A Comparison Study of Short Term Scheduling of Hydrothermal System using PSO and GA

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Abstract- **In recent years various heuristic optimization methods have been developed. This paper presents an efficient and reliable Particle swarm optimization (PSO) based solution to solve short term scheduling of hydro thermal system. The solution approaches based on PSO technique is implemented and demonstrated to solve the hydro thermal scheduling problem with quadratic thermal cost function. PSO algorithm is compare with Genetic algorithm (GA) and results conformed the performance of solving non linear optimization problems .PSO algorithms are also capable of finding very nearly global solutions within a reasonable time.**

Key words- Hydrothermal scheduling; Particle swarm optimization, Genetic algorithm

I.INTRODUCTION

Hydrothermal scheduling (HTS) is an important planning task in power system operation whereby the generations of hydroelectric and thermal plants are so allocated as to minimize total operating cost of the thermal plants in a schedule horizon of 1 day or 1 week while satisfying various constraints on hydraulic and power system network. HTS is one of the most important and challenging optimization problems in the economic operation of power system. The optimal scheduling of hydrothermal power system is usually more complex than that for an all thermal system. It is basically a nonlinear programming problem involving non-linear objective function and a mixture of linear and non-linear constraints. Here Hydro energy is used for profit maximization that leads to thermal cost minimization of a hydro-Thermal system. The objective of the short term hydrothermal scheduling problem is to determine the water releases from each reservoir of the hydro system at each stage such that the operation cost is minimized along the planning period. The operation cost includes fuel costs for the thermal units, import costs from neighboring systems and penalties for load shedding. The basic question in hydro thermal coordination is to find a trade-off between a relative gain associated with immediate hydro generation and the expectation of future benefits coming from storage. HTS is basically a nonlinear programming problem which involves nonlinear objective function and a mixture of linear and nonlinear constraints. Particle swarm optimization a flexible, efficient global optimization technique is implemented to solve hydrothermal scheduling problem. Several methods have used to solve this complex problem such as fast evolutionary technique, differential evolution technique, La grangian relaxation technique [4], dynamic programming approach , genetic algorithm[8], mixed integer programming etc . Here in this paper the performance of PSO and GA is compared. The factors which influence power generation are operating efficiencies of generators, fuel cost and transmission losses.

The performances of different stochastic techniques have been studied in the literature .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. 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[8] and evolutionary programming [9-11].

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 . 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 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 .The same problem has been solved by GA [8] are compared. The performance of the proposed method is found to be quite encouraging as compared with Ganetic algorithm.

II. PROBLEM STATEMENT NOMENCLATURE:

PD_t: power demand at time t.

PH(j,t): power generation of h hydro plant at time t . PT(i,t):Power generation of h thermal plant at time t. I_{hjt}: water inflow rate of h reservoir at time t.

Q_{hjt}: water discharge rate of h hydro unit at time t.

$Q_{hj\ min}$,Q_{hjmax} :minimum and maximum water discharge rate of h reservoir.

S_{hjt} : spillage of $h$reservoir at time t.

V_{hjt} : storage volume of $h$reservoir at time t.

$V_{hj\ max}$, $V_{hj\ min}$: minimum and maximum storage volume of h reservoir.

a_i ,b_i,c_i,d_i ,e_i : cost coefficients of $h$thermal unit.

: Number of thermal generating unit.

h: Number of hydro generating unit.

τ : The water delay time between reservoir l and its upstream u at interval m.

R_u: Set of upstream units directly above the hydro plant j.

T , T^{ax}: Minimum and Maximum thermal power generation of a unit.

H , H^{ax} :Minimum and Maximum hydro power generation of h unit

h : Water discharge rate of $h$hydro unit at m interval

V_h : Volume of h hydro unit at m interval

H $^{ax}_{H}$: Minimum and maximum discharge rate of $h$hydro unit at any

V_H V^{ax}_H : Minimum and Maximum volume of h hydro unit at any interval

P_{so} : Prespecified power

V : Volume of h particle in d dimension for h interval

W : weight factor

x_c : Position of h particle in d dimension for h interval

Pbest ,gbest : particle best and global best value ngu : Number of generating unit

