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A HYBRID GENETIC ALGORITHM BASED LAGRANGIAN RELAXATION APPROACH FOR PROFIT BASED UNIT COMMITMENT PROBLEM

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ABSTRACT

In this paper an application of a combined method for the profit based unit commitment problem (PBUC) using Genetic Algorithm and Lagrangian Relaxation (LR) is presented. The algorithm is proposed to solve PBUC under deregulated environment with the objective of maximizing GENCO's profit and minimizing the operating cost. The problem formulation of the unit commitment takes into consideration the minimum up and down time constraints, start-up cost, and spinning reserve. UC schedule depends on the market price in the deregulated market. However demand satisfaction is not an obligation. GENCO can consider a schedule that produce less than the predicted load demand and reserve but creates maximum profit. The LR procedure solves the UC problem by dual optimization. The Genetic Algorithm (GA) develops the optimal schedule and Lagrangian Relaxation method produces Economic Dispatch. The proposed hybrid approach improves the performance of solving the Unit Commitment problem. The resultant schedule maximizes the profit and the proposed algorithm is tested for a 10 unit system taken as an individual GENCO and the simulations are carried out using MATLAB.

Keywords: deregulation, economic dispatch, GENCO, genetic algorithm, lagrangian relaxation, market price, profit based unit commitment (PBUC).

INTRODUCTION

Unit Commitment (UC) involves scheduling the on/off status of generating units of the thermal power plants. Economic dispatch is a sub problem of unit commitment which involves the scheduling the real power outputs of units of the power plants. The UC problem has been formulated as a non-linear, large scale, mixed-integer combinational problem with constraints [1]. There are many solution techniques stated in literature to solve to solve the unit commitment problem [2]. As the electrical industry restructures, many of the traditional algorithms for controlling generating units need modification or replacement. In the restructured environment, generation companies (GENCOS) schedule their generators with objective to maximize their own profit with the relaxation of demand fulfilment constraint. This is known to be the profit based unit commitment problem. UC under deregulated environment is more complex and more competitive than traditional one. There are many solution techniques to solve the PBUC problem [3]. Various numerical optimization techniques are found in the literature [4]-[5]. Solution methods like Dynamic Programming, Lagrangian Relaxation, Fuzzy, Neural Networks, Simulated Annealing and Genetic Algorithms are used to solve PBUC. In this paper, Hybrid Genetic Algorithm and Lagrangian Relaxation methods are proposed to satisfy the objective function. The basic idea of this approach is that Genetic Algorithm is applied to obtain UC schedule and Lagrangian Relaxation method is used in finding the economic dispatch. A description of this method is presented in section II. Derived from the biological model of evolution genetic algorithms are based on the Darwinian principle of natural selection [6]. It is one of the optimization techniques in solving complex optimization problems of unit commitment in electric power systems [7]-[10]. The application of Genetic Algorithm to PBUC is also reported and is found to evolve bidding strategies that maximize profit for the spot market. A profit based GA for the competitive environment provides the information to identify the schedules which provides maximum flexibility for a given level of profit. The LR procedure solves the PBUC problem by temporarily ignoring or "relaxing" the coupling constraints and solving the problem as if they did not exist. This is done by dual optimization theory, which generates a separable problem by integrating coupling constraints into objective function. Lagrangian Relaxation method is dependent on the initial status of the Lagrangian multipliers and lagrangian multipliers are to be updated. The LR procedure solves the UC problem by temporarily ignoring or "relaxing" the coupling constraints and solving the problem as if they did not exist. This is done by dual optimization theory, which generates a separable problem by integrating coupling constraints into objective function. This Lagrangian Relaxation method is dependent on the initial status of the Lagrangian multipliers and the method used to update multipliers. Several LR based approach for solving unit commitment problem in deregulated industry is proposed in the literature [11]-[15].

This paper incorporates Genetic Algorithm into Lagrangian Relaxation method in order to improve the performance of LR method in solving UC problems. This method involves two stages. First stage involves the generation of Unit Commitment schedule by genetic

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algorithm and the second is to determine Economic Dispatch.

PROBLEM FORMULATION

Unit commitment problem

The objective of the UC problem is to minimize the total operating cost subjected to a set of system and unit constraints over the scheduling horizon. The fuel cost for the unit i at any given time interval is assumed as a quadratic function of the generator power output, p_i at that time the objective function is

$$\text{Min } TFC = \left[\sum_{t=1}^{T}\sum_{i=1}^{n}\left(a_i + b_i P_{it} + c_i P_{it}^{\ 2}\right)\right] + SUC \quad (1)$$

- Subject to system constraints

(a) Unit initial conditions

First hour schedule is based on the unit initial status

(b) Unit status restrictions

Certain units under all load conditions are assigned with the must run status.

(c) $$\sum_{i=1}^{n} P_{it} = PD_t \quad (2)$$

is the power balance constraint

(d) $$\sum_{i=1}^{n} P_i^{\max} \geq PD_t + R_{it} \quad (3)$$

is the reserve constraint

- Subject to local constraints

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

(f) Minimum Up and Minimum Down time constraints indicate that a unit must be ON/OFF for a certain number of hours before it can be committed or decommitted.

$$T_{it}^{ON} \geq T_i^{UP} \quad (5)$$

$$T_{it}^{OFF} \geq T_i^{DOWN} \quad (6)$$

(g) Start up Cost (SUC)

$$SUC_{it} = \begin{cases} \text{hot startup cost, if downtime} \leq \text{coldstart hours} \\ \text{cold startup cost, otherwise} \end{cases} \quad (7)$$

With an assumption that the shut-down cost is zero, the total operating cost for the scheduling period T is the sum of fuel costs and start-up costs for n units.

Profit based unit commitment problem

Profit Based Unit Commitment problem in deregulated power system determines the generating unit schedules for maximizing the profit of GENCO's in addition to cost minimization. The PBUC problem can be mathematically formulated by the following equations.

$$\max PF = RV - TC \quad (8)$$

$$RV = \sum_{i=1}^{N}\sum_{t=1}^{T}(P_{it}.SP_t)U_{it} \quad (9)$$

$$TC = \sum_{i=1}^{N} \sum_{t=1}^{T} C_{it}(P_{it}) + S_{it})P_{it} \quad (10)$$

Subjected to the following constraints

Demand constraint

$$\sum_{i=1}^{N} P_{it}U_{it} \leq PD_t \text{ for t=1 to T} \quad (11)$$

Reserve constraint

$$\sum_{i=1}^{N} R_{it}U_{it} \leq SR_t \text{ for t=1 to T} \quad (12)$$

Power balance constraint

$$P_i^{min} \leq P_i \leq P_i^{max} \text{ for i=1 to N} \quad (13)$$

Minimum up/down time constraints

Minimum Up and Minimum Down time constraints indicate that a unit must be ON/OFF for a certain number of hours before it can be committed or decommitted.

Where

TFC	= Total Fuel Cost
a_i, b_i, c_i	= Cost coefficients
t	= Time Interval (1 to 24 hrs)
n	= Number of generating units
PF	= Profit of the GENCO
RV	= Revenue
TC	= Total Operating Cost
P_{it}	= Power Generation of i^{th} unit at time t
SP_t	= Spot Price at hour t
U_{it}	= Unit ON/OFF status of unit i at hour t
$C_{it}(P_{it})$	= Cost of power generation of unit i at hour t

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S_{it} = Startup cost f Unit i
PD_t = Power Demand at time t
R_{it} = Reserve generation of unit i at time t
SR_t = Forecasted reserve at time t
P_i^{min} = Min limit of power generation of unit i
P_i^{max} = Max limit of power generation of unit i
T_{it}^{ON} = ON time of unit i at time t
T_{it}^{OFF} = OFF time of unit i at time t
T_i^{UP} = Minimum ON time of unit i
T_i^{DOWN} = Minimum OFF time of unit i

GENETIC ALGORITHMS AND LAGRANGIAN RELAXATION

Genetic algorithm

Derived from the biological model of evolution, genetic algorithms (GA's) operate on the Darwinian principle of natural selection. A population of data structures appropriate for the optimization problem is "randomly" initialized. Each of these candidate solutions is termed an individual or a creature. Each creature is assigned a fitness, which is simply a heuristic measure of its quality. Then during the evolutionary process, those creatures that have a higher fitness are favored and allowed to procreate. During each generation of the evolutionary process, creatures are randomly selected for reproduction with some bias toward higher fitness. After parents are selected for reproduction, they produce children via the processes of crossover and mutation. The creatures formed during reproduction explore different areas of the solution space than did the parents. These new creatures replace lesser fit creatures of the existing population.

The basic algorithm can be written as follows:

a) Randomly initialize a population and set the generation counter to zero
b) Randomly generate additional populations and increase generation counter
c) Calculate the fitness of each member of the population.
d) Select parents using some fitness bias.
e) Crossover the parents to create candidate offspring.
f) Mutate these new offspring.
g) Replace the lesser fit members with the offspring.
h) Increment the generation counter and go to step 5.

