PSO Based Short-Term Hydrothermal Scheduling with Prohibited Discharge Zones

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Abstract— **This paper presents a new approach to determine the optimal hourly schedule of power generation in a hydrothermal power system using PSO technique.. The simulation results reveal that the proposed PSO approach appears to be the powerful in terms of convergence speed, computational time and minimum fuel cost.**

Keywords- Hydrothermal scheduling; Particle Swarm Optimization; Valve - point loading effect; Prohibited Discharge Zones.

I. INTRODUCTION

The optimal scheduling of generation in a hydrothermal system involves the allocation of generation among the hydroelectric and thermal plants so as to minimize the total operation costs of thermal plants while satisfying the various constraints on the hydraulic and power system network. In Short-term scheduling it is normally assumed that the largest dam levels at the end of the scheduling period have been set a medium term scheduling process that takes into account longer term river inflow modeling and load predictions. The short term scheduler than allocates this water (Power) to the various time intervals in an effort to minimize thermal generation costs while attempting to satisfy the various unit and reservoir constraints.

The main constraints include the time coupling effect of the hydro sub problem, where the water flow in an earlier time intervals affects the discharge capability at a later period of time, the time varying system long demand, the cascade nature of the hydraulic network, the varying hourly reservoir inflows, the physical limitations on the reservoir storage and turbine flow rate and loading limits of both thermal and hydro plants. Further constraints could be depending on the particular requirements of a given power system, such as the need to satisfy activities including, flood control, irrigation, fishing, water supply etc., The hydrothermal scheduling problem has been the subject of intensive investigation for several decades now.

Most of the methods that have been used to solve the hydrothermal co-ordination problem make a number of simplifying assumptions in order to make the optimization problem more tractable.

The performances of different stochastic techniques have been studied in the literature [6-14]. Though stochastic techniques have been proved to be very efficient and having faster performances than the conventional methods, there are some limitations in the goodness of the solutions to the problem that are obtained in [13]. From the literature it is found that particle swarm optimization technique has the fastest convergence rate to the global solution amongst all algorithms and has highest potential of finding more nearly global solutions to hydrothermal co-ordination problems [13]. Early works on PSO have shown the rich promise of emergence of a relatively simple optimization technique this is easier to understand compared to other evolutionary computation techniques presently available eg. Genetic algorithm and evolutionary programming.

Another advantage of PSO can be the possibility of tuning smaller number of free, tunable parameters to arrive at the desired goal. The PSO technique has been applied to various fields of power system optimization. Yu et al applied PSO technique to solve short-term hydrothermal scheduling [16] with an equivalent thermal unit having smooth cost functions connected to hydel systems. Here the constraints were handled by penalty function method [16]. But the performance of PSO to Short-term hydrothermal scheduling for interconnected individual thermal units with non-smooth cost function has not been tested yet.

In this paper PSO method is proposed for short-term optimal scheduling of generation in a hydrothermal system which involves the allocation of generation among the multi-reservoirs cascaded hydro plants and thermal plants with prohibited discharge zones and valve point loading effects so as to minimize the fuel cost of equivalent thermal plant while satisfying the various constraints on the hydraulic and power system network.

To validate the PSO based hydrothermal scheduling algorithm, the developed algorithm has been illustrated for a test system [11]. The same problem has been solved by GA and the results are compared. The performance of the proposed method is found to be quite encouraging as compared with other methods.

II. PROBLEM STATEMENT

NOMENCLATURE :