III. MATHEMATICAL FORMULATION

Short term hydro thermal scheduling involves optimal hourly scheduling of power generation among all the units so as to minimize the total operation cost subjected to various constraints. Schedules for hydro electric systems are developed which simulates the water system and leaves the reservoir levels with maximum amount of stored energy. Hydro plants has negligible operation cost but we need to operate under several constraints. Here hydro plant with cascaded reservoirs are considered, which involves constraints such as water inflow, water transport delay between reservoirs, physical limitations on reservoir storage. The problem of minimizing the operation cost of hydro thermal system can be viewed as one of minimizing the fuel cost of thermal plants under several hydraulic constraints. short- term scheduling of hydro-thermal systems is typically a large scale nonlinear optimization problem with complex constraints. Besides, it is also a non convex problem due to the prohibited operation regions of the thermal and hydro plant .In this scheduling as the scheduling interval of short range problem is small, the solution of the short-range problem can assume the head to be fairly constant. The amount of water to be utilized for the short- range scheduling problem is known from the solution of the long-range scheduling problem. Short-range hydro- scheduling (1 day to 1 week) involves the hour-by-hour scheduling of all generation on a system to achieve minimum production cost for the given time period. In such a scheduling problem, the load, hydraulic inflows, and unit availabilities are assumed known. A set of starting conditions (e.g. reservoir levels) is given, and the optimal hourly schedule that minimizes a desired objective, while meeting hydraulic steam, and electric system

constraints, is sought. Part of the hydraulic constraints may involve meeting “end- point” conditions at the end of the scheduling interval in order to conform to a long-range, water-release schedule previously established

A.OBJECTIVE FUNCTION

The optimization of a hydro thermal scheduling problem is done with a nonlinear objective cost function with dynamic network flow constraints. As hydro electric plants have no incremental cost the main objective of short term hydro thermal scheduling problem is to minimize the fuel cost of thermal plants such that the load demand is

For any time j,

$$\sum_{=1}^{max} \quad _{h}^{ax} \quad \geq \quad _{D} \quad , \quad = 1 \ldots\ldots\ldots\ldots\ldots \quad _{ax}$$

However, the energy the energy available from the hydro plant is insufficient to meet the load

$$\sum_{j=1}^{j_{max}} P_{hj} n_j \leq \sum_{j=1}^{j_{max}} P_{Dj} n_j$$

Where

n_j :Represents number of hours in period j

$\sum_{j=1}^{j_{max}} n_j = T_{max}$ = Total interval

use here the entire amount of energy from hydro plant in such a manner the cost of running steam power plant is minimized. The thermal power required is

$$\sum_{j=1}^{j_{max}} P_{Dj} n_j - \sum_{j=1}^{j_{max}} P_{hj} n_j = E$$

(Load energy) − (Hydro energy)= steam energy

It is not required the steam energy to run for the entire interval of T_{max} hours.

Therfore

$$\sum_{j=1}^{N_s} P_{tj} n_j = E$$

N_s is the run period for steam power plant

Then

$$\sum_{j=1}^{N_s} n_j \le T_{max}$$

The scheduling problem becomes

$$\text{Min } F_T \sum_{j=1}^{N_s} F(P_{tj})\, n_j$$

Subjected to

$$\sum_{j=1}^{N_s} P_{tj} n_j - E = 0$$

And the lagrange function is

$$£ = \sum_{j=1}^{N_s} F(P_{tj}) n_j + \alpha\left(E - \sum_{j=1}^{N_s} P_{tj} n_j\right)$$

Then

$$\frac{\partial £}{\partial P_{tj}} = \frac{dF(P_{tj})}{dP_{tj}} - \alpha = 0 \qquad , j = 1 \ldots\ldots\ldots\ldots\ldots\ldots N_s$$

This means that the steam power plant should be run at constant incremental cost for the entire period it is on. The total cost over the interval is

$$F_T = \sum_{j=1}^{N_s} F(P_t^*) n_j = F(P_t^*) \sum_{j=1}^{N_s} F(P_t^*) T_s^*$$

Where

$T_s = \sum_{j=1}^{N_s} n_{j=}$ The total run time for the steam power plant

The steam plant cost can be expressed as:

