



APPLICATION OF INTEGRATED GENETIC ALGORITHMS AND TABU SEARCH FOR SHORT TERM HYDROTHERMAL SCHEDULING WITH PROHIBITED OPERATING ZONES

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ABSTRACT

This paper presents a deterministic model, which takes into account the final water storage and the effects of water head, for optimal short term generation scheduling of a hydrothermal system. Considering its large scale mixed integer nonlinear structure, a hybrid algorithm based on Genetic Algorithm and tabu search is developed to solve it. The model is divided into thermal power dispatch and hydro power dispatch subproblems respectively by using reservoir volumes as genetic variables which consider the complex relationship between reservoirs. These two subproblems are independently solved according to their own characteristics. The simulation results reveal that comparing with GA the hybrid algorithm is an effective method with shorter computation time and higher precision.

Keywords-hydrothermal scheduling; genetic algorithm; short term; tabu search; decomposition algorithm; prohibited operating zones

I. INTRODUCTION

The efficient use of available energy resources for satisfying load demands is an important task in power systems due to resources shortage and environmental pollution nowadays. Hydrothermal scheduling is of great significance [1], for the rich water storage and the significant number of hydro plants participated in southern, central, and northwestern parts of India. After the mid-long term hydrothermal generation scheduling, coal consumption, total amount of pollutant emission and power shortage is basically fixed. Hence, it is of great potential to energy conservation by a rational mid-long term hydrothermal scheduling. Several approaches have been proposed for the solution of the mid-long term hydrothermal scheduling. In [2] a convex programming model, under certain assumptions, was introduced by minimizing the sum of total fuel cost and outage cost minus the stored potential water energy at the end of plan period, and it was solved by a closed-loop algorithm. In [3] a principle to meet the requirement of making the best use of hydropower in an “open, impartial and just manner” was proposed that

used hydropower firstly and then allocated load between thermal power plants with the rule of same annual utilization hours or minimum purchasing charge. In [4] the problem was formulated to minimize the total coal consumption solved by real coded genetic algorithms, which were carried out according to a given probability distribution of crossover, mutation. In [5] a hydrothermal power system multiobjective optimal dispatching model solved by an interactive algorithm with tolerant constraint was introduced. The above methods have their own advantages and disadvantages respectively. The short term hydrothermal generation scheduling is a large scale nonlinear problem with equality and inequality constraints which is very difficult to figure out [6]. Network flow algorithm [7], mixed integer programming approach [8], linear programming [9], dynamic programming [10], GA [11], PSO [12], etc. are all applied to this problem. GA has been successfully applied to power system problems since it could handle with nonlinear and nonconvex problems with discrete variables effectively and it also has

advantage of good robustness, global optimization, and parallel processing.

This paper established a deterministic short term hydrothermal model solved by a hybrid algorithm based on Genetic Algorithm and decomposition algorithm. Lastly, the model is computationally evaluated through two different scale experiments.

II. MATHEMATICAL MODEL

Given that generating units in the same plant may have different characteristics, the mid-long term hydrothermal model is established to the unit level to improve model accuracy.

A. Objective Function

The model proposed aims at minimizing the total quantity of coal consumption minus the stored potential water energy at the end of plan period. Formally, this is represented by the objective function:

$$f_{CTk} = \sum_{t=1}^T \sum_{i=1}^n F_{C_i}(P_{si}(t)) \quad (1)$$

Where

n – no of units
 T – no of interval

Where T is the plan period; NI and NS are numbers of thermal units and hydro plants; $Fi(wi,t)$ is quantity of coal consumption for the thermal i during the period t ; Ehp is the potential water energy stored finally at hydro plant hp ; vhp,T and vhp,min are final capacity and dead storage capacity of reservoir hp ; $\omega hp-v$ is mean water coal transformation coefficient of reservoir hp ; $VT(hp)$ is water stored finally at hydro plant hp ; Uhp is the set of direct upstream hydro plants of plant hp .

