conventional method to highlight the superiority of the proposed approach.

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