$F(Pt) = a+bPt+cP_t^2$

Then $FT= (a+bPt+cP_t^2)\, Ts$

Also

$$\sum_{j=1}^{j_{max}} P_{tj} n_j = \sum_{j=1}^{j_{max}} P_t^* n_j = P_t^* T_s$$

It is clear from the above that solution of hydrothermal scheduling problem requires solving for the thermal unit commitments and generation dispatch as well as the hydro schedules. The steam plant should be run at constant incremental cost for the entire period it is on. This optimum value of steam-generated power is P_t. This optimum value of steam generated power Pt resulting optimal hydro thermal schedule shows if the thermal and hydro plants are operated with each other then it results in economy. Steam plants and hydro plants, both are used to supply base load. During peak load it is economical to use hydro plants. Hence the thermal plant is preferred as a base load plants whereas the hydroelectric plant is run as a peak load plant.

B.SYSTEM CONSTRAINTS

The hydrothermal scheduling optimization problems are subjected to various hydraulic and network constraints depending on several thermal and hydro plant operating limits, variable demand, reservoir inflows, time coupling effect of hydro sub problem water discharge rate, initial and final reservoir volume. These constraints are discussed below:

Power balance equation: (Demand constraint)

The active power generation must balance the total demand and power losses in each time interval

$$\sum_{j=1}^{N_h} PH_{jm} + \sum_{i=1}^{N_s} PT_{im} = P_{Dm} + P_{loss}, \quad m \in M$$

Where m is the scheduling period.

Thermal generator constraint:

The thermal plant has a maximum and minimum power generation limit so that generation lies within this limit

$$PT^{min} \le PT_{im} \le PT^{max}, m \in M$$

Hydro generator constraint:

The hydro plant has a maximum and minimum power generation limit within which the generation of jth unit lies

$$PH_j^{min} \le PH_m \le PH_j^{max}, \quad m \in M, j \in Nh$$

Hydraulic Network constraints

Power generation characteristics

In hydro plant the power output is a function of the net hydraulic head H, reservoir volume V_H, and the rate of water discharge.

$P_{hjm} = F(Q_{hjm}, V_{hjm})$ and $V_{hjm} = F(Hjm)$

The model can be expressed in terms of reservoir volume as:

$$P_{hjm} = C1jV_{Hjm}^2 + c_{2j}Q_{Hjm}^2 + c_{3j}V_{Hjm}Q_{Hjm} + c_{4j}V_{Hjm} + c_{5j}Q_{Hjm} + c_{6j}, \quad j \in Nh, m \in M$$

Reservoir capacity constraints:

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

$$V_{Hj}^{min} \le V_{Hjm} \le V_{Hj}^{max}, \quad j \in Nh, m \in M$$

Reservoir end condition:

It is the desired volume of water to be discharged by each reservoir over a scheduling period.

$$VHjm|_{m=0} = V_{Hj}^{begin}, \quad j \in Nh$$

$$VHjm|_{m=m} = V_{Hj}^{end}$$

Water discharge constraint:

The physical limitation of water discharge of turbine, QHjm must lie in between maximum and minimum operating limits.

$$\le \quad {}_{HJ} \le {}^{ax}_{H}, \quad \in h, m \in$$

Hydraulic continuity equation constraint:

The storage reservoir volume is dependent on initial and final reservoir volume.

$$VHjmH = VHjm + \sum_{u=1}^{Ru} [Q_{Hu}(m - \tau_{lj}) + S_u(m - \tau_{lj})] - Q_{Hj(m+1)} - S_{j(m+1)} + \gamma_{j(m+1)}$$

for j∈Nh, m∈M

IV.PARTICLE SWARM OPTIMIZATION

PSO is a random search method (stochastic).The algorithm uses some kind of randomness or probability in definition and its literature.PSO mimics the behavior of individual in a swarm to maximize the survival of species. The PSO algorithm is population-based: a set of potential solutions evolves to approach a convenient solution (or set of solutions) for a problem. In the optimization process number of particles are created in a multidimensional search space. In quest of reaching optimum solution, the position and velocity of particles are updated based on summated influence of each particle present velocity, distance of particle from its own best performance and distance from leading particle (i.e particle that containing global best solution) . For present problem the position of each particle in the population is composed of set of elements which is the discharge rate of each hydro plant and power generated by each thermal plant. The coordinate of particle represents the objective function to be minimized. Let X be the position of the particle and V denotes the velocity. The position and velocity of ith particle in a d-dimensional space is represented as

Xi=(xi1, x id,........xid) and Vi=(vi1,vi2,........vid) respectively.