B. Constraints

1) Load balance

$$\sum_{t=1}^T w_{i,t} + \sum_{h=1}^n w_{h,t} = W_{D,t} \quad (2)$$

Where NH is number of hydro units; $w_{i,t}$ and $w_{h,t}$ are energy generated by thermal unit i and hydro unit h ; $W_{D,i}$ is load demand.

2) Power generation limits of units

$$w_{i,t} \leq w_{i,t \max} \quad (3)$$

$$w_{h,t} \leq w_{h,t \max} \quad (4)$$

Where $w_{i,t \max}$ and $w_{h,t \max}$ are maximum power output deducting the influence of maintenance.

3) Flow limits of units

$$q_{h,t} \leq Q_h \quad (5)$$

Where $q_{h,t}$ is mean water flow in unit h in period t ; Q_h is max flow in unit h .

4) Hydro output equation

$$P_{h,t} = f(q_{hp}, v_{hp,t}) \quad (6)$$

Where ph,t is the mean output in unit h ; vhp,t is the water volume in reservoir hp which unit h belongs to.

5) Expected output limits of hydro units

$$w_{h,t} \leq W_{hp,v} \quad (7)$$

Where $w_{h,t}$ is the maximum output for hydro unit h when the water volume in the reservoir hp is v .

6) Limit storage capacity for each reservoir

$$V_{hp,t \min} \leq v_{hp,t} \leq V_{hp,t \max} \quad (8)$$

7) Initial volume

$$v_{hp,0} = V_{hp,0} \quad (9)$$

8) Flow limits of reservoir

$$\begin{aligned} QS_{hp,t \max} &\geq qs_{hp,t} \geq QS_{hp,t \min} \\ qs_{hp,t} &= q_{hp,t} + s_{hp,t} \\ q_{hp} &= \sum_{h \in Hhp} q_{h,t} \end{aligned} \quad (10)$$

Where $q_{shp,t}$ and $q_{hp,t}$ are mean discharge through reservoir hp and mean flow used to generate power in reservoir hp ; $s_{hp,t}$ is mean spillage, H_{hp} is the set of hydro units belonging to plant hp ; $q_{h,t}$ is mean flow through turbine h ; $QS_{hp,t \min}$ and $QS_{hp,t \max}$ are minimum and maximum flow.

9) reservoir water balance

$$V_{hp,t} = v_{hp,t-1} + (R_{hp,t} + \sum_{k \in Uhp} qs_{k,t}) * \Delta t \quad (11)$$

Where R_{hp} is mean inflow in reservoir hp , Δt is the length of period t .

III. GENETIC ALGORITHM

Generally, both hydro power and thermal power variables are chosen to be genes (described in Figure 1) and a near-optimal solution is achieved by the global searching ability of GA. To get a more accurate solution, the number of iterations needs to be increased. Once the scale of the hydrothermal system becomes larger, the number of GA genes will increase simultaneously while the computation time will significantly increase too. To overcome this problem, a better way to solve it must be found. Note that if a hydro power generation scheme is made, there will only be one optimal thermal power generation scheduling scheme corresponding to it. Thus, this paper develops a hybrid algorithm (described in Figure 2) by embedding decomposition algorithm and traditional mathematical programming in GA. Through this method the multi-period hydrothermal generation problem is decoupled into a single-period economic dispatch subproblem for each hydro plant and a single-period economic dispatch subproblem for thermal power system respectively (described in Figure 3). Then these two subproblems are solved independently according to their own characteristics.

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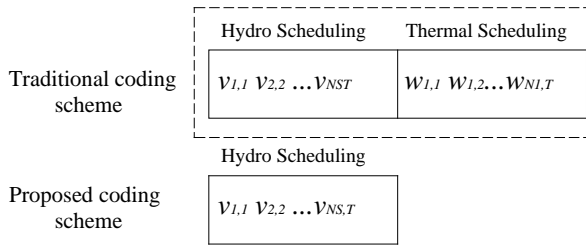


Figure 1. Coding schemes of GA and of hybrid Algorithm

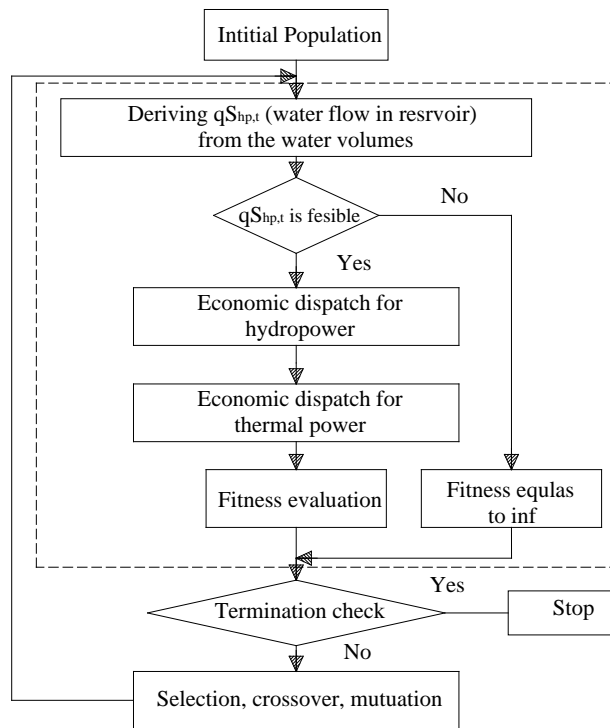


Figure 1. Flow Chart of the hybrid algorithm

A. Initialization

Reservoir volumes are chosen as decision variables for GA. The binary coding method is mostly used in GA which is easily to be elaborated by evolution theory and also makes the crossover and mutation operation easy. But it has the disadvantage that the chromosome string is very much long and inaccurate, constraints need to be converted to binary variables, and the calculated amount increases for the encoding and decoding operations in every iteration. To overcome these problems a real coded method is used in this paper.

1) *Calculating discharges of reservoir:* Reservoir discharge is a function of reservoir inflows and reservoir volumes. Discharges of each reservoir in every period can be calculated by equation (11), the reservoir volumes obtained by genes and the known reservoir inflows. If the discharges can't meet constraint (10), go to part C directly and set fitness value of the individual to infinity. 2) *Solving*

hydropower subproblems: After Step 1) there is one certain reservoir discharge corresponds to each reservoir h in one period t . Hydropower subproblems can be defined as allocating reservoir discharge to hydro units in one reservoir for one period economically, which can be expressed as:

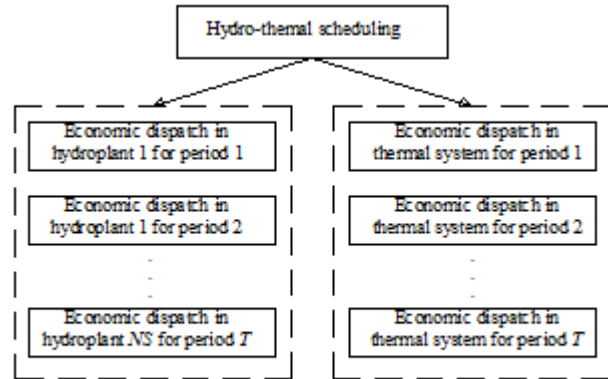


Figure 3 Decomposition for the hydrothermal generation problem

GA's initial population has a great impact on the final solution. If more feasible and scattered population is generated initially, the convergence speed will be faster and the accuracy of the results will be higher [13]. For the complex relationship between reservoir volumes both in time and space in this large-scale hydropower problem, the feasibility of initial population generated randomly is difficult to be guaranteed. And even if a feasible solution is got through series of selection, crossover, and mutation latterly, it still tends to fall into local optimum for lack of diversification. Therefore, it is necessary to find a way to generate feasible initial population with high efficiency for our problem. So the dynamic method proposed in paper [14] is used to generate initial feasible population that satisfying the constraints (8)-(11).

B. Decoding and Fitness Evaluation

$$\max \sum p_{h,t} \quad h \in H, p \quad (12)$$

And the constraints are (4)-(7), (10). The solution is acquired by solving this subproblem with some appropriate method, such as Lagrange multipliers. After applying this model to every hydro plant in every period the whole hydro power scheme is obtained.

3) *Solving thermal power subproblems:* Thermal power is used to balance the remaining load by deducting hydro power output. This subproblem can be defined as a single-period economic dispatch of thermal units satisfying energy balance which can be expressed as:

$$NI$$

$$(13) \quad \min \sum_{i=1} F_i(w_{i,t})$$

And the constraints are (2)-(3). Since the using of GA constraint (2) can be rewritten as:

$$NI \quad NH \\ \sum_{i=1} w_{i,t} + \sum_{h=1} w_{h,t} + \Delta w_t = W_{D,t} \quad (14)$$

The generation scheme of thermal units and power shortage Δw_t are acquired by solving this subproblem with some appropriate method. After applying this model to every period, the whole thermal power scheme is obtained.

4) *Calculating individual fitness:* In order to compare different solutions, the fitness evaluation of each individual must be done. It is achieved by the function as:

$$T \quad NI \quad NS \quad t=T \\ \min \sum_{t=1} \sum_{i=1} F_i(w_{i,t}) - \sum_{hp=1} E_{hp} + \lambda \sum_{t=1} \Delta w_t \quad (15)$$

Where λ is a penalty factor for power imbalance.

C. Termination Check

Once some individual meet the termination condition, output the current optimal solution and stop the calculation.

D. Selection

Tournament and Elitism is used to pick out individuals that the better one in two individuals, randomly selected from the current population, is selected and the best individual of the current population is directly copied to be member of next generation. This selection method avoid the selection probability of the individual to be directly proportional to its fitness value, while ensuring better individuals are more probably to be selected than others.

E. Crossover and Mutation

Two-point crossover is used in crossover operation. It selects two bits randomly, and the parents selected exchange the string between these bits. A non-uniform mutation operator is applied to prevent the premature stopping of the algorithm in a local solution. The mutation factor changes with the evolutionary generation that a random search is applied in the initial stage of evolution and a local search is applied in the late stages. After crossover and mutation it turns to part B.

IV. TABU SEARCH

GAs can identify the high performance region of the solution space at quick execution time. But faces difficulties in exactly locating the global optimal

solution in the search space. Tabu search (TS) is one of the modern evolutionary computing techniques suitable for local search. TABU means "Forbidden Repetitions". The repeated visits of the search algorithm on the already visited points in the solution space can be avoided by TS. By maintaining Tabu list and Aspiration criteria, the above can be achieved.

V. COMPUTATIONAL RESULTS

The hybrid algorithm proposed was applied to two different hydrothermal systems and compared with GA. In order to prove the validity and usefulness of the proposed algorithm with TS, result of hydrothermal scheduling problem was considered.

Interval Number	Day	Interval	Demand (MW)
1	1 st day	0 hour – 12.0 hour	855
2	1 st day	12.0 hour – 24.0 hour	815
3	2 nd day	0 hour – 12.0 hour	800
4	2 nd day	12.0 hour – 24.0 hour	856
5	3 rd day	0 hour – 12.0 hour	889
6	3 rd day	12.0 hour – 24.0 hour	900

Table 1. The Load Demands Over Six 12-Hour Intervals

The test system is from Yang et al [6]. It consists of a hydro plant and an equivalent thermal plant. The load demands over six 12-hour intervals are shown in table 1.

Constraints:

- *Steam Power:* $50MW \leq P_{S1} \leq 200MW$
 $40 MW \leq P_{S2} \leq 170MW$
 $30 MW \leq P_{S3} \leq 215MW$
- *Hydro Power:* $0 \leq P_H \leq 1100MW$
- *Volume of reservoir :* $60000 \leq V \leq 120000$
- *Rate Of Discharge :* $330 \leq Q \leq 7000$

TABLE II. PROHIBITED OPERATING ZONES FOR THE THERMAL UNIT IN THE TEST SYSTEM

ZONE I	ZONE II	ZONE III	ZONE IV
870 - 910	790 - 810	750 - 755	1200 - 1230

The test case was solved by proposed algorithm and the solution obtained is compared with the other methods like genetic algorithm, genetic algorithm with POZ as additional constraint, particle swarm optimization, and PSO using POZ as additional constraint.

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Interval	Steam power of plant 1 (MW)	Steam power of plant 2 (MW)	Steam power of plant 3 (MW)	Hydro power (MW)	Volume of reservoir m ³
1	69.4	92.5	208.4	429.6	91,138
2	147	106.2	201.2	345.45	82,276
3	110	147	175.8	367.11	80,819
4	160.5	46.1	61.1	532.09	78,964
5	51.1	108.8	85.1	554.86	63,930
6	144.7	168.47	184.9	401.9	60,000

Table 3. GA Results

The following are the results obtained by applying only Genetic Algorithms with prohibited operating zones as additional constraint for the chosen test problem. The steam powers, hydro powers, rate of discharge, volume of the reservoir and total cost are displayed.

Interval	Steam power of plant 1 (MW)	Steam power of plant 2 (MW)	Steam power of plant 3 (MW)	Hydro power (MW)	Volume of reservoir m ³
1	171.3	93.3	166.6	423.6	94,924
2	112.5	124.3	158.8	419.3	89,699
3	109.4	98.4	163.1	429	84,731
4	98.4	80	128.6	549	79,185
5	85.8	92.9	92.9	617.2	66,486
6	143.9	119.2	192	444.7	60,000

Table 3. Integrated Genetic Tabu search Results

TABLE IV. COMPARISON OF RESULTS

Sl. No	Optimization Method	Generation Cost (\$)
1	Genetic Algorithms (GA)	77,995
2	Integrated Genetic Tabu search	75,565

This shows the efficiency of the proposed algorithm. The generation cost is decreased by using the proposed algorithm and also by including Prohibited Operating Zones as additional constraint.

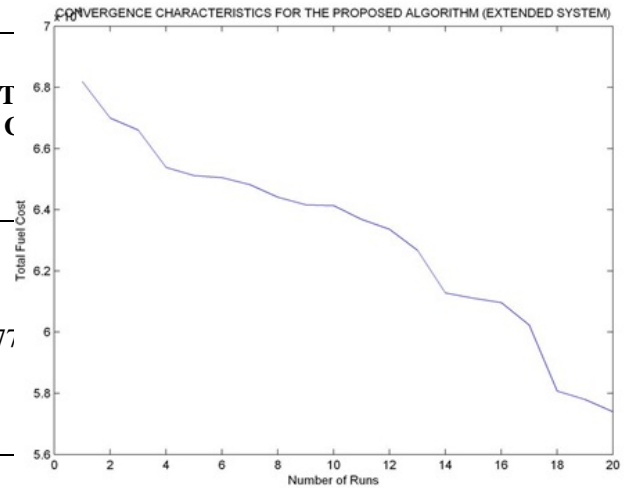


Figure 4. Convergence characteristics of proposed technique.

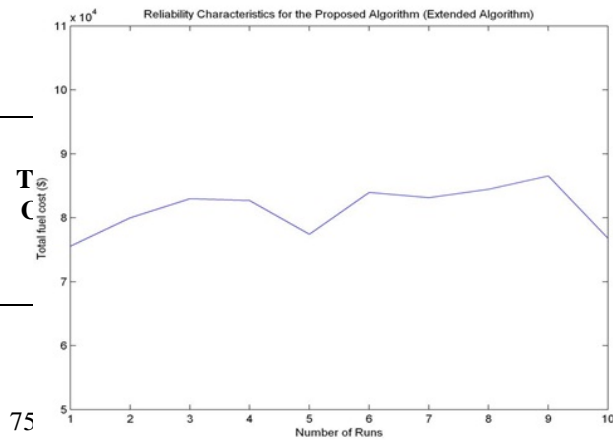


Figure 5. Reliability Characteristics of Proposed Algorithm.

V. CONCLUSIONS

In this paper, integrated genetic tