HYDROTHERMAL COORDINATION FOR SHORT RANGE FIXED HEAD STATIONS USING FAST GENETIC ALGORITHM

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ABSTRACT

This paper presents a Fast genetic algorithm for solving Hydrothermal coordination (HTC) problem. Genetic Algorithms (GAs) perform powerful global searches, but their long computation times, put a limitation when solving large scale optimization problems. The present paper describes a Fast GA (FGA) to overcome this limitation, by starting with random solutions within the search space and narrowing down the search space by considering the minimum and maximum errors of the population members. Since the search space is restricted to a small region within the available search space the algorithm works very fast. This algorithm reduces the computational burden and number of generations to converge. The proposed algorithm has been demonstrated for HTC of various combinations of Hydro thermal systems. In all the cases Fast GA shows reliable convergence. The final results obtained using Fast GA are compared with simple (conventional) GA and found to be encouraging.

KEYWORDS

Hydrothermal scheduling, Genetic algorithms, Optimal scheduling, Incremental fuel cost of generators

Nomenclature:	
K_{max}	number of intervals
n_t	number of thermal plants
t_k	duration of interval k
$F_{ik}(P_{sik})$	fuel cost function of ith thermal plant in kth interval
P_{sik}	Thermal generation of ith plant in kth interval
P_{Hik}	Hydro generation of ith plant in kth interval
P_{Dk}	power demand in interval k
P_{Lk}	system loss in interval k
$Q_{ik}(P_{Hik})$	water discharge rate of ith plant in interval k
Z	objective function
$\mathcal{L}$	augmented objective function
P_{si}^{min}, P_{si}^{max}	minimum and maximum limits on ith thermal unit
P_{Hi}^{min}, P_{Hi}^{max}	minimum and maximum limits on ith hydro unit
a_i,b_i,c_i	cost coefficients of ith thermal plant
x_i,y_i,z_i	water discharge coefficients of ith hydro plant
v_{i}^{avl}	available water for ith hydro plant over the scheduling period
NET	Net execution time

1. INTRODUCTION

Hydrothermal coordination (HTC) means determination of thermal power and hydro power such that total system generation cost is minimum while satisfying the system constraints. However the operating cost of hydro plant is negligible, so our objective is to minimize the total fuel cost of thermal units, subjected to the water availability constraint and energy balance condition for a given period of time. It is basically non-linear programming problem involving non-linear objective function and a mixture of linear and non-linear constraints.

The HTC problem is divided into three types based on the duration of interval; these are long, mid and short-range problems. Mid and long-range HTC is for one or more years on a weekly or monthly basis [1]. The final output is the amount of water to be discharged at each hydroelectric plant throughout the coming week. Short-range planning on the other hand is concerned with distributing the generation among the available units over a day or week, usually on an hourly basis, satisfying the operating constraints. In short-range problems a fixed water head is assumed and the net head variation can be ignored for relatively large reservoirs, in which case power generation is solely dependent on the water discharge [1].

Earlier, a wide variety of optimization techniques have been applied to solving HTC [2] problems such as dynamic programming (DP), gradient search methods etc. But, because of the drawbacks, such as drastic growth of computation, dimensionality requirement, and insecure convergence properties these local optimization techniques are not suitable for HTC problem.

In recent years, due to their flexibility, versatility and robustness in seeking global optimal solution, heuristic optimization techniques are gaining lot of interest.

Simple genetic algorithm is capable of locating the near optimal solutions, but it takes large number of iterations to converge and taking large CPU time. In addition to simple GA, there exists a number of advanced GAs, designed to have advanced features.

A number of heuristic techniques like GAs, simulated annealing, evolutionary strategy, particle swarm optimization have been attempted for solution of HTC. All these techniques used large number of variables which not only depend on number of generators, but also on number of intervals in the planning horizon. [1] presented optimal gamma based GA for solving HTC problem, which reduces the number of variables to be considered to a minimum. GA has also been applied for solution of HTC. [2] proposed an efficient method for optimal scheduling of fixed head hydro thermal plants. A fast computational genetic algorithm for solving the economic load dispatch problem of thermal units has been presented in [3]. [6] presents short term hydro thermal coordination by Lagrangian relaxation method using dual optimization technique.[10] presented a fast evolutionary technique for short-term hydrothermal scheduling. [11] presents HTC using GA. A unit based encoding scheme is used, which restricts the applicability of GA to large-scale systems. In unit based encoding the chromosome length increase with increase of number of units in the system.