C	Composite Cost function

C_i	fuel cost of i^{th} thermal unit
P_{GTjM}	Output power of i^{th} thermal unit at time 'm'
P_{GHjM}	Output power of j^{th} hydro unit at time 'm'
P_{GTi}^{min} ,P_{GTi}^{max}	Lower and Upper generation limits for i^{th} thermal units
a_i ,b_i, c_i and d_i , e_i	–cost curve co - efficients ofi^{th} thermal unit
P_{Dm}	Load demand at time 'm'
P_{GHj}^{min} ,P_{GHj}^{max}	Lower and Upper generation limits for i^{th} thermal unit
Q_{Hjm}	Water discharge rate of i^{th} reservoir at time 'm'
V_{HJm},	Storage volume of j^{th} reservoir at time 'm'
Q_{HJ}^{min} ,Q_{HJ}^{max}	Minimum and Maximum water discharge rate of j^{th} reservoir
V_{HJ}^{min} ,V_{HJ}^{max}	Minimum and Maximum Storage volume of j^{th} reservoir
P_{Lm}	Total transmission line losses at time 'm'
C_{1j}, C_{2j}, C_{3j}, C_{4j}, C_{5j}, C_{6j},	Power generation co - efficients of j^{th} hydro unit
I_{Hjm}	Inflow rate of j^{th} reservoir at time 'm'
S_{Hjm}	Spillage of j^{th} reservoir at time 'm'
T_{lj}	Water transport delay from reservoir l to j
R_{uj}	Set of upstream units directly above j^{th} hydro plant
N_{GT}	Number of thermal generating units
N_{GH}	Number of hydro generating units
m, M	Time index, scheduling period
V_{Hj}^{begin}	Initial storage volume of j^{th} Reservoir
V_{Hj}^{end}	Final storage volume of j^{th} Reservoir

III. MATHEMATICAL FORMULATION

Hydrothermal Scheduling involves the optimization of a problem with a non-linear objective function, with a mixture of linear, non-linear and dynamic network flow constraints. The problem difficulty is compounded by a number of practical considerations and unless several simplifying assumption are made, this problem is difficult to solve for practical power systems as shown in fig 1.

Due to Zero incremental cost of hydro generating units, the prime objective of the short-term hydrothermal scheduling problem becomes to minimize the fuel cost of thermal plants, while making use of the availability of hydropower as much as possible, such that the load demands P_D supplied from hydro plants and a thermal plant in the intervals of the generation scheduling horizon can be met and simultaneously, all the equality and inequality operation constraints are satisfied.

The objective function and associated constraints of the Hydrothermal scheduling problem are formulated as follows.

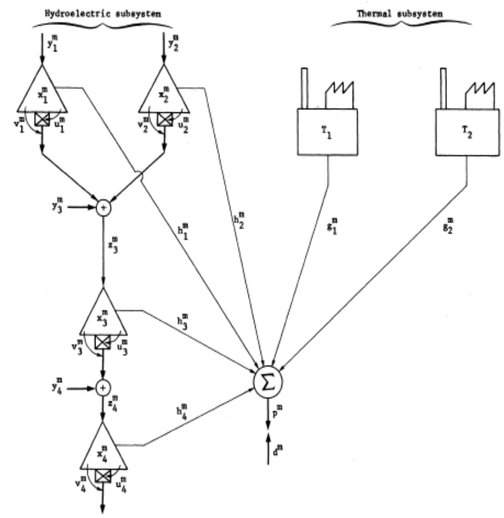

Fig.1 Practical Hydrothermal Power system Network

A. Objective Function

The total fuel cost for running the thermal system to meet the load demand in scheduling horizon is given by C. The objective function is expressed mathematically, as

$$\text{Minimize} \quad C = \sum_{i=1}^{N_{GT}} C_i\,(P_{GTi}) \qquad (1)$$

When considering valve-point effects, the fuel cost function of each thermal generating unit is expressed as the sum of a quadratic and a sinusoidal function. The total fuel cost in-terms of real power output can be expressed as :

$$C = \sum_{m=1}^{M}\sum_{i=1}^{N_{GT}}\Big[a_i + bi\,P_{GTim} + c_iP_{GTim}^{\;2} + \left|d_i\sin\left\{e_i\left(P_{GTi}^{min} - P_{GTim}\right)\right\}\right|\Big] \qquad (2)$$

subject to a number of unit and power system network constraints.

B. constraints

This non-linear constrained hydrothermal scheduling optimization problem is subjected to a variety of constraints depending upon practical implications like the varying system load demand, the time coupling effect of hydro subsystem, the cascading nature of the hydraulic network, the time varying hourly reservoir inflows, thermal plant and hydro plant operating limits, system losses, reservoir storage limits, water discharge rate limits, hydraulic continuity constraints and initial and final reservoir storage limits. These constraints are discussed below.