The crossover operator recombines the extremely important features of two chromosome to make the offspring chromosome not only inherit some important characteristics from their parent chromosomes but also have the chance to get closer to the optimal solution. In the LRGA, we adopt a new crossover technique known as "uniform crossover" which exchanges bits between the parent chromosomes to create two new offspring chromosomes by a randomly generated mask. The scheme of "uniform crossover" is shown in Figure-1. In the random mask, the "1" represents bit swapping and "0" denotes bit unchanged. The mutation operator allows us to create new chromosome in the population and provides background variation depending on a mutation probability. The scheme of mutation operator is shown in Figure-2.

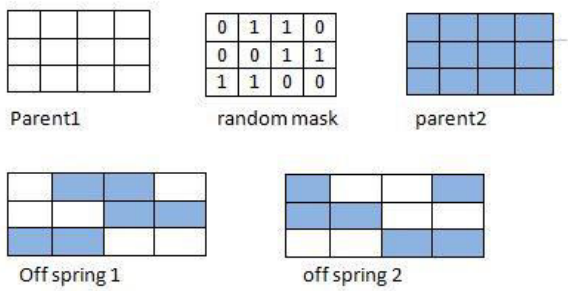

Fig. 1. Uniform cross over operation.

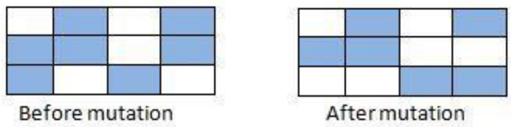

Fig. 2. Mutation operator

Following the crossover process, the offsprings are mutated. Mutation introduces new genetic material into the gene at some low rate. If the gene to be mutated in the offsprings is represented by a binary string, mutation involves flipping the bit (0 goes to 1, 1 goes to 0) at each location in the string with some probability. The "roulette wheel parent selection" technique is used to select the "best" parent chromosomes according to their fitness. It consists of the following steps:

Step-1: Sum the fitness of all chromosomes in the population; call it the FITSUM.

Step-2: Generate a random number between 0 and FITSUM.

Step-3: Return the first chromosome whose fitness, added to the fitness of preceding chromosomes, is greater than or equal to.

Lagrangian relaxation

The Lagrange relaxation procedure solves the unit commitment problem through the dual optimization procedure. The Lagrangian function for the economic dispatch problem is

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$$L(P, U, \lambda) = F(P_{it}, U_{it}) + \sum_{t=1}^{T} \lambda^{t}(PD_{t} - \sum_{i=1}^{n} P_{it}U_{it})$$

The unit commitment problem requires that we minimize this Lagrange function, subject to local unit constraints.

The constraints to be satisfied are

1) Power balance constraint
2) Capacity limits constraints
3) Unit minimum up and downtime constraints.

The cost function $F(P_{it},U_{it})$ are each separable over units. That is, what is done with one unit does not affect the cost of running another unit, as far as the cost function and the unit limits (constraint 2) and the unit up and down time (constraint 3) are concerned. Constraint 1 is coupling constraint across the units so that what we do to one unit affects other units if the coupling constraints are to be met. The dual procedure attempts to reach the constrained optimum by maximizing the Lagrangian with respect to the Lagrange multipliers, while minimizing with respect to the other variables in the problem.

$q^*(\lambda)=\max q(\lambda)$
Where $q(\lambda)=\min L(P,U,\lambda)$

This is done in two basic steps:

Step-1: Find a value for each λ^t which moves q (λ) toward a larger value.

Step-2: Assuming that the λ^t found in step 1 are now fixed, find the minimum of L by adjusting the values of P^t and U^t.

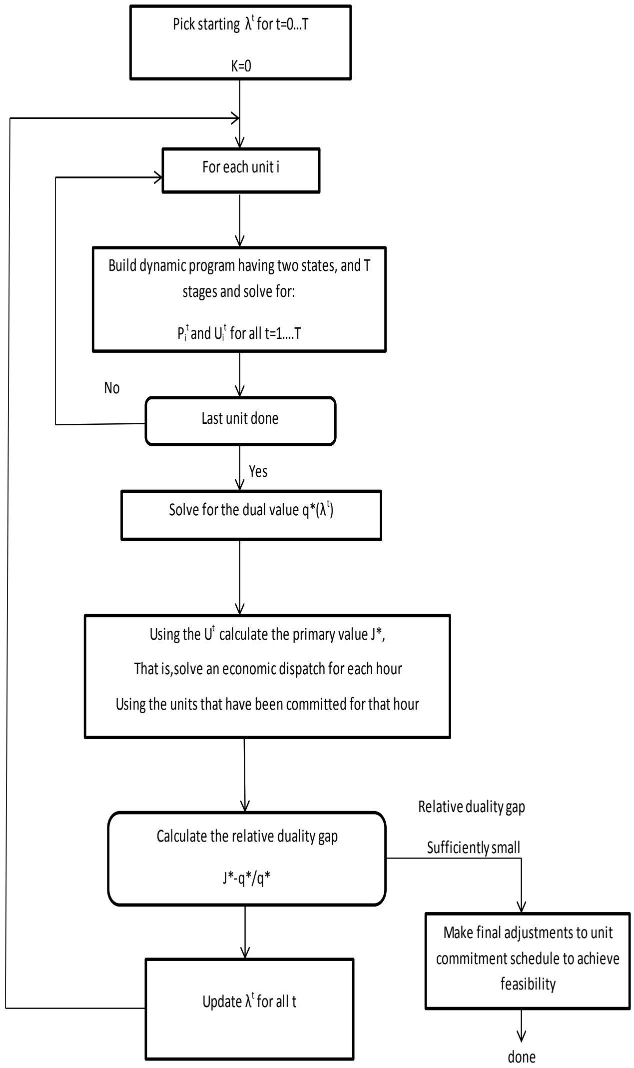
The minimum of the Lagrangian is found by solving for the minimum for each generating unit over all time periods

$$\min q(\lambda)= \sum_{t=1}^{T} min(\sum_{i=1}^{N}\{[F_i (P_i^t) + \text{Start up cost}_{i,t}]-P_i^tU_i^t \lambda^t\}) \quad (4)$$

Subject to

$U_i^tP_i^{min} \leq P_i^t \leq U_i^tP_i^{max}$ for t=1……T

The flowchart for the Lagrangian Relaxation method is shown in Figure-1.



HYBRID GA APPROACH WITH LAGRANGIAN RELAXATION

Two UC solutions are generated using random generation and a predefined solution through Roulette wheel method. Ten populations are generated using the two solutions with cross over and mutation operators. The initial solution obtained from random generation and Roulette wheel selections are given in Table 1 and 2.

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Table-1. Initial solution obtained from Random Generation.

Hour/ Units	1	2	3	4	5	6	7	8	9	10
1	1	1	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0	0	0
4	1	1	0	0	1	0	0	0	0	0
5	1	1	0	0	1	0	0	0	0	0
6	1	1	0	0	1	1	0	0	0	0
7	1	1	0	0	1	1	0	0	0	0
8	1	1	0	0	1	1	1	0	0	0
9	1	1	1	1	1	1	1	0	0	0
10	1	1	1	1	1	1	1	0	0	0
11	1	1	1	1	1	1	1	0	0	0
12	1	1	1	1	1	1	1	1	0	0
13	1	1	1	1	1	1	1	0	0	0
14	1	1	1	1	1	1	1	0	0	0
15	1	1	0	0	1	1	1	0	0	0
16	1	1	0	0	1	1	0	0	0	0
17	1	1	0	0	1	1	0	0	0	0
18	1	1	0	0	1	1	0	0	0	0
19	1	1	0	0	1	1	1	0	0	0
20	1	1	1	1	1	1	1	0	0	0
21	1	1	1	1	1	1	1	0	0	0
22	1	1	0	0	1	1	0	0	0	0
23	1	1	0	0	0	0	0	0	0	0
24	1	1	0	0	0	0	0	0	0	0

Table-2. Initial solution obtained from Roulette wheel.

Hour/ Units	1	2	3	4	5	6	7	8	9	10
1	1	1	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0	0	0
4	1	1	1	1	0	0	0	0	0	0
5	1	1	1	1	0	0	0	0	0	0
6	1	1	1	1	0	0	0	0	0	0
7	1	1	1	1	1	0	0	0	0	0
8	1	1	1	1	1	0	0	0	0	0
9	1	1	1	1	1	0	0	0	0	0
10	1	1	1	1	1	1	0	0	0	0
11	1	1	1	1	1	1	1	1	0	0
12	1	1	1	1	1	1	1	1	1	0
13	1	1	1	1	1	1	0	0	0	0
14	1	1	1	1	1	0	0	0	0	0
15	1	1	1	1	1	0	0	0	0	0
16	1	1	1	1	1	0	0	0	0	0
17	1	1	1	1	1	0	0	0	0	0
18	1	1	1	1	1	0	0	0	0	0
19	1	1	1	1	1	0	0	0	0	0
20	1	1	1	1	1	1	0	0	0	0
21	1	1	1	1	1	0	0	0	0	0
22	1	1	1	0	1	0	0	0	0	0
23	1	1	1	0	0	0	0	0	0	0
24	1	1	0	0	0	0	0	0	0	0

