A Genetic Algorithm Approach to Price-Based Unit Commitment

Jignesh Solanki, *Student Member, IEEE*, Sarika Khushalani, *Student Member, IEEE* and Anurag Srivastava, *Member, IEEE*

Abstract **– Deregulation creates competition amongst generator companies. The generator company objectives are to maximize their profit and to place proper bids in the market. In order to do this they need to determine the schedule and operating points based on the load and price forecasts. The traditional unit commitment problem aims at minimizing the cost of operation subject to fulfillment of demand. However in a deregulated environment the traditional unit commitment objective needs to be changed to maximization of profit with relaxation of the demand fulfillment constraint. This paper applies a genetic algorithm technique to price based unit commitment (PBUC) for GENCO with 3 generators and compares the solution with that obtained by dynamic programming. Proposed algorithm can be extended to 'n' number of generators.**

Index Terms **- Price based unit commitment, genetic algorithm, deregulation, dynamic programming.**

I. Introduction

DEREGULATION is the unbundling of vertically integrated power system into generation, transmission and distribution companies. The basic aim of deregulation is to create competition among generating companies (GENCOs) and provide choice to consumers at cheaper price. Deregulation also challenges the existing solutions to technical problems of electric power systems. The interest of GENCOS is in maximizing their profit unlike the vertically integrated systems where the objective was to minimize the operation cost. This leads to change in strategies. One of the problems that need a new strategy is the Unit Commitment (UC) problem. The UC involves economically scheduling the ON/OFF status of the generators and the outputs to meet the forecasted load. Since the objective of GENCOS is the maximization of their profit, the problem needs to be termed differently as price-based unit commitment (PBUC). There are different type of markets, such as real time market, hour-ahead market, day ahead market and the GENCO places bids depending on the price forecast, load forecast, unit characteristics and unit availability in different markets. In order to achieve this they have to conduct PBUC with relaxation of demand constraints. The PBUC is a large-scale combinatorial problem involving several binary variables. Combinatorial problems are hard to solve due to large number of variables.

Several approaches have been used to solve the UC problem viz. Linear Programming, Non-Linear Programming, Dynamic Programming, Evolutionary Techniques and other Meta-Heuristics [1-5]. The PBUC problem has been approached using Lagrangian Relaxation and Dynamic Programming [6]. Li and Shahidehpour [7] presented tradeoff between Lagrangian Relaxations (LR) and MIP to solve PBUC problem. Hybrid LR and evolutionary programming have been used for PBUC in [8]. Dynamic Programming suffers the curse of dimensionality with increase in number of GENCOS or the hours. Enumeration of each and every state is nearly impossible within a reasonable time. Priority lists have also been used to simplify the process but may not end up with even near-optimal solution [9]. Application of intelligent application like multi agent, particle swarms and genetic algorithm (GA) for PBUC appears in [10-13]. None of these papers have considered optimizing the MW quantity of energy and ancillary service to get more profit with unit commitment problem.

This paper presents a Genetic Algorithm approach to PBUC. Since PBUC is formulated as a stochastic problem it would be appropriate to use GA. It is assumed that price is forecasted for a particular load forecast and available as this is out of the scope of this paper. The problem is a mixed integer problem with N sub problems, where N is the number of generators for which PBUC is being solved. Profit will be maximized for selling not only the energy but also spinning and non-spinning reserve. Energy and ancillary services are optimized simultaneously, and the PBUC results provide a portfolio of energy and ancillary services bids. These results are used for exploring arbitrage opportunities between energy and ancillary services. Arbitrage refers to making profit by a simultaneous purchase and sale of the same or equivalent commodity with net zero investment and without any risk. Section 2 gives the problem statement, section 3 gives the overview of GA and section 4 gives details of simulation results for the application of GA to 3 generators for PBUC with 4 hours.

II. Problem Formulation

Mathematically the problem can be formulated as objective function subject to several constraints [14]. The profit

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maximization is formulated as minimization function. For initial work the minimum on time, off time constraints and start up costs have been ignored.

Objective function can be defined as:

$$\min \sum_{i=1}^{i=nhrs} \left\{\left(-RP_i^j * P_i^j - RR_i^j * R_i^j - RN_i^j * N_i^j\right) + C\left(P_i^j + R_i^j + N_i^j\right)\right\} * I_i^j + \left\{\left(-RN_i^j * N_i^j\right) + C\left(N_i^j\right)\right\} * (1 - I_i^j)$$

Subject to following constraints:

Unit ON

$$N^j - \min(R_{\max}^j, P_{\max}^j - P^j - R^j) \leq 0$$

$$P_{\min}^j \leq P^j \leq P_{\max}^j$$

$$R_{\min}^j \leq R^j \leq R_{\max}^j$$

$$P_{\min}^j \leq P^j + R^j + N^j \leq P_{\max}^j$$

Unit OFF

$$P^j = 0$$

$$R^j = 0$$

$$N_{\min}^j \leq N^j \leq N_{\max}^j$$

Where j $\in$ set of generators for GENCOs. *RP, RR* and *RN* are the forecasted prices for energy, spin and non-spin and *R, P* and *N* are the MW values. *I* is the binary variable to define the state of generator. $R_{\max}^j$ is the maximum spin unit *j* can provide within 10 minutes of ramping. $N_{\max}^j$ is the quick start capability of the generator. C is the cost of generation defined as:

C = Heat Rate Curve * Fuel Cost

$$= \left(a + b * (P + R + N) + c * (P + R + N)^2\right) * FuelCost$$

Where a, b and c are the cost coefficients. The objective has three continuous variables namely energy, spin and non-spin and one binary variable that is the ON/OFF status of the generator.

III. Genetic Algorithm

Genetic Algorithm (GA) is an optimization technique based on the natural evolution process. GA represents each variable as a binary number of m bits. 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 offsprings. Mutation is performed in the fifth step so that parent selection and cross over operations do not lead to identical individuals. The PBUC was solved using the GA toolbox from MATLAB® [15]. Different parameters related to genetic algorithm application in PBUC have been described here.

Population Size - is the number of individuals in each generation. A large population size has higher chances of finding global optimum but leads to longer convergence time. The population size in MATLAB was selected as 120 and the variables in the fitness functions were 4 so a 120-by-4 matrix did the representation of population.

Selection- is used to choose parents for the next generation. Stochastic uniform selection was used.

Reproduction- is used to specify how to create children for the next generation. MATLAB uses elite count and crossover fraction.

Mutation- is used to specify small random changes in population to create mutation children. Gaussian mutation where in a random number is taken to each entry in the parent vector is used.

Crossover- is used to specify how the combination of two parents is performed to form a crossover child. Scattered crossover function was selected.

Penalty Factor- Initial penalty is 10 and is incremented by 100 if accuracy is not met and constraints are not satisfied.

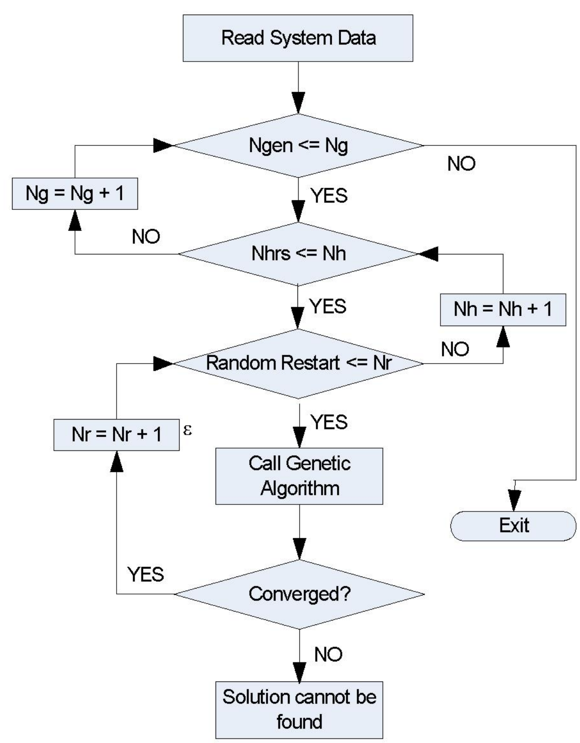

Fig.1 Flow Chart of Program Execution

GA terminated with sub optimal solutions initially. So random restarts were done to generate initial population and the optimal solution was obtained. Dynamic Programming was also used to check the validity of the formulation. The solutions matched with those obtained using dynamic programming. A flow of the developed code in GA is as shown in fig. 1 and the steps are:

1. Read Ng (Number of Generator), Nh (Number of Hours) and Nr (Number of random restarts) along with heat rate coefficients, fuel cost, ramp rate, quick start capability, P_{min} and P_{max}.
2. Options are specified for the GA – (a) Mutation Function – Mutationadaptfeasible (b) Stall Time – 1000 Secs (c) Population – 120 (d) Initial Population – Generated by random restarts.
3. Genetic algorithm is called by specifying fitness function, number of variables, lower bound and upper bound on variables, constraints and options as in step-2.
4. The stopping criterion for GA is – (a) Number of Generations exceeded (100) (b) Stall Generations exceeded (50) (c) Stall time limit reached (1000) (d) Function tolerance met (1e-6) (e) Constraints tolerance met. Stall generations
5. Steps 1 to 4 are repeated for all Ng and for all Nh hours.

Five random restarts are considered. A structure was utilized for storage of states and objective with size hours×random restarts×number of generators. Fig. 2 gives visualization for dimensions of state matrix and fitness matrix.

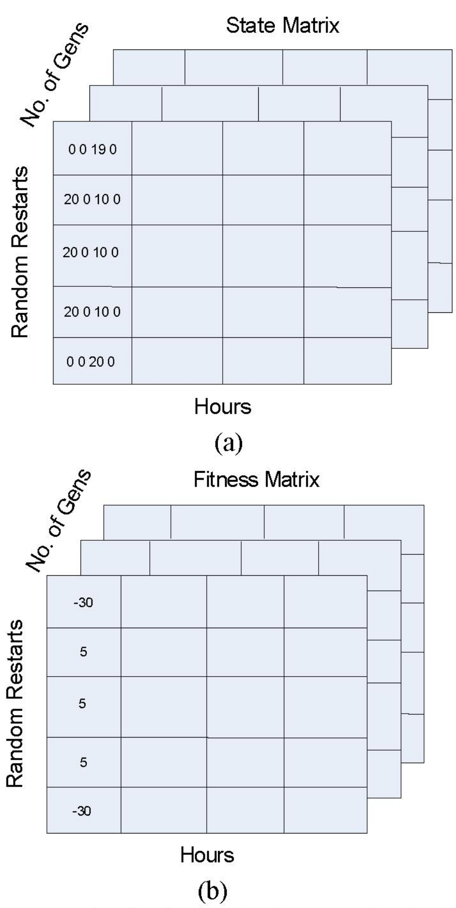

Fig.2 (a) State Matrix Visualization (b) Fitness Matrix Visualization

IV. Simulation Results

The developed formulation was used to test the PBUC for three generators for four hours. The fuel prices, cost curve values and forecasted prices at each hour is taken as given in tables 1-3 and needed for input to developed GA tool.

TABLE I
FUEL PRICE

Generator	Fuel Price ($/Mbtu)
I	2
II	2
III	2.5

TABLE II
HEAT RATE CURVE

Generator	Heat Rate Curve (Coefficients)		
	a	b	c
I	400	8	0.01
II	25	10	0.025
III	25	10	0.02

TABLE III
FORECASTED PRICE

Hour	Energy Price ($/MWh)	Spin Price ($/MWh)	Non-spin Price ($/MWh)
1	20	22	21
2	25	28	27
3	30	34	33
4	22	24	25

Developed PBUC tool based on GA determines the ON/OFF status of each generator as shown in table 4. Table 5 shows the MW values of generation, spin and non-spin as obtained by GA. For generator I as seen from table 4 the optimum is to remain off in the first hour, on with P=180 MW and R=20 MW in the second hour, on with P=180 MW and R=20 MW in the third hour and off in fourth hour. Optimal unit commitment and MW values for other generators can be observed from the table 4 and 5.

A comparison of profits and costs obtained by dynamic programming and that obtained by GA is shown in table 6. It is clear that the solutions obtained by both methds are the same for this test case.

TABLE IV
STATUS OF GENERATORS

Gen	I				II				III			
Hrs	1	2	3	4	1	2	3	4	1	2	3	4
On(1)/Off(0)	0	1	1	0	0	1	1	0	0	0	1	0

A plot of the results for hour 3 and generators I-III is shown in figs. 3-5. These figures illustrate the improvement in fitness value, the optimal value of states and the generations required for the solution. It is observed that the best fitness function value and mean fitness function value are same for generator 1, 2 and 3 at hour 3. Current best individual shows the vector entries with best fitness function values of energy, spin, non-spin and ON/OFF status. No scaling is applied to the problem. Since there is improvement in function values there is no stall time. For the first generator for some generations there is no further improvement in fitness function, which is shown as stall generation. Also shown are the numbers of generations needed for best fitness function value.

Results show successful application of genetic algorithm to PBUC problem. Developed tool can be applied to ‘n’ number of generators and can overcome the problem of dimensions faced by dynamic programming.