1) Power balance constraints(Demand Constraints)

This constraint is based on the principle of equilibrium between the total active power generation from the hydro and thermal plants and the total system demand plus the system losses in each time interval of scheduling 'm'

$$\sum_{i=1}^{N_{GT}} P_{GTim} P_{im} + \sum_{j=1}^{N_{GH}} P_{GHjm} = P_{Dm} + P_{lossm} \quad m \in M \qquad (3)$$

2) Thermal Generator Constraints

The operating limit of equivalent thermal generator has a lower and upper bound so that it lies in between these bounds.

$$P_{GT}^{min} \leq P_{GTim} \leq P_{Gi}^{max}, \quad m \in M \qquad (4)$$

3) Hydro Generator Constraints

The operating limit of hydro plant must lie in between its upper and lower bounds.

$$P_{GHj}^{min} \leq P_{GHjm} \leq P_{GHj}^{max}, \quad j \in N_{GH}, m \in M \qquad (5)$$

HYDRAULIC NETWORK CONSTRAINTS

The hydraulic operational constraints comprise the water balance (Continuity) equations for each hydro unit (System) as well as the bounds on reservoir storage and release targets.

These bounds are determined by the physical reservoir and plant limitations as well as the multipurpose requirements of the hydro system. These constraints include :

1) Reservoir Capacity Constraints

The operating volume of reservoir storage limit must lie in between the minimum and maximum capacity limits.

$$V_{Hj}^{min} \leq V_{Hjm} \leq V_{Hj}^{max}, \quad j \in N_H, m \in M \qquad (6)$$

2) The Water Discharge Constraints

The variable net head operation is considered and the physical limitation of water discharge of turbine, Q_{Hjm}, Must lie in between maximum and minimum operating limits, as given by

$$Q_{Hj}^{min} \leq Q_{Hjm} \leq Q_{Hj}^{max}, j \in N_H, \quad m \in M \qquad (7)$$

3) Reservoir end conditions

The desired volume of water to be discharged by each reservoir over the scheduling period,

$$V_{Hjm}\Big|_{m=0} = V_{Hj}^{begin}$$

$$V_{Hjm}\Big|_{m=m} = V_{Hj}^{end} \qquad j \in N_H \qquad (8)$$

4) Hydraulic Continuity Equation Constraint

The storage reservoir volume limits are expressed with given initial and final volumes as

$$V_{HjmH} = V_{Hjm} + \sum_{u=1}^{Ru} \left[Q_{Hu}(m-\tau_{lj}) + S_u(m-\tau_{lj}) \right] - Q_{Hj(m+1)} - S_{j(m+1)} + \gamma_{j(m+1)} \text{ for } j \in N_H, m \in M \qquad (9)$$

Where τ_{lj} is the water delay time between reservoir *l* and its upstream u at interval' m'.

R_u is the set of upstream units directly above the hydro plant 'j'.

5) Power Generation Characteristics

The Power generated from a hydro plant is related to the reservoir characteristics as well as the water discharge rate. A number of models have been used to represent this relationship. In general, the hydro generator power output is a function of the net hydraulic head, H, reservoir volume, V_H, and the rate of water discharge, Q_H,

$$P_{GHjm} = f(Q_{Hjm}, V_{Hjm}) \text{ and } V_{Hjm} = f(H_{jm}) \qquad (10)$$

The model can also be written in-terms of reservoir volume instead of the reservoir net head, and a frequently used functional is

$$P_{GHjm} = C_{1j}V^2_{Hjm} + C_{2j}Q^2_{Hjm} + C_{3j}V_{Hjm}Q_{Hjm} + C_{4j}V_{Hjm} + C_{5j}Q_{Hjm} + C_{6j}, j \in N_H, m \in M \quad (11)$$

Net head variation can only be ignored for relatively large reservoirs, in which case power generation is solely dependent on the water discharge. In setting the generation levels of the thermal plants, a quadratic cost function is used to model the fuel input power output characteristic of thermal units.