In the present paper a fast computation GA [3] is used considering the optimal gamma based approach for short term hydrothermal coordination. The paper presents a methodology to overcome the long computation times involved with simple Genetic Algorithms.

2. PROBLEM FORMULATION

The main objective of HTC [1] problem is to determine the optimal schedule of both thermal and hydro plants of the power systems while minimizing the total operating cost of the system, i.e. fuel cost required for the systems thermal generation. It is required to meet the forecasted load demand over the scheduled time, while satisfying various system and unit constraints. The HTC problem can be defined as
Minimize

$$z = \sum_{k=1}^{kmax} \sum_{i=1}^{nt} t_k . F_{ik}(P_{sik}) \quad (1)$$

Subject to power balance constraint (2) and the water availability constraint (3)

$$\sum_{i=1}^{nt} P_{Sik} + \sum_{j=1}^{nh} P_{Hjk} - P_{Dk} - P_{Lk} = 0; \qquad K=1, 2 \ldots k_{max} \quad (2)$$

$$\sum_{k=1}^{kmax} t_k . Q_{ik}(P_{Hik}) = V_i^{avl}; \qquad i = 1,2, \ldots \ldots nh \quad (3)$$

With

$$P_{S_i}^{min} \leq P_{S_i} \leq P_{S_i}^{max} \; ; i = 1,2 \ldots nt$$

$$P_{H_i}^{min} \leq P_{H_i} \leq P_{H_i}^{max} \; ; i = 1,2 \ldots . nh \quad (4)$$

Where

$$F_{ik}(P_{sik}) = a_i P_{sik}^2 + b_i P_{sik} + c_i \;\; \$/h \quad (5)$$

$$Q_{ik}(P_{Hik}) = x_i P_{Hik}^2 + y_i P_{Hik} + z_i \;\; m3/h \quad (6)$$

2.1 Classical λ – γ iteration method[4]

The Lagrange function for the HTC can be written as

$$\mathcal{L} = \sum_{k=1}^{kmax} [\sum_{j=1}^{nt} t_k Fjk(P_{sj}) + \lambda_k (P_{Dk} + P_{Lk} - \sum_{j=1}^{nh} P_{Hj} - \sum_{j=1}^{nt} P_{sj})] + \gamma \sum_{j=1}^{nh} [\sum_{k=1}^{kmax} t_k Q_{jk}(P_{Hjk}) - V_j^{avl}] \quad (7)$$

The co-ordination equations from the above function can be obtained for interval k

$$t_k \frac{dF_{ik}}{dP_{sik}} + \lambda_k \frac{\partial P_{Lk}}{\partial P_{sik}} = \lambda_k \quad (8)$$

$$\gamma t_k \frac{dq(P_{Hik})}{dP_{Hik}} + \lambda_k \frac{\partial P_{Lk}}{\partial P_{Hik}} = \lambda_k \quad (9)$$

the above co-ordination equations along with constraints (2)-(4) can be iteratively solved to obtain optimal HTC.

3. PROPOSED METHODOLOGY

The GA is essentially a search process based on the mechanics of natural selection and natural genetics to obtain a global optimal solution of a combinatorial optimization problem. The execution of GA involves initialization of population of chromosomes. Based on the fitness values, the process of generation of new chromosomes and selection of those with better fitness values are continued until the desired conditions are satisfied.

In this method the γ values of the hydel plants are considered as GA decision variables. By using the values of (γ) gamma the optimal thermal and hydro powers are found using (8) and (9). In fast GA approach the lower and upper limits of γ (gamma) are reduced based on the constraint (3). Thus the search space is effectively reduced to be close to optimal value, due to which the number of generations to get optimal solution are drastically reduced and reduced CPU execution time.

