Advanced Research in Electrical and Electronic Engineering
Print ISSN: 2349-5804; Online ISSN: 2349-5812 Volume 2, Number 10 April-June (2015) pp. 108-112

http://www.krishisanskriti.org/areee.html

Hybrid GSA-SQP for SHORT Term Multi-chain Hydrothermal Scheduling

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Abstract—*This paper presents the hybrid Gravitational search algorithm(GSA) and sequential quadratic programming(SQP) technique to obtain an optimal solution for a short term multi chain hydrothermal system in order to minimize the total operating cost of the thermal power plant while satisfying the various operational and physical constraints. Gravitational search algorithm is a heuristic optimization technique based on the Newtonian law of gravity and motion in which all agents attracts each other and global movement is towards the agents with heavier masses. GSA is used as the global search technique for the exploration of the search space and obtaining a near global or global solution. Sequential Quadratic programming method is a local search technique used for the exploitation of the results obtained from the global search technique for short term multi chain hydrothermal scheduling.*

Keywords*: Gravitational search algorithm, hydrothermal scheduling, valve point loading, activemass, passive mass*

1. INTRODUCTION

The short term hydrothermal scheduling (STSH) plays an important in the optimal operation of the interconnected system. The objective of the short term multi chain hydrothermal scheduling is the optimal generation of the thermal power and optimal discharge of hydro plant in order to minimize the operating cost of the thermal power plant while satisfying various hydraulic and operational constraints [1].In past, STHS problem is solved by many conventional methods such as dynamic programming [2], lagrangian relaxation method [3], interior point method [4], mixed integer programming [5] and Newton raphson method [6] .In conventional methods simplified assumptions are made which results in the increase in computational time and slow convergence rate [7].Recently , many modern heuristic technique such as evolutionary programming method [8], simulated annealing method [9], artificial neural network [10] and genetic algorithm[11] has been used by theresearcher because of fast convergence and ability to determine almost global solution for the problem[12].

In 2009, Rashedi et al. [13] introduced Gravitational search algorithm (GSA) which is based on the Newton's law of gravity in which agents move towards the heavier agent because of the gravitational force from the other agents. Many researchers has used GSA on large number of problems such as multi-objective optimal reactive power dispatch problem [14], optimal power flow [15], designing of power system stabilizer [16], optimal energy management of microgrid [17].The drawback of the heuristic search techniques are trapping into local minima and giving near to global solution [18]. In order to avoid the drawbacks of the heuristic techniques, hybrid techniques are used .Hybrid techniques are the integration of local search and heuristic search. Heuristic technique is used to explore and obtain near to global optimum solution in the feasible space. Local search technique is used to exploit and obtain final solution [19]. Sivasubramani and Shanti Swarup [20] applied the hybrid DE-SQP technique to solve the short term hydrothermal scheduling problem and showed that the results obtained using the hybrid technique are better quality solutions.

In this paper, a hybrid method combining GSA and SQP has been proposed for the solution of the short term multi chain hydro thermal scheduling problem. Gravitational search algorithm is used for the exploration of the search space while SQP is used for the exploitation of the results obtained from GSA. In order to show the effectiveness of the proposed hybrid method, it has been applied to a hydrothermal test system having four hydro and three thermal units.

2. NOMENCLATURE

F_T is the total fuel cost of the thermal unit ($)

a_i,b_i,c_i,e_i,f_i are the cost curve coefficient of the i^{th}thermal unit.

P_{gik} and P_{hjk} are the output power of the i^{th} thermal unit and j^{th} hydro unit in the sub-interval *k*.

P_{gi}^{min} and P_{gi}^{max} are the lower and upper generating limits of the i^{th} thermal unit.

N and *M* are the number of the thermal unit and hydro units.

P_{Dk} and P_{Lk} are the power demand and transmission line losses in the sub-interval k in (MW).

P_{hj}^{min} and P_{hj}^{max} are the lower and upper limits of the j^{th} hydro power generated in (MW).

V_{hj}^{min} and V_{hj}^{max} represents minimum and maximum storage limit of the reservoir of reservoir j.

q_{hj}^{min} and q_{hj}^{max} are the minimum and maximum limit of the water discharge rate of reservoir j.

V_{hj}^{begin} and V_{hj}^{end} represents initial and final storage volume of the reservoir j.

I_{hjk} and S_{hjk} represents the inflow and spillage of the reservoir j in the sub-interval k.

d_{lj} and Ruj is the water transport delay from the lth to the jth reservoir and number of the upstream reservoir above the jth reservoir.

$C_{1j}, C_{2j}, C_{3j}, C_{4j}, C_{5j}, C_{6j}$ represents the power generation coefficient of the hydro power plant j.

q_{hjk} and V_{hjk} represents water discharge and storage of the hydro plant j in the sub-interval k.