The algorithmic steps for the GA based LR approach is given below:

Algorithm

Step-1: Develop initial solution using Dynamic programming. Using Roulette wheel generate a predefined Unit Commitment solution. These two solutions will be the parent solution.

Step-2: Using crossover, mutation and both crossover and mutation create more population.

Step-3: Check for power demand constraint.

Step-4: Check for minimum up time and down time constraint.

Step-5: Calculate the fitness value to determine the best population.

Step-6: Perform the economic dispatch for the particular hour, for hour 1 and calculate the optimum power to be generated from each unit in the system. The starting value of lambda (λ) is taken as per unit (p. u) of the load and the iteration is started. This gives the dispatch for the first iteration

Step-7: Now, compare the primal value (j) with the optimal value q (λ); the difference between the two values is taken as the relative duality gap. Relative duality gap = (j*-q*)/q*

Step-8: Check for duality gap and update the value of λ for all values of t.

Step-9: Make the final adjustment to Unit Commitment schedule to achieve feasible solution.

Step-10: Print out the final solution.

5. RESULTS AND DISCUSSIONS

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The algorithm is checked for the IEEE 10 unit system. The required unit data for the 10-unit generating system is given in Table-1. The load data for this system is given in Table-2.

Table-1. Unit data for the 10-unit system.

	Unit 1	**Unit 2**	**Unit 3**	**Unit 4**	**Unit 5**
Pmax (MW)	455	455	130	130	162
Pmin (MW)	150	150	20	20	25
a ($/hr)	1000	970	700	680	450
b ($/Mwh)	16.19	17.26	16.60	16.50	19.70
c ($/Mwh^2)	0.00048	0.00031	0.002	0.00211	0.00398
MUTi (h)	8	8	5	5	6
MDTi (h)	8	8	5	5	6
$Hcost_i$ ($)	4500	5000	550	560	900
$Ccost_i$ ($)	9000	10000	1100	1120	1800
$Chour_i$ (h)	5	5	4	4	4
IniState (h)	8	8	-5	-5	-6
	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
Pmax(MW)	80	85	55	55	55
Pmin (MW)	20	25	10	10	10
a ($/hr)	370	480	660	665	670
b ($/Mwh)	22.26	27.74	25.92	27.27	27.79
c ($/Mwh^2)	0.00712	0.00079	0.00413	0.00222	0.00173
MUTi (h)	3	3	1	1	1
MDTi (h)	3	3	1	1	1
$Hcost_i$ ($)	170	260	30	30	30
$Ccost_i$ ($)	340	520	60	60	60
$Chour_i$ (h)	2	2	0	0	0
IniState (h)	-3	-3	-1	-1	-1

Table-2. Load data of 10 unit system for 24 hours.

Hour [h]	**Load** [MW]	**Hour** [h]	**Load** [MW]
1	700	13	1400
2	750	14	1300
3	850	15	1200
4	950	16	1050
5	1000	17	1000
6	1100	18	1100
7	1150	19	1200
8	1200	20	1400
9	1300	21	1300
10	1400	22	1100
11	1450	23	900
12	1500	24	800

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The simulation was carried out using Matlab Sofware and the Unit Commitment Schedule together with the dispatch for IEEE 10 unit system is given in Table-3

Table-3. Unit commitment and economic schedule of IEEE 10-Unit system for 24 hours.

Hour	Operating cost	Start-up cost	Spinning reserve	Spot pricing	Unit commitment	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
1	13683.12	0.00	210.00	15505	1100000000	455	245	0	0	0	0	0	0	0	0
2	14554.49	0.00	160.00	16500	1100000000	455	295	0	0	0	0	0	0	0	0
3	16301.88	0.00	60.00	19635	1100000000	455	395	0	0	0	0	0	0	0	0
4	18720.49	1100.0	90.00	22467.5	1110000000	455	455	40	0	0	0	0	0	0	0
5	19563.49	0.00	40.00	22250	1110000000	455	455	90	0	0	0	0	0	0	0
6	21922.69	1120.0	70.00	25245	1111000000	455	455	130	60	0	0	0	0	0	0
7	22765.63	0.00	20.00	25875	1111000000	455	455	130	110	0	0	0	0	0	0
8	24150.34	1800.0	132.00	26580	1111100000	455	455	130	130	30	0	0	0	0	0
9	26184.02	0.00	32.00	29640	1111100000	455	455	130	130	130	0	0	0	0	0
10	28768.21	340.00	12.00	41090	1111110000	455	455	130	130	162	68	0	0	0	0
11	30592.78	520.00	47.00	43717.5	1111111000	455	455	130	130	162	80	38	0	0	0
12	33306.05	120.00	52.00	47475	1111111100	455	455	130	130	162	80	68	10	10	0
13	29344.25	0.00	12.00	34440	1111110000	455	455	130	130	162	48	20	0	0	0
14	26184.02	0.00	32.00	31850	1111100000	455	455	130	130	130	0	0	0	0	0
15	24150.34	0.00	132.00	27000	1111100000	455	455	130	130	30	0	0	0	0	0
16	21604.18	0.00	282.00	23415	1111100000	455	455	95	20	25	0	0	0	0	0
17	20760.18	0.00	332.00	22250	1111100000	455	455	45	20	25	0	0	0	0	0
18	22450.17	0.00	232.00	24255	1111100000	455	455	130	35	25	0	0	0	0	0
19	24150.34	0.00	132.00	26640	1111100000	455	455	130	130	30	0	0	0	0	0
20	28768.21	340.00	12.00	31710	1111110000	455	455	130	130	162	68	0	0	0	0
21	26661.94	0.00	132.00	30030	1111100000	455	445	130	110	30	20	0	0	0	0
22	22406.52	0.00	70.00	25245	1111000000	455	445	130	40	0	20	0	0	0	0
23	17177.90	0.00	10.00	20475	1100000000	455	445	0	0	0	0	0	0	0	0
24	15427.41	0.00	110.00	18040	1100000000	455	345	0	0	0	0	0	0	0	0
TOTAL	**549598.65**	5340	2413	**651330**											

Total Cost : Rs 554938.65/-
Total Revenue : Rs 651330/-
Profit : Rs 96391.35/-

The computation time was below 5s. Final solution shows the least cost of operation. The choice of appropriate penalty terms for constrained optimization is a serious problem. Large constraint penalties separate the invalid solutions from the valid ones but lead to a more complicated hypersurface to be searched whereas small penalties result in a smoother hypersurface but increase the possibility of misleading the GA toward invalid solutions. An answer to this problem can be the use of varying penalty terms, less stringent at the beginning and rising gradually to appropriately large values at later stages. The penalty terms used are linearly proportional to the generation index. The presented technique gives the GA a significantly better chance of locating the global optimum especially in the case of problems with many constraints that result in a complicated search hypersurface. The results show that the varying fitness function outperforms the traditional non varying fitness function technique. All the constraints such as unit capacity constraints, minimum up time, minimum down time and load constraints are satisfied. The results are compared with other methods in literature and are shown in Table-4.

Table-4. Comparison of various approaches.

Method	**Total cost** (Rs)	**Time** (Sec)
GA based [13]	565825	74
LR based [13]	565825	56
Dynamic programming approach	564429.01	32
Genetic algorithm and Lagrangian Relaxation (Proposed)	554938.65	5

The Genetic algorithm based Lagrangian Relaxation method is compared with Dynamic Programming, Lagrangian Relaxation and Genetic Algorithm. Total production cost of the Unit Commitment obtained in the proposed hybrid method is less compared to the other approaches listed above. It is found that through the proposed approach there is a net saving of Rs 12630.64/-

5. CONCLUSIONS

Application of GA for the solution of the unit commitment problem is demonstrated with detail in this paper. This method is efficient and can handle large scale system unit commitment. The total objective is the profit maximization and cost minimization and constraints satisfaction. The power balance constraint (equality constraint) is satisfied prior to genetic operation. This ensures a feasible solution during every stage of the GA simulation. The paper solves the profit based unit commitment (PBUC) problem by the hybrid Genetic Algorithm and Lagrangian Relaxation approach and the results shows better performance in terms of computational time. The advantage of using normalized Lagrangian multipliers instead of units' on/off state as the encoded parameters is that the number of bits of chromosome will be entirely independent of number of units and only dependent of number of hours. This is particularly attractive in large-scale systems. The numerical tests and results show that better solution of the unit commitment (UC) problem can be obtained by thismethod.

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