IV. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization is one of the most recent developments in the category of combinatorial metaheuristic optimizations. This method has been developed under the scope of artificial life where PSO is inspired by the natural phenomenon of fish schooling or bird flocking. PSO is basically based on the fact that in quest of reaching the optimum solution in a multi-dimensional space, a population of particles is created whose present coordinate determines the cost function to be minimized. After each iteration the new velocity and hence the new position of each particle is updated on the basis of a summated influence of each particle's present velocity, distance of the particle from its own best performance, achieve so far during the search process and the distance of the particle from the leading particle, i.e. the particle which at present is globally the best particle producing till now the best performance i.e. minimum of the cost function achieved so far.

Let x and v denote a particle position and its corresponding velocity in a search space, respectively. Therefore, the i^{th} particle is represented as $x_i = (x_{i1}, x_{i2}, \ldots, x_{id})$ in the 'd' dimensional space. The best previous position of the i^{th} particles recorded and represented as $pbest_i = (pbest_{i1}, pbest_{i2}, \ldots, pbest_{id})$. The index of the best particle among all the particles in the group is represented by the $gbest_d$. The rate of the velocity for the particle i is represented as $v_i=(v_{i1}, v_{i2}, \ldots, v_{id})$.

The modified velocity and position of each particle can be calculated using the current velocity and the distance from $pbest_{id}$ to $gbest_d$ as shown in the following formulas:

$$v_{id}^{k+1}=w \times v_{id}^{k}+c_1 \times rand(\,) \times (pbest- x_{id}^{k})+c_2 \times rand(\,) \times (gbest_d-x_{id}^{k}) \quad (12)$$

$$x_{id}^{k+1}=x_{id}^{k}+ v_{id}^{k+1}$$

$$i=1,2,\ldots,N_p, d=1,2,\ldots,N_g \quad (13)$$

where, N_P is the number of particles in a group, Ng the number of members in a particle, k the pointer of iterations, w the inertia weight factor, C_1, C_2 the acceleration constant, rand()the uniform random value in the range [0,1], v_i^k the velocity ofa particle i at iteration k, $v_d^{min}\leq v_{id}^k\leq v_d^{max}$ and $x_i^k$is the current position of a particle i at iteration k.In the above procedures, the parameter v^{max} determined the resolution, with which regions are to be searched between the present position and the target position.

If v^{max} is too high, articles might fly past good solutions. If v^{max} is too small, particles may not explore sufficiently beyond local solutions. The constants C_1 and C_2 represent the weighting of the stochastic acceleration terms that pull each particle toward the pbest and gbest positions. Low values allow particle to roam far from the target regions before being tugged back. On the other hand, high values result in abrupt movement toward or past, target regions. Hence, the acceleration constants C_1 and C_2were often set to be 2.0 according to past experiences. Suitable selection of inertia weight 'w' provides a balance between global and local explorations, thus requiring less iteration on average to find a sufficiently optimal solution.

As originally developed,' w 'often decreases linearly from about 0.3to -0.2 during a run. In general, the inertia weight w is set according to the following equation:

$$w = w_{max}-\frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (14)$$

where $iter_{max}$ is the maximum number of iterations and 'iter' is the current number of iterations.

V. PSO Based Hydrothermal Scheduling

Taking the number of particles to be N, the no. of Scheduling intervals as m and the number of hydro unit, as N_H, each initial trial vector Q (j, m, p) denoting the particles of population to be evolved for P = 1, 2, …. N is selected. The discharge of j^{th} hydro plant at m^{th} interval is randomly generated as $Q_{GHjm}\sim\upsilon\,(Q_{GHj}^{min}, Q_{GHj}^{max})$

Let $P_K = \left[P_{GT1}, P_{GT2}, \ldots P_{GTi}, \ldots PG_{TNT}, Q_{GH}, Q_{GH1}, Q_{GH2}, \ldots Q_{GHj}\ldots, Q_{GHNH}\right]^T$ be a trail matrix designating the K^{th} individual of population to be evolved and

$$P_{GTi} = [P_{GTi1}, P_{GTi2}, \ldots P_{GTim},\ldots P_{GTiM}],$$
$$Q_{GHj} = [Q_{GHj1}, Q_{GHj2}, \ldots Q_{GHjm}, \ldots Q_{GHjM}]$$

The elements P_{GTim} and Q_{GHjm} are the power output of the i^{th} thermal unit and the discharge rate of the j^{th} hydro plant at time interval m. The range of elements P_{GTim} and Q_{GHjm} should satisfy the thermal generating capacity and the water discharge rate constraints in equations (3) and (7) respectively.