3.1 Encoding and decoding

The implementation of GA starts with parameter encoding. Here binary representation is used because of the ease of binary number manipulation. In this method γ values of all hydel plants are considered as GA variables and each of them represented by L-binary bits. The resolution of the solution depends upon length of chromosome. The higher the number of bits used, the finer will be resolution. However, higher the number of bits used for encoding, slower will be convergence. The total chromosome is obtained by concatenating the bits representing each decision variable. The value of γ_i for each sub-string of the chromosome is evaluated first by decoding its binary values into its decimal equivalent D_i and then the following expression is computed

$$\gamma_i = \gamma_i^{min} + \frac{\gamma_i^{max} - \gamma_i^{min}}{2^L - 1} * D_i \tag{10}$$

However the lower and upper bounds are chosen using (4).

3.2 Fitness function

Water availability constraint is considered as fitness function for the hydrothermal coordination problem. The optimal value of γ gives optimal thermal and hydro powers.
The fitness function of each chromosome 'i' is given by

$$FIT_i = \frac{1}{1+\sum_{j=1}^{nh}[V_j^{avl} - \sum_{k=1}^{kmax} t_k Q_{jk}(P_{H\,jk})]} \tag{11}$$

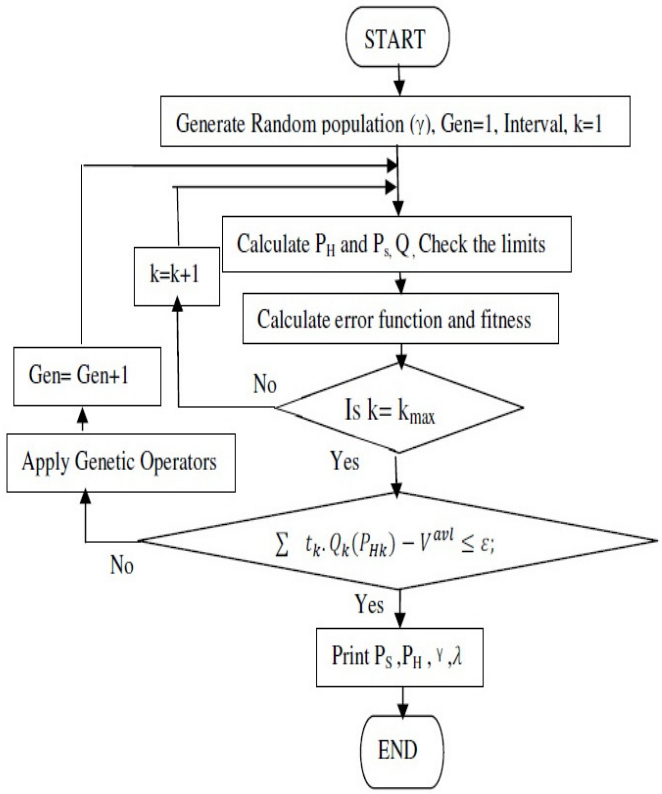

Figure 1.Flow chart of HTC using simple GA

3.3. HTC using SGA and FGA

For solution of HTC using SGA, γ values of each hydro plant is encoded in the chromosome. The flowchart for implementing HTC using simple GA is shown in fig.1. For HTC using fast GA, γ values of each hydro plant is encoded in chromosome. The flowchart for implementing HTC using fast GA is shown in fig.2. In fast GA, after the errors of all chromosomes are evaluated, search space is restricted by identifying minimum positive error, and setting the gamma_act of this chromosome to be gamma_max. Then, identifying the chromosome with minimum negative error, and set the gamma_act of this chromosome to be gamma_min. This will largely reduce the search space from wide gamma_max, gamma_min to small region and hence help in faster convergence.

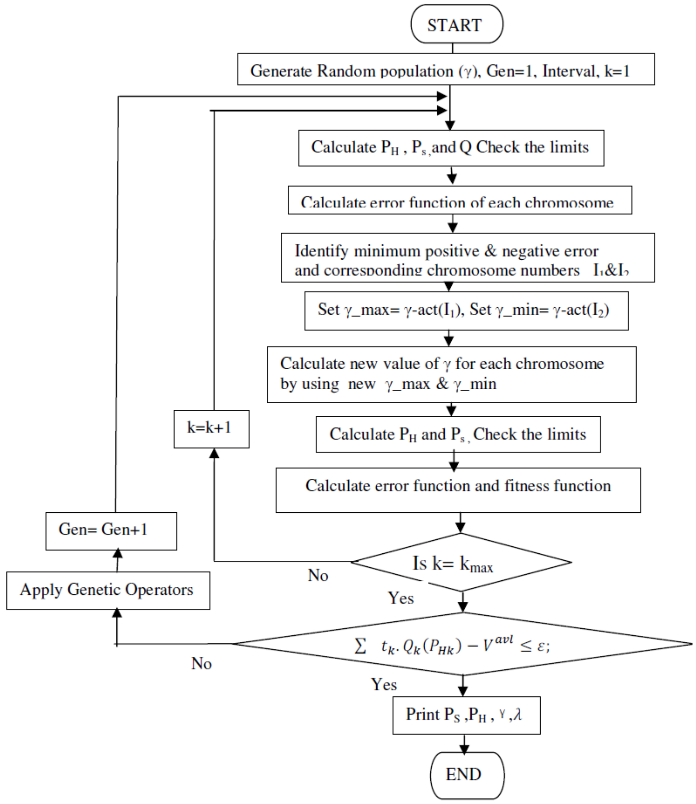

Figure 2. Flow chart of HTS using fast GA

4. Results and Discussion

The developed algorithm is tested for four cases. In every case studied the chromosome length, population size, probability of crossover, mutation and elitism considered with simple GA and fast GA are same. Tournament selection, uniform crossover and bit wise mutation are used in all the cases. The GA parameters considered for all the cases are Population size: 40, chromosome length: 12 bits (one γ), Crossover probability: 0.85, Mutation probability: 0.005, Elitism probability: 0.19. The system data for all the cases is taken from [2].

Case- 1: It consists of one thermal and one hydro plant with 12 hour load demand of two intervals.

Interval	Demand(MW)	Ps (MW)	P_H(MW)	λ ($ / MWH)
2400-1200	1200	560.2651	676.328	133.525
1200-2400	1500	691.922	868.407	138.291

Table 1. Case 1: Optimal solution using simple GA

Interval	Demand(MW)	Ps (MW)	P_H(MW)	λ ($/MWH)
2400-1200	1200	551.925	685.683	133.11
1200-2400	1500	683.79	861.03	37.87

Table 2. Case 1: Optimal solution using fast GA

Variable	Simple GA	Fast GA	Ref.[1]	Ref.[2]
Generations	102	7	51	-
NET(s)	1.387	0.23	19	-
Fuel cost($/day)	169471.321	169354.8	169637.5	169637.6
γ ($/ M cubic ft)	1.997071	1.997071	2.02837	2.02

Table 3. Comparison of results for case 1

Tables 1 and 2 present the results of one thermal and one hydro unit with 12 hour load demand of each interval. Table 3 presents comparison of results for case 1 using simple GA and Fast GA. It is obvious from the results that, for same GA parameters, Fast GA gives the optimal solution in 7 generations as compared to 102 generations taken by simple GA. Further, a reduction in Fuel cost can also be observed.

From table 3 it can be concluded that using fast GA optimal solution can be obtained with reduced number of generations and with minimum CPU time.

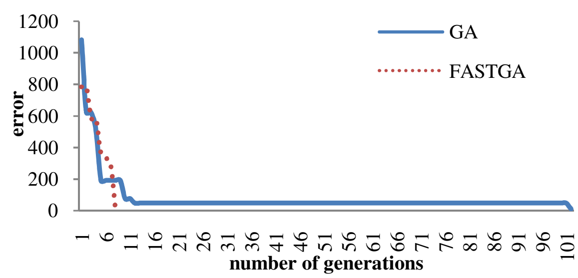

Figure 3. Variation of error vs number of generations for case-1

Fig. 3 shows the variation of error of the best fit chromosome with number of generations. This clearly demonstrates the superiority of the developed Fast GA over Simple GA.

Case-2: It consists of one thermal and one hydro generating station with hourly load demand for each interval.

Tables 4 and 5 present the optimal solution of one thermal and one hydro unit with hourly load demand of each interval (one day) using simple GA and Fast GA respectively. The results obtained are in agreement with the results shown in [1] and [2]. For this case Fast GA provides better optimal solution in just four iterations. Table 6 presents the comparison of results for case 2. Fast GA gives a fuel cost of 95809.366 $/day compared to 95847.86 $/hr. A better optimal solution is obtained in just four generations and shows reduced CPU time.

Interval	**Demand(MW)**	**Ps(Mw)**	**P_H(MW)**	**λ ($ / MWH)**
1	455	230.5785	236.5652	10.5235
2	425	202.1266	234.0816	10.4102
3	415	192.6606	233.2553	10.3726
4	407	185.0943	232.5948	10.3424
5	400	178.4785	232.0173	10.3161
6	420	197.3925	233.6683	10.3914
7	487	261.0172	239.2222	10.6447
8	604	373.1122	249.0072	11.0911
9	665	432.0659	254.1534	11.3258
10	675	441.7645	255.0000	11.3644
11	695	461.1907	256.6958	11.4418
12	705	470.9183	257.5449	11.4805
13	580	350.0142	246.9910	10.9991
14	605	374.0758	249.0914	11.0949
15	616	384.6817	250.0172	11.1371
16	653	420.4404	253.1386	11.2795
17	721	486.5029	258.9053	11.5425
18	740	500.0000	260.5011	11.6164
19	700	466.0533	257.1203	11.4611
20	678	444.6760	255.2542	11.3760
21	630	398.1966	251.1969	11.1909
22	585	354.8218	247.4106	11.0182
23	540	311.6376	243.6410	10.8463
24	503	263.5561	239.4439	10.6548

Table 4. Case 2: Optimal solution using simple GA

Interval	**Demand(MW)**	**Ps(MW)**	**P_H(MW)**	**λ ($ / MWH)**
1	455	230.4735	236.6757	10.5237
2	425	202.0228	234.1909	10.4104
3	415	192.5573	233.3642	10.3727
4	407	184.9913	232.7034	10.3426
5	400	178.3757	232.1256	10.3162
6	420	197.2889	233.7775	10.3915
7	487	260.9107	239.3340	10.6449
8	604	373.0007	249.1236	11.0912
9	665	431.9517	254.2723	11.3260
10	675	441.6498	255.1193	11.3646
11	695	461.0751	256.8158	11.4419
12	705	470.8023	257.6654	11.4807
13	580	349.9037	247.1064	10.9993
14	605	373.9642	249.2078	11.0951
15	616	384.5696	250.1340	11.1373
16	653	420.3266	253.2570	11.2797
17	721	486.3861	259.0264	11.5427
18	740	500.0000	260.6234	11.6155
19	700	465.9375	257.2405	11.4613
20	678	444.5611	255.3735	11.3762
21	630	398.0839	251.3143	11.1911
22	585	354.7111	247.5263	11.0184

23	540	311.5288	243.7549	10.8464
24	503	263.4447	239.5553	10.6550

Table 5. Case 2: Optimal solution using Fast GA

Variable	Simple GA	Fast GA	Ref.[1]	Ref.[2]
Generations	116	4	15	-
NET(s)	6.09	0.306282	52	-
Fuel cost ($/day)	95847.86	95809.366	96024.368	96024.37
γ value ($/ M cubic ft)	29.1432	29.1356	28.2144	28.17

Table 6. Comparison of results for case 2

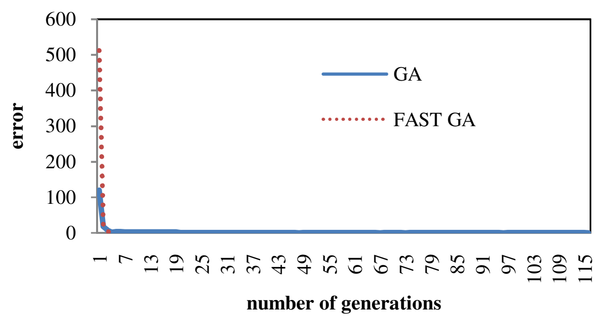

Figure 4.Variation of error vs number of generations for case-2

Fig. 4 shows the variation of error of the best fit chromosome with number of generations. This clearly demonstrates the superiority of the developed Fast GA over Simple GA.

Case-3: It consists of one thermal and two hydro generating stations with hourly load demand for each interval.

Interval	Demand(MW)	P_S (MW)	P_{H1} (MW)	P_{H2} (MW)	λ ($/MWh)
1	30	2.6831	18.5743	9.1293	3.0537
2	33	3.2817	19.8234	10.3414	3.0656
3	35	3.6813	20.6571	11.1504	3.0736
4	38	4.2815	21.9094	12.3656	3.0856
5	40	4.6821	22.7453	13.1767	3.0936
6	45	5.6855	24.8389	15.2082	3.1137
7	50	6.6915	26.9379	17.245	3.1338
8	59	8.5089	30.7299	20.9245	3.1702
9	61	8.9139	31.575	21.7445	3.1783
10	58	8.3065	30.3077	20.5148	3.1661
11	56	7.9021	29.4639	19.6961	3.158
12	57	8.1043	29.8857	20.1053	3.1621
13	60	8.7113	31.1523	21.3344	3.1742
14	61	8.9139	31.575	21.7445	3.1783
15	65	9.7252	33.2678	23.3872	3.1945
16	68	10.3349	34.5398	24.6215	3.2067
17	71	10.9341	35	25.8346	3.2187

18	62	9.1166	31.9978	22.1549	3.1823
19	55	7.7001	29.0423	19.287	3.154
20	50	6.6915	26.9379	17.245	3.1338
21	43	5.2839	24.0008	14.395	3.1057
22	33	3.2817	19.8234	10.3414	3.0656
23	31	2.8825	18.9904	9.5331	3.0577
24	30	2.6074	18.4164	8.9761	3.0521

Table 7. Case 3: Optimal solution using simple GA

Tables 7 and 8 present the optimal solution of one thermal and two hydro units with hourly load demand of each interval (one day) using simple GA and Fast GA respectively. The results obtained are in agreement with the results shown in[1]& [2]. For this case FGA provides better optimal solution in twenty iterations.

Table 9 presents the comparison of case 3 with hourly load demand of each interval. Figure 5 shows the variation of error with number of generations for case 3. From table 9 and fig.5, it is well established that Fast GA outperforms simple GA, and results are superior incomparison with [1] and [2]. From the results it can be concluded that FGA gives better optimal solution with minimum number of generations and reduced CPU time.

Interval	Demand(MW)	P_S (MW)	P_{H1} (MW)	P_{H2} (MW)	λ ($/MWh)
1	30	2.2866	18.5912	9.513	3.0457
2	33	2.8838	19.8406	10.7268	3.0577
3	35	3.2824	20.6746	11.537	3.0656
4	38	3.8812	21.9271	12.7539	3.0776
5	40	4.2808	22.7632	13.5661	3.0856
6	45	5.2818	24.8573	15.6005	3.1056
7	50	6.2853	26.9567	17.6402	3.1257
8	59	8.0983	30.7496	21.325	3.162
9	61	8.5024	31.5949	22.1462	3.17
10	58	7.8965	30.3273	20.9147	3.1579
11	56	7.493	29.4833	20.0948	3.1499
12	57	7.6947	29.9052	20.5046	3.1539
13	60	8.3003	31.1722	21.7355	3.166
14	61	8.5024	31.5949	22.1462	3.17
15	65	9.3117	33.2882	23.7912	3.1862
16	68	9.9199	34.5605	25.0272	3.1984
17	71	10.5174	35	26.2415	3.2103
18	62	8.7046	32.0179	22.5571	3.1741
19	55	7.2915	29.0617	19.6851	3.1458
20	50	6.2853	26.9567	17.6402	3.1257
21	43	4.8811	24.019	14.7861	3.0976
22	33	2.8838	19.8406	10.7268	3.0577
23	31	2.4856	19.0075	9.9174	3.0497
24	30	2.2103	18.4317	9.358	3.0442

Table 8. Case 3: Optimal solution using Fast GA

Variable	Simple GA	Fast GA	Ref. [1]	Ref. [2]
Generations	100	20	39	-
NET(s)	39.403	3.02	90	-
Fuel cost($/day)	848.867	843.5	848.488	848.346
γ_1 ($/ M cubic ft)	95.84	95.6	90.668	90.66
γ_2 ($/ M cubic ft)	49.39	49.202	48.533	48.53

Table 9. Comparison of results for Case 3

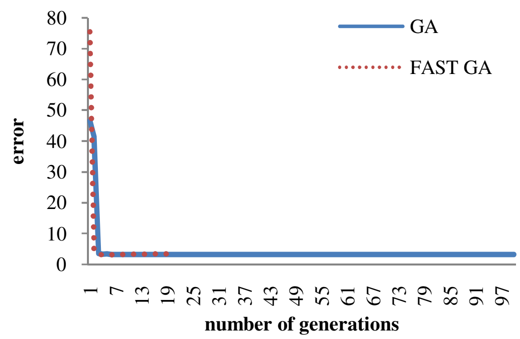

Figure 5. Variation of error with number of generations for case-3

Case- 4: It consists of two thermal and two hydro generating stations with hourly load demand for each interval. For this problem the chromosome length is taken as 24 bits (for each gamma 12 bits) and remaining GA parameters are same. Tables 10 and 11 present the optimal solution of two thermal and two hydro units with hourly load demand of each interval (one day) using GA and Fast GA respectively. The results obtained are in agreement with the results shown in [1] and [2]. For this case Fast GA provides better optimal solution in fifteen iterations.

Interval	Demand (MW)	P_{S1} (MW)	P_{S2} (MW)	P_{H1} (MW)	P_{H2} (MW)	λ ($/MWh)
1	400	81.8954	130.923	170.301	22.5657	3.6095
2	300	66.2693	82.0915	151.282	3.6782	3.5313
3	250	58.5157	57.8615	141.845	0	3.4926
4	250	58.5157	57.8615	141.845	0	3.4926
5	250	58.5157	57.8615	141.845	0	3.4926
6	300	66.2693	82.0915	151.282	3.6782	3.5313
7	450	89.7496	155.467	179.861	32.0592	3.6487
8	900	161.728	380.401	267.468	119.061	4.0086
9	1230	216.083	550.260	333.624	184.760	4.2804
10	1250	219.422	560.696	337.689	188.797	4.2971
11	1350	236.201	613.129	358.111	209.077	4.381
12	1400	244.641	639.506	368.384	219.279	4.4232

13	1200	211.083	534.637	327.539	178.717	4.2554
14	1250	219.422	560.696	337.689	188.797	4.2971
15	1250	219.422	560.696	337.689	188.797	4.2971
16	1270	222.767	571.149	341.760	192.840	4.3138
17	1350	236.201	613.129	358.111	209.077	4.381
18	1470	256.516	676.614	382.837	233.633	4.4826
19	1330	232.835	602.609	354.013	205.008	4.3642
20	1250	219.422	560.696	337.689	188.797	4.2971
21	1170	206.096	519.050	321.469	172.689	4.2305
22	1050	186.262	457.071	297.329	148.716	4.1313
23	900	161.728	380.401	267.468	119.061	4.0086
24	600	111.557	223.618	206.404	58.4191	3.7578

Table 10. Case 4: Optimal solution using simple GA

Interval	**Demand(MW)**	**P_{S1}(MW)**	**P_{S2}(MW)**	**P_{H1}(MW)**	**P_{H2}(MW)**	**λ ($/MWh)**
1	400	81.99	131.248	170.455	21.979	3.61
2	300	66.37	82.4095	151.433	3.1051	3.5319
3	250	58.61	58.1819	141.996	0	3.4931
4	250	58.61	58.1819	141.996	0	3.4931
5	250	58.61	58.1819	141.996	0	3.4931
6	300	66.37	82.4095	151.433	3.1051	3.5319
7	450	89.85	155.796	180.016	31.467	3.6493
8	900	161.8	380.762	267.638	118.41	4.0092
9	1230	216.2	550.645	333.806	184.06	4.281
10	1250	219.5	561.083	337.872	188.09	4.2977
11	1350	236.3	613.524	358.297	208.36	4.3816
12	1400	244.7	639.903	368.572	218.56	4.4238
13	1200	211.2	535.019	327.720	178.02	4.256
14	1250	219.5	561.083	337.872	188.09	4.2977
15	1250	219.5	561.083	337.872	188.09	4.2977
16	1270	222.8	571.537	341.944	192.14	4.3145
17	1350	236.3	613.524	358.297	208.36	4.3816
18	1470	256.6	677.017	383.027	232.90	4.4832
19	1330	232.9	603.002	354.199	204.30	4.3648
20	1250	219.5	561.083	337.872	188.09	4.2977
21	1170	206.2	519.431	321.649	172.00	4.2311
22	1050	186.3	457.443	297.505	148.04	4.1319
23	900	161.8	380.762	267.638	118.41	4.0092
24	600	111.6	223.958	206.565	57.81	3.7583

Table 11. Case 4: Optimal solution using fast GA

Variable	Simple GA	Fast GA	Ref. [1]	Ref.[2]
Generations	100	15	20	-
NET(s)	2.48	0.142	92	-
Fuel cost($/day)	53020.0	53015.5	53055.712	53051.47
γ_1 ($/ M cubic ft)	9.509	9.5091	9.55142	9.466
γ_2 ($/ M cubic ft)	5.74	5.75	5.82	5.70

Table 12. Comparison of results for Case 4

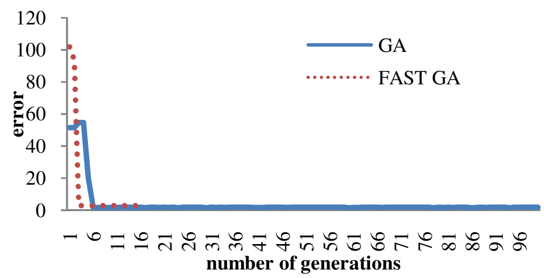

Figure 6. Variation of error Vs number of generations for case-4

A comparison of SGA and FGA for this case of two thermal and two hydro units with hourly load demand of each interval is presented in Table 12. From the fig.6 it is obvious that FGA gives better optimal solution in just 15 generations. Figures 7 to 10 display the optimal power dispatched by hydro and thermal generators for cases1-4 using fast GA.

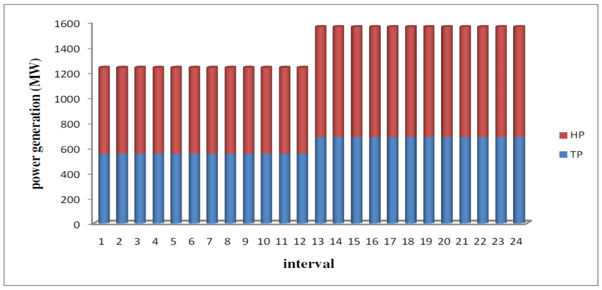

Figure 7. Power dispatch over the interval for case-1 using fast GA

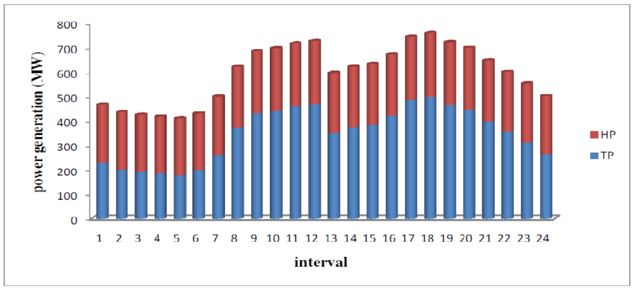

Figure 8. Power dispatch over the interval for case-2 using fast GA

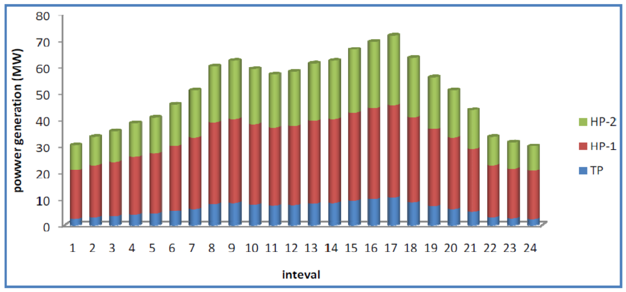

Figure 9. Power dispatch over the interval for case-3 using Fast GA

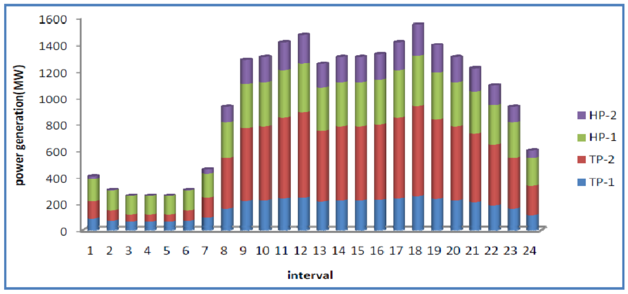

Figure 10. Power dispatch over the interval for case-4 using Fast GA

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