The best position of ith particle can be expressed as Pbesti=(Pbesti1,Pbesti2,.......Pbestid) and the index of best particle among all the particles in the group is expressed as gbestd . The velocity and position of each particle can be modified using current velocity and distance from Pbestid to gbestd by following formula:

$$V_{id}^{k+1} = w * V_{id}^{k} + c1rand()(Pbest_{id} - x_{id}^{k}) + c2rand()(gbest_{d} - x_{id}^{k})$$

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

For i=1,2,......... Np and d=1,2,...... Ng

Where Np is the number of particles in a group and Ng is the number of members in particles.
K is the iteration number.
W is the inertia weight factor. Suitable selection of w provides balance between global and local exploration, so require less number of iteration on average to get a global optimum solution. Generally w value decreases from 0.3 to -0.2during a run.
The w value is set according to the equation

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} * iter$$

where itermax is the maximum number of iteration and iter is the current iteration.
C1 and C2 are the acceleration constant which represent the weighting of the stochastic acceleration terms that pull each particle towards the Pbest and gbest positions.C1 ,C2 values are often set as 2 from past experience low or higher values may allow particles roam far from global solution .
Rand() is a function which provide uniform random value in the range of [0,1] .
v_i^k is the velocity of ith particle at kth iteration , $v_d^{min} \leq v_{id}^{k} \leq v_d^{max}$
x_i^k is the current position of ith particle at kth iteration.
As the position of each particle presents the discharge rate of hydro unit and power generation of thermal unit, the initialization kth individual with Nh number of hydro units and Ns number of thermal units can be done

$$x_k = [Q_{h1}^{(0)}, Q_{h2}^{(0)}, \ldots\ldots\ldots Q_{hj}^{(0)}, \ldots\ldots.. Q_{hN_h}^{(0)}, P_{s1}^{(0)}, P_{s2}^{(0)}, \ldots\ldots\ldots P_{si}^{(0)}, \ldots\ldots.., P_{sN_s}^{(0)}]^T$$

With

$$Q_{hj}^{(0)} = [Q_{hj1}^{(0)}, Q_{hj2}^{(0)}, \ldots.., Q_{hjt}^{(0)}, \ldots.. Q_{hjt}^{(0)}]^T \text{ and}$$

$$P_{si}^{(0)} = [P_{si1}^{(0)}, P_{si2}^{(0)}, \ldots\ldots\ldots P_{sit}^{(0)}, \ldots\ldots.. P_{siT}^{(0)}]^T$$

$Q_{hjt}^{(0)}$ is discharge rate of jth hydro plant $P_{sit}^{(0)}$ is the power output of ith thermal plant at time t.
Here for simplification spillage of the reservoir is assumed to be zero. The plants generation must lie within the permissible range and should meet the power balance constraint and discharge rate must satisfy the hydraulic constraints. Individual plants hydro and thermal must satisfy the constraints.

V.PSO ALGORITHM

The algorithm of PSO can be expressed as:

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 = [q11, q12, ……, q1m, q21, q22, …. q2m,…qn1, qn2, …., qnm], be the trait vector denoting the particles of population to be evolved. The elements of qjm are the discharges of turbines of reservoirs at various intervals subjected to their capacity constraints. qid, be the dependent discharge of ith hydro plant at dth interval is randomly selected from among the committed m intervals. Then, knowing the hydro discharges, storage volumes of reservoirs Vjm are calculated. Then PGHjm is calculated from for all the intervals.

Step 4

Compare each particle value with its Pbest, the best evaluations value among Pbest is denoted as gbest.

Step 5

Update the iteration as K = K+1 ; inertia weight, velocity& position .

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 gbest is the solution of the problem and then print the result and stop.

VI. GENETIC ALGORITHM:

It is a directed search algorithms based on the mechanics of biological evolution. It was developed by John Holland, University of Michigan in 1970.It is based on "Darwin"s Theory of Evolution" In the computer science field of artificial intelligence, a genetic algorithm (GA) is a search heuristic that mimics the process of natural evolution.