Assuming the spillage in Eq (9) to be zero for simplicity the hydraulic continuity constraints are

$$V_{Hjo} - V_{HjM} = \sum_{m=1}^{M} Q_{GHjm} - \sum_{m=1}^{M} \sum_{l=1}^{R_{uj}} Q_{GHl}(m-\tau ij) - \sum_{m=1}^{M} I_{Hjm}, j\in N_H \quad (15)$$

To meet exactly the restrictions on the initial and final reservoir storage in eq.(9), the water discharge rate of j^{th} hydro plant in the dependent interval 'd' is then calculated by

$$Q_{GHjd}=V_{Hjo}-V_{HjM}+ \sum_{m=1}^{M} I_{Hjm} + \sum_{\substack{m=1\\ m\neq d}}^{M}\sum_{l=1}^{R_{uj}} Q_{GHl}(m-\tau ij) - \sum_{m=1}^{M} Q_{GHjm}, j\in N_H \quad (16)$$

The dependent water discharge rate must satisfy the constraints is Eq (7).After knowing the water discharges, the reservoir volumes of different intervals are determined. Then, the hydro generations are calculated from Eq (11). Knowing the calculated hydro generations, P_{GHjm} and the given load demand P_{Djm} for m =1, 2 …..m, thermal generations P_{GTi} can be calculated as

$$P_{GTim}= P_{Dm} + P_{Lossm} - \sum_{j=1}^{N_H} P_{GHjm} \quad (17)$$

Also to meet exactly the power balance constraints in Eq (3), the thermal power generation P_{GTdm} of the dependent thermal generating unit can then be calculated using the following equation.

$$P_{GTdm}= P_{Dm} - \sum_{\substack{i=1\\ i\neq d}}^{N_{GT}} P_{GTim} - \sum_{j=1}^{N_H} P_{GHjm} \quad (18)$$

The dependent thermal generation must satisfy the constraints in Eq. (4).All the generation levels, discharges, reservoir water volumes and initial and final reservoir storage volumes must be checked against their limiting values as per eq's.(4)–(11).

Stopping Rule :

The iterative procedure of generating new solutions with minimum function value is terminated when a predefined maximum number of iterations (generations) is reacted.

VI. PSO ALGORITHM

The computational process of PSO technique can be described in the following steps.

Step 1 Input parameters of the system and specify the upper and lower boundaries of each variable.

Step 2 Initialize randomly the particles of the population according to the limit of each unit including individual dimensions, searching points and velocities. There initial particles must be feasible candidate solutions that satisfy the practical operating constraints.

Step 3 Let, Qp = [q_{11}, q_{12}, ……, q_{1m}, q_{21}, q_{22}, …. q_{2m},…q_{n1}, q_{n2}, …., q_{nm}], be the trait vector denoting the particles of population to be evolved. The elements of q_{jm} are the discharges of turbines of reservoirs at various intervals subjected to their capacity constraints in (7). q_{id}, be the dependent discharge of i_{th} hydro plant at d_{th} interval is randomly selected from among the committed 'm' intervals. Then, knowing the hydro discharges, storage volumes of reservoirs V_{jm} are calculated by (9). Then P_{GHjm} is calculated from (11) for all the intervals.

Step 4 Compare each particle (4 x 24) evaluation value with its P_{best} the best evaluations value among P_{best} is denoted as g_{best}.

Step 5 Update the iteration as K = K+1 ; inertia weight, velocity& position by (12-14).

Step 6 Each particle is evaluated according to its updated position, only when satisfied by all constraints. If the evaluation value of each particle is better than the previous P_{best}. The current value is set to be P_{best}.
If the best P_{best} is better than g_{best}, the value is set to be g_{best}.

Step 7 If the stopping criterion is reacted, then go to Step-8, otherwise go to Step-2.

Step 8 The individual that generates the latest g_{best} is the solution of the problem and then print the result and stop.