T and r are scheduling period and exterior penalty factor.

3. PROBLEM FORMULATION OF THE SHORT TERM MULTI CHAIN HYDROTHERMAL SCHEDULING

Total operating cost [21] of the thermal power plant is given by :

$$F_T = \sum_{k=1}^{T}\sum_{i=1}^{N} a_i P_{gik}^2 + b_i P_{gik} + c_i + \left|e_i \times \sin(f_i \times (P_{gik}^{min} - P_{gik}))\right| \quad (1)$$

Reservoir volume [21] of the j^{th} reservoir in multi chain hydrothermal system is given by:

$$V_{hj}^{k+1} = V_{hjk} + I_{hjk} - q_{hjk} - S_{hjk} + \sum_{l=1}^{Ruj}\left(q_{hl,k-d_{lj}} + S_{hl,k-d_{lj}}\right) \quad (2)$$

Hydro power of the j^{th} hydro unit in multi chain hydrothermal system [21] is given by:

$$P_{hjk} = C_{1j} V_{hjk}^2 + C_{2j} q_{hjk}^2 + C_{3j} V_{hjk} q_{hjk} + C_{4j} q_{hjk} + C_{5j} q_{hjk} + C_{6j} \quad (3)$$

Subjected to :

(i) Real power balance constraint

$$\sum_{i=1}^{N} P_{gik} + \sum_{J=1}^{M} P_{hjk} = P_{Dk} + P_{Lk} (k \in T) \quad (4)$$

(ii) Thermal generator limit constraint

$$P_{gi}^{min} \le P_{gik} \le P_{gi}^{max} \; (i \in N \;\; , k \in T) \quad (5)$$

(iii) Hydro generator limit constraint

$$P_{hj}^{min} \le P_{hjk} \le P_{hj}^{max} \; (j \in M \;\; , k \in T) \quad (6)$$

(iv) Reservoir storage volume constraint

$$V_{hj}^{min} \le V_{hjk} \le V_{hj}^{max} \; (j \in M \;\; , k \in T) \quad (7)$$

(v) Water discharge rate limit constraint

$$q_{hj}^{min} \le q_{hjk} \le q_{hj}^{max} \; (j \in M \;\; , k \in T) \quad (8)$$

(vi) Initial and end reservoir storage volume constraint

$$V_{hjk}^{0} = V_{hj}^{begin} \; (j \in M \;\; , k \in T) \quad (9)$$

$$V_{hjk}^{T} = V_{hj}^{end} \; (j \in M \;\; , k \in T) \quad (10)$$

4. CONSTRAINT HANDLING

In short term multi chain hydrothermal scheduling,equality constraints are related to the demand and the final storage volume of the reservoir and inequality constraints are related to the reservoir storage volume and hydro generation of the hydro plant.

i) Error generated from the mismatch of demand and final storage volume are represented as:

$$e_d = (P_{Dk} + P_{Lk} - \textstyle\sum_{i=1}^{N} P_{gik} - \sum_{J=1}^{M} P_{hjk}) \quad (k \in T) \quad (11)$$

$$e_{veq} = (V_{hj}^{end} - V_{hjk}^{T}) \quad (12)$$

where, e_d and e_{veq} represents the error generated from the mismatch of demandand final volume of the reservoir.

ii) Error generated from the reservoir storage volume and hydro generation inequality is represented as follows:

(a) If the reservoir storage and hydro power has violatedits maximum limits

$$e_{vinq} = (V_{hj}^{max} - V_{hjk}) \quad (13)$$

$$e_{hydro} = (P_{hj}^{max} - P_{hjk}) \quad (14)$$

where ,e_{vinq} and e_{hydro} represent the error from the reservoir storage volume and hydro power inequalities.

(b) If the reservoir storage and hydro power has violated its minimum limits

$$e_{vinq} = (V_{hjk} - V_{hj}^{min}) \quad (15)$$

$$e_{hydro} = (P_{hjk} - P_{hj}^{min}) \quad (16)$$

Overall objective function formed is by adding all the errors with theirexterior penalties and fuel cost is calculated as :

$$\text{Objective} = F_T + r \times (e_d^2 + e_{veq}^2 + e_{vinq}^2 + e_{hydro}^2) \quad (17)$$

5. GRAVITATIONAL SEARCH ALGORITHM

Gravitational search algorithm is a heuristic optimization technique based on the law of gravity was developed by Rashidi et al.[13] in the year 2009.In GSA, agents are the objects and performance of the object are measured by their masses ,objects with higher fitness value will have heavier mass .All agents attract each other based on newton law of gravity resulting in a global movement of all the objects towards the object with heavier masses. The object with the heavier mass corresponds to the global solution .The steps involved in GSA are as follows:

Step 1: Initializing the position and velocity of the agent.

Position of the N number of agents is defined as

$X_i = (x_i^1, x_i^2 \ldots\ldots..x_i^d, \ldots\ldots\ldots..x_i^n)$, i ∈ N (18)

$V_l^0 = (V_{l1}^0, V_{l2}^0, \ldots\ldots\ldots\ldots\ldots\ldots, V_{lN}^0)$,i ∈ N (19)

where , x_i^d and V_l^0 represents the position and velocity of the i^{th} agent in the d^{th} dimension.

Step 2 : fitness calculation of all the agents

The best and worst fitness of all agents at each iteration is calculated as

$best(t) = \min \quad fit_j(t)$(20)

$worst(t) = \max \quad fit_j(t)$ (21)

fit_j represents the fitness value of the jth agent at iteration t , $best(t)$ and $worst(t)$ represents the best and the worst value of the fitness at iteration t.

Step 3: Gravitational constant (G) computation:

At each iteration, Gravitational constant G is computed as follows.

$G(t) = G_o e^{(-at/IT)}$(22)

G_o and a are initialized at the beginning. IT is the total number of iteration.

Step 4: Update the Gravitational and inertial masses

At each iteration, Gravitational and inertia masses for agents are updated as.

$M_{ai} = M_{pi} = M_{ii} = M_i, i \in N$ (23)

$m_i(t) = \frac{fit_i(t) - worst\,(t)}{best\,(t) - worst\,(t)}$(24)

$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)}$ (25)

M_{ai} and M_{pi} are the active and passive gravitational masses respectively, while M_{ii} is the inertia mass of the i^{th} agent.

Step 5: Calculation of the total force of the agents

At each iteration, total force on the agent is calculated as :

$F_i^d(t) = \sum_{j \in Kbest, j \neq i} rand_i F_{ij}^d(t)$(26)

where, $F_i^d(t)$ is the total force acting on i^{th} agent at d^{th} dimension . Kbest is the set of first K agents / solution vector with the biggest mass and best fitness value.

$F_{ij}^d(t)$ is computed as the following equation:

$$F_{ij}^d(t) = G(t).\left(M_{pi}(t) \times \frac{M_{aj}(t)}{R_{ij}(t)} + \varepsilon\right).\left(x_j^d(t) - x_i^d(t)\right) \quad (27)$$

$F_{ij}^d(t)$is the acting on agent i from agent j at d^{th} dimension andt^{th} iteration. $R_{ij}^d(t)$ is the Euclidian distance between two agents i and j at iteration t and ε is a small constant.

Step 6 : Calculation of the acceleration of the agent

At each iteration, acceleration of the agent is calculated as :

$a_i^d(t) = F_i^d(t)/M_{ii}(t)$(28)

Step 7: Update the Velocity and positions of agents:

Velocity and the position of the agents at next iteration (t+1) are computed based on the following equations:

$v_i^d(t+1) = rand_i \times v_i^d(t) + a_i^d(t)$(29)

$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1)$ (30)

Step 8: Repeat steps 2 to 7 till maximum iterations is reached

Step 2 to Step 7 is repeated until maximum iteration is reached. The best value of the fitness at final iteration corresponds to the global solution of the optimization problem.

6. SEQUENTIAL QUADRATIC PROGRAMMING

Sequential quadratic programming is one of the most effective method used for solving constrained optimization problem [22].Wilson proposed SQP in 1963, which is efficiently used as the local optimization technique [23] .SQP is considered as the generalization of the Newton's method for constrained optimization in which approximations are made for updating the hessian matrix using Boyden-Fletcher-Goldfarb-Shannon (BFGS) quasi-newton updation method. The results obtained from the approximation are used for generating quadratic programming (QP) sub-problem which gives the search direction for the line search procedure [22].

Quadratic programming problem is given as follows [24]:Minimize the following

$\frac{1}{2}(d^t)^T B^t d^t + \nabla f(x^t)^T d^t$(31)

Subjected to

$g_i(x^t)$+$[\nabla g(x^t)]^T g^t = 0$(i=1,2,3…..,$m_c$)(32)

$g_i(x^t)$ +$[\nabla g(x^t)]^T g^t \leq 0$ (i=m_c+1,…..…, m) (33)

where,B^t is the hessian matrix, d^t is search direction at t^{th} iteration, f(x) is objective function, g(x) is constraints, m is number of constraints, m_c is number of equality constraints.

7. DEVELOPMENT OF PROPOSED TECHNIQUE

Step 1:Read the value of all the parameters related to the proposed algorithm.

Step 2:Initializing the position and velocity of agentsusing equation (18) and (19)respectively.

Step3:For each agent, calculate the objective function using eq.(17).