This heuristic is routinely used to generate useful solutions to optimization and search problems. Genetic algorithms belong to the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover.

STEPS :

1. Randomly initialize the chromosome size and then initialize the iteration size.
2. Find out the objective value (minimum cost) & convert the decimal no. to binary no.
3. Now cross-over between different sets of population.
4. Those chromosomes that are less fittest remove that set of chromosome and initialize new chromosome on that place.
5. If maximum iteration reached then terminate or go back to step 3.

VII. NUMERICAL RESULTS

A. Test System

To evaluate performance of proposed algorithm PSO, a test system consisting of a hydro and an equivalent thermal power plant is adapted. The schedule horizon is 3 days and there are six 12 hour intervals. The load pattern showing the load demand is shown in the table no.

The fuel cost function of the equivalent thermal unit is $F(Pt) = 0.00184P_t^2 + 9.2Pt + 575$ \$/h

Where $150 \leq P_t \leq P_t \leq 1500$MW

The water discharge rate of the hydro plant between 0 and 1000MW, and that between 1000 and 1100 MW are given as :

$Q = 330 + 4.97P_h$ acreft/h

$Q = 5300 + 12(P_h - 1000) + 0.05(P_h - 1000)^2$ acreft/h

The initial and final volumes of water in reservoir are 100000 and 60000 acre-ft, respectively. The minimum and maximum volumes of water are 60000 and 120000 acre-ft in all intervals .The water inflow rate is assumed to be constant at 2000 acre-ft/h and spillage is not considered .Also the electrical loss from the hydro plant to the load is taken to be negligibly small. The performance of proposed PSO algorithm is verified using a test system which consists of three hydro units and one equivalent thermal unit. The hydro unit is having cascaded reservoirs. The water transport delay between the connected reservoirs is considered. The reservoir configuration and water transport delays are shown below in the figure. The power generation of plants at lower stream is effected by transport delay and discharge of plant at upper stream. The hourly load demand is shown in the table10. The hydro units have four connected reservoirs out of which two are parallel and two are in series.

CONVERGENCE CHARACTERISTICS OF HT SYSTEM

The performance of proposed algorithm PSO is compared with Genetic algorithm (GA). All the programs were implemented in MATLAB command line .The control parameters in the PSO programs used for solving the test case were tuned .The Hydrothermal generation and the system costs obtained from proposed GA and PSO are summarized in Table. It can be seen from the table that the optimal cost obtained by the proposed PSO is the lowest compared to GA . The hourly varying load is tabulated below.

Interval number	Interval	Demand (MW)
1	1st day 12:00-24:00 h	1200
2	24:00 - 12:00	1500
3	2nd day 12:00 -	1100
4	24:00 -	1800
5	3rd 12:00 -24:00h	950
6	24:00 -	1300

Comparison of PSO with GA:

Technique	Interval number	Thermal generation	Hydro generation	Volume (acre-ft)	Discharge (acre-ft/h)	Cost ($)
GA	1	896.86	301.14	101960.94	1836.59	
	2	897.15	602.85	86046.83	3326.18	
	3	893.85	206.15	93791.98	1354.57	709863.56
	4	897.38	902.62	60000.00	4816.01	
	5	794.45	155.55	70763.09	1103.08	
	6	783.52	516.48	60000.01	2896.92	
PSO	1	902.2346	297.7654	102281.27	1089.89	
	2	898.8685	601.1315	86469.79	3317.62	
	3	871.1946	228.8054	92863.83	1467.16	709841.16
	4	912.9471	887.0529	60000.00	4738.65	
	5	790.8561	159.1439	70548.66	1120.94	
	6	787.1117	512.8883	60000.00	2879.06	

VIII. CONCLUSION

In this paper an approach of PSO method is verified and demonstrated in solving the short term hydro thermal scheduling problem. Numerical results show that highly near optimal solutions can be obtained by PSO. Particle swarm optimization method is compared with Genetic algorithm (GA) and it is found that PSO is better in terms of better solution quality and faster convergence rate. In the algorithm thermal generators are represented by equivalent unit. The generator load power balance equations and total water discharge equation have been subsumed into system model. Constraints on the operational limits are also included in the algorithm.

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