VII. NUMERICAL RESULTS

A. Test System

To verify the applicability and to evaluate the performance of the proposed PSO algorithm, a test system has been adapted from [22], [23]. It consists of a multi chain cascade of four hydro units, and a number of thermal units represented by an equivalent thermal plant. The schedule horizon is one day with 24 intervals of 1 hour each.

The cost of thermal generation can be obtained in two ways:

a) By using a standard economic dispatch technique to find the optimal operation cost of the on-line thermal generators.

b) By assuming the thermal generation is represented by an equivalent single plant, where characteristic can be determined as described in [1].

The hydraulic Sub-system is characterized by the following:

c) A multi chain cascade flow network, with all of the plants on one stream;

d) Reservoir transport delay between successive reservoirs;

e) Variable head hydro plants;

f) Variable natural inflow rates into each reservoir;

g) Variable load demand over scheduling period.

The data of the test system considered here are the same as in [10] and the additional data with valve point loading effect are also same as in Reference[11].

The hydro Sub-system configuration is shown in fig 1.

The hydraulic test network models most of the complexities encountered in practical hydro networks. The load demand, hydro units power generation Coefficients, river inflows, reservoir limits are given in reference [11].

The fuel cost function of the equivalent thermal plant unit with valve point loading is

$$C_i(P_{GTi}) = 5000 + 19.2\, P_{GTi} + 0.002\, P_{G2Ti} + \left| 700 \,\mathrm{Sin}\, (0.085\, (P_{GTi}^{min} - P_{GTi}) \right|$$

And the inequality constraint limit of this unit is

$$500_{\,(MW)} \leq P_{GTi} \leq 2500_{(MW)}$$

The Spillage rate for the hydraulic system is not taken into account for simplicity and further the electric loss from the hydro plant to the load is taken to be negligibly small.

To demonstrate the effectiveness of the proposed PSO method, the system is considered with prohibited discharge zones and with valve point loading effects.

B. Simulation Results

In short term hydrothermal scheduling problem, the two important parameters, that can be allowed to vary, are the satisfaction of the final reservoir levels and the cost of thermal generation. The present work has been implemented in command line of Matlab-7.0 for the solution of hydrothermal scheduling. The program was run on a 2.70 GHz, Pentium-® Dual core, with 1GB RAM PC. After a number of trails of run with different values of PSO parameters tuning , such as inertia weight, number of particles, maximum allowable velocity, the details of key parameters selected are: w_{max}=0.9,w_{min}=0.4,N=20,c_1=c_2=2.0,$iter_{max}$=100.

The optimal hydro generations , optimal hydro discharges, hydro reservoir levels with minimum cost obtained by the proposed PSO methods are reported in tables 6-8 respectively.

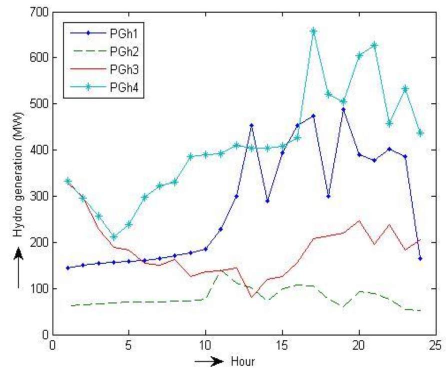

Fig.2 Hourly Hydro plant Power Generations

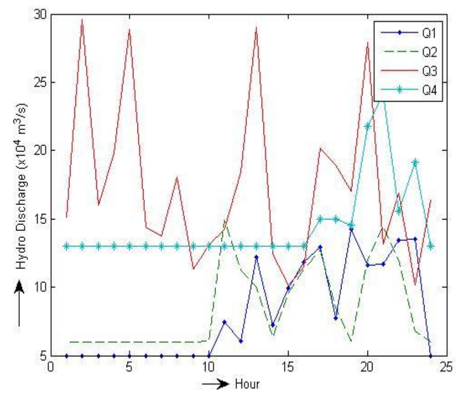

Fig.3 Hydro plant Discharge

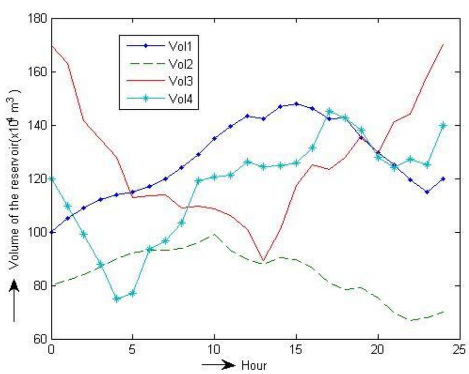

Fig.4 Hydro Reservoir Storage Volumes.