Step 4:Calculate the best and worst value of the objective function using the equation (20) and (21) respectively

Step 5: Calculate the value of the gravitational constant (G) using the equation (22).

Step 6: Gravitational and inertia masses for each agent after each iteration are calculated using the equation (24) and (25) respectively.

The inertia mass, active and the passive gravitational mass is calculated with the help of the equation (23).

Step7: Calculation of total force and acceleration: using equation (27)and (28) respectively.

Step 8:Update the velocity and the position of the agents. using equation (29) and (30) respectively.

Step 9: Step 3 to Step 8 are repeated till maximum iteration is reached.

Step 10:Feasible solution obtained from the step 8 acts as the decision variables for SQP.

Step 11:Read the values of all parameters to the SQP ; viz. Maximum number of iteration, initial hessian matrix, step length.

Step 12:Calculate the search direction by solving quadratic programming (QP) sub-problem using equation (31)

Step 13:Update the position of the agent.

Step 14:If maximum number of iteration reached, go to step(15), otherwise go to step (12).

Step 15: The value of the objective function obtained is the final result.

8. SIMULATION RESULTS

To show the performance of the proposed algorithm, a test system having four hydro and three thermal units is considered[25]. The value of the G_o is set at 100 and the value of α is set at 10. The value of optimal discharge and thermal power generated are given in the table 2 and table 3, respectively. The cost obtained from the GSA-SQP and its comparison with other techniques is given in the table 1.

Table 1: Comparison of performance for Test system

Method	Total Fuel cost ($)
EP [26]	45,063
DE [27]	43,500
MDE [28]	43,453.41
PSO[29]	42,474
QPSO[30]	42,359
GSA-SQP	42,267.29

Tables 2: Optimal Hydro discharge ($\times 10^4 m^3/hr$)

Hours	q_1	q_2	q_3	q_4
1	9.864011	6.000000	30.00000	13.0000
2	9.351000	7.212898	18.17112	13.0000
3	10.50948	8.289877	30.00000	13.0000
4	5.000000	6.000000	30.00000	13.0000
5	6.697925	6.000000	30.00000	13.0000
6	6.786058	6.000000	13.12428	13.0000
7	7.945269	7.066204	13.71716	13.0000
8	15.00000	8.181024	13.57849	13.0000
9	8.384143	6.280075	13.59457	13.0000
10	8.829890	8.330127	30.00000	13.0000
11	9.457459	8.547413	10.01679	13.0000
12	8.713047	8.999712	24.57505	13.00000
13	7.126343	10.45817	11.83695	25.00000
14	7.643392	6.000000	30.00000	14.00797
15	9.725950	6.000000	14.40713	13.00000
16	5.000000	9.369091	13.86228	16.11900
17	8.252104	6.000000	15.49933	25.00000
18	10.36399	10.97428	10.00000	16.28006
19	8.661289	11.94274	15.00180	15.54235
20	8.527038	12.87386	13.11836	13.73087
21	7.866520	12.87563	10.00000	14.56397
22	5.000000	9.092800	10.00000	15.68425
23	5.000000	9.420831	10.00000	17.40943
24	5.470220	10.12190	10.00000	25.00000

Table 3: Optimal thermal power (MW)

Hour	P_{g1}	P_{g2}	P_{g3}
1	94.40157	147.3524	172.6284
2	70.26575	172.6136	166.3215
3	89.68177	233.4853	50.00000
4	20.00000	211.8134	156.3370
5	98.18646	78.88477	194.6243
6	103.9415	157.6028	192.9117
7	20.00000	276.2679	273.7021
8	112.9990	300.0000	171.8573
9	175.0000	233.9001	269.6313
10	126.8521	276.1512	289.5848
11	146.4870	269.0651	249.1898
12	89.95898	167.0826	500.0000
13	129.7886	204.4565	282.3550
14	175.0000	197.3196	274.1905
15	115.2532	236.8766	233.4640
16	89.32261	300.0000	219.5672
17	134.1251	174.6958	253.3245
18	70.39182	287.6437	264.6953
19	143.8571	213.2755	232.2151
20	150.3682	199.2674	234.1356
21	175.0000	78.34879	187.0075
22	78.38979	116.5456	225.0708
23	67.15701	169.8674	158.4690
24	57.15262	40.00000	217.8372

9. CONCLUSION

This paper presents a hybrid GSA-SQP technique for solving short term multi chain hydro thermal scheduling problem. The effectiveness of the proposed algorithm is illustrated by using four hydro and three thermal units. The results obtained by using hybrid GSA-SQP has been compared with other evolutionary algorithm used in the literature. It can be observed from the comparison that the proposed GSA-SQP technique provides better results from other evolutionary algorithm.

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