TABLE V
GENERATION ALLOCATION AND PROFIT

Gen	Hrs	P (Energy)	R (Reserve)	N (Non-Spin)	Profit
I	1	0	0	0	0
	2	180	20	0	260
	3	180	20	0	1280
	4	0	0	0	0
II	1	0	0	0	0
	2	40	10	0	105
	3	90	10	0	490
	4	0	0	20	30
III	1	0	0	0	0
	2	0	0	0	0
	3	40	10	0	102.5
	4	0	0	0	0

TABLE VI.
COMPARISON OF PROFITS AND COSTS

	Genetic Algorithm			Dynamic Programming		
Gen	Gen I	Gen II	Gen III	Gen I	Gen II	Gen III
Profit	1540	625	102.5	1540	625	102.5
Cost	9600	4195	1437.5	9600	4195	1437.5

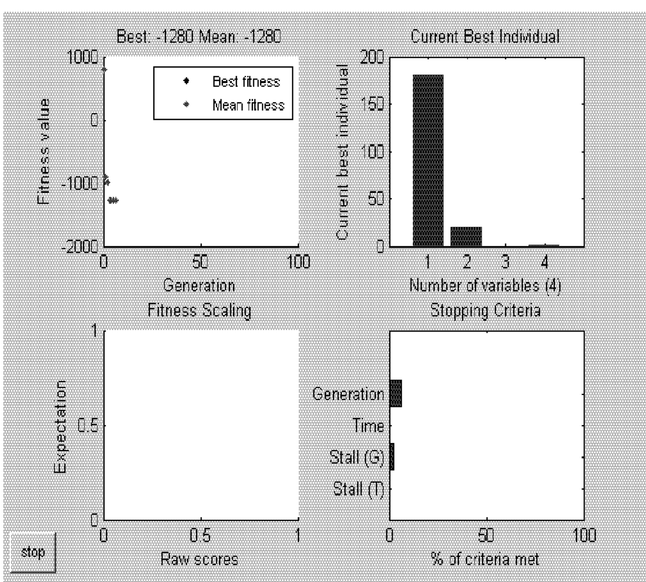

Fig. 3 Fitness Value, States, Generation of Generator 1 at Hour 3

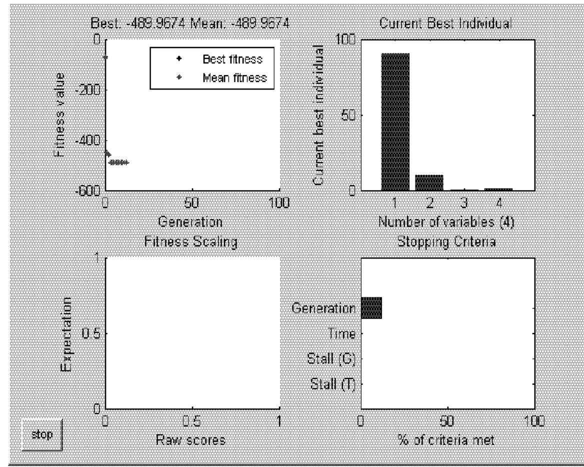

Fig. 4 Fitness Value, States, Generation of Generator 2 at Hour 3

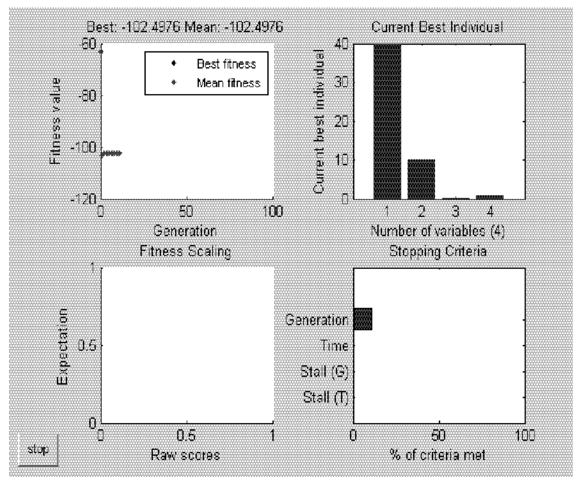

Fig. 5 Fitness Value, States, Generation of Generator 3 at Hour 3

V. Conclusion

Genetic algorithm application to price based unit commitment problem has been presented here and has been implemented for small 3-generator GENCO. Developed algorithms provide optimal unit commitment and also optimal MW values for energy, spinning reserve and non-spin. Proposed algorithm can be applied to ‘n’ generators system. Presented algorithm and analysis could be beneficial to GENCO with big number of generators to maximize the profit and bid in competitive electricity market.

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