TABLE: 2 HOURLY PLANT DISCHARGES (X 10^4 M^3)

Hour	Q1	Q2	Q3	Q4
1	5.0000	6.0000	20.0855	13.0000
2	5.0000	6.0000	14.8462	13.0000
3	5.0000	6.0000	14.5574	13.0000
4	5.0000	6.0000	29.9338	13.0000
5	5.0000	6.0000	19.7629	13.0000
6	5.0000	6.0000	19.5213	13.0000
7	5.0000	11.1817	13.9664	13.0000
8	5.0000	8.5639	21.9058	13.0000
9	5.0000	11.6833	10.6531	13.0000
10	11.6845	11.1089	14.8067	13.0000
11	9.7279	10.0058	19.9333	13.0000
12	9.9741	10.3444	15.4261	13.0000
13	11.7367	8.4407	14.2368	13.0000
14	6.7460	11.6675	15.6500	13.0000
15	14.0606	6.1333	14.0058	13.0000
16	6.4655	11.7517	19.5437	13.0000
17	10.3722	8.9621	11.0288	13.0000
18	11.8711	8.9506	11.4574	13.0000
19	14.7748	10.8394	28.1152	15.7367
20	13.4112	6.6569	28.3459	13.0041
21	6.3168	8.4911	15.4668	22.2915
22	10.5628	6.5219	18.7661	23.0842
23	7.2958	8.6968	12.7706	23.4654
24	5.0000	6.0000	21.0000	13.0000

TABLE:1 HYDRO THERMAL POWER GENERATIONS AND OPERATING COST OF EQUIVALENT THERMAL UNIT.

Hour	Hydro1	Hydro2	Hydro3	Hydro4	Equivalent Thermal	Operating Cost	Loss	Demand
1	143.8144	61.8151	321.2825	332.7922	510.2957	14804.9367	0.0000	1370.0000
2	149.4909	63.5051	246.4740	296.0982	634.4318	18665.8623	0.0000	1390.0000
3	153.7395	66.0341	231.7937	256.5596	651.8732	18649.0470	0.0000	1360.0000
4	156.5676	68.5559	270.9775	211.3765	582.5224	16643.8241	0.0000	1290.0000
5	157.9804	70.2331	222.8005	236.0156	602.9704	16655.0631	0.0000	1290.0000
6	160.8036	71.0705	209.2636	242.4304	726.4318	20472.3135	0.0000	1410.0000
7	165.0319	108.7630	172.6008	247.8405	955.7637	25839.2282	0.0000	1650.0000
8	170.6580	87.6200	192.4158	306.5693	1242.7369	31761.7471	0.0000	2000.0000
9	177.6717	103.0794	130.8265	329.9760	1498.4464	38941.6308	0.0000	2240.0000
10	387.8581	96.4377	168.7674	352.5204	1314.4164	33180.3073	0.0000	2320.0000
11	336.3422	88.5497	182.2171	355.8591	1267.0319	33234.1502	0.0000	2230.0000
12	344.0508	87.0328	182.7510	386.6004	1309.5650	32919.0708	0.0000	2310.0000
13	394.6999	75.0250	194.3870	378.5038	1187.3842	31317.4820	0.0000	2230.0000
14	248.5863	88.4380	223.0302	384.7371	1255.2084	32716.0318	0.0000	2200.0000
15	469.3308	58.5306	227.5507	408.6391	965.9489	25699.8086	0.0000	2130.0000
16	239.6118	87.2711	279.7513	416.9959	1046.3699	27468.6170	0.0000	2070.0000
17	367.1793	71.1986	209.9862	421.2548	1060.3812	27083.0721	0.0000	2130.0000
18	400.2948	67.3058	221.6939	430.3770	1020.3285	27167.5092	0.0000	2140.0000
19	447.9425	69.5130	389.0751	501.1761	832.2933	21670.4962	0.0000	2240.0000
20	384.6560	51.9737	364.7770	447.0443	1031.5490	27629.5083	0.0000	2280.0000
21	198.8359	62.5183	279.2299	638.0259	1061.3901	27071.1105	0.0000	2240.0000
22	308.8412	53.9597	340.2419	583.4025	833.5546	21694.0029	0.0000	2120.0000
23	225.5577	65.7688	255.4101	619.4911	683.7723	18472.1612	0.0000	1850.0000
24	165.0319	51.6079	364.9660	436.9659	571.4283	17001.5918	0.0000	1590.0000

TABLE: 3 HOURLY STORAGE VOLUME OF HYDRO RESERVOIRS ($\times 10^4 m^3$)

Hour	Vol1	Vol2	Vol3	Vol4
0	100.0000	80.0000	170.0000	120.0000
1	105.0000	82.0000	158.0145	109.8000
2	109.0000	84.0000	151.3683	99.2000
3	112.0000	87.0000	145.8109	87.8000
4	114.0000	90.0000	128.8771	74.8000
5	115.0000	92.0000	123.1142	81.8855
6	117.0000	93.0000	118.5929	83.7317
7	120.0000	87.8183	118.6265	85.2891
8	124.0000	86.2544	109.7208	102.2229
9	129.0000	82.5711	111.0677	108.9858
10	128.3155	80.4622	113.4427	115.5071
11	130.5876	79.4564	108.0733	116.4735
12	130.6135	77.1120	118.0151	125.3792
13	129.8768	76.6713	128.6151	123.0323
14	135.1308	74.0038	135.9449	124.8390
15	132.0702	76.8705	147.0202	131.7723
16	135.6047	73.1188	144.6632	134.1984
17	134.2325	71.1567	161.3625	135.4352
18	130.3614	68.2061	164.5039	138.0852
19	122.5866	64.3667	159.5126	136.3543
20	115.1754	65.7098	152.9999	142.8939
21	115.8586	66.2187	163.2585	131.6312
22	113.2958	68.6968	170.7429	120.0043
23	115.0000	68.0000	171.9461	124.6541
24	120.0000	70.0000	170.0000	140.0000

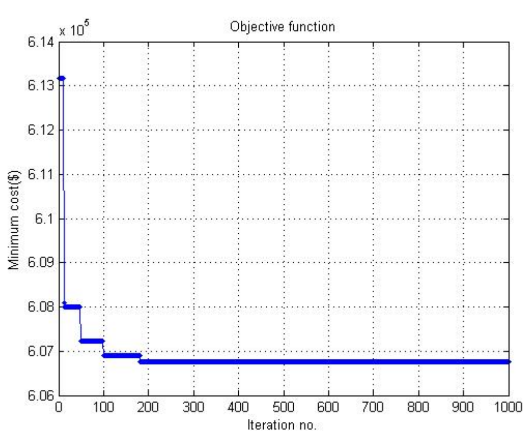

Fig.5 Convergence characteristic of PSO Algorithm for the test case.

TABLE: 4 SUMMARY OF TEST RESULTS

Method	Operating cost of equivalent thermal unit (in $)		Execution time(in sec)	
	Without Prohibited Discharge Zones	With Prohibited Discharge Zones	Without Prohibited Discharge Zones	With Prohibited Discharge Zones
PSO	602255.525216	606758.572623	111.916082	122.182410
GA	606958.862515	607154.561663	398.333785	422.213541

VIII. CONCLUSION

In this paper an approach of particle swarm optimization has been proposed and demonstrated to solve short – term hydrothermal scheduling problem. In the algorithm, the thermal generator units are represented by and equivalent unit. The generator load power balance equations and total water discharge equation have been subsumed into system model .constraints on the operational limits of the thermal and hydro units on the reservoir volume limits are also included in the algorithm. the numerical results show that the proposed approach is better than generic algorithm in terms of having better solution quality and good convergence characteristics. The PSO approach can easily be extended to other complex optimization problems faced by the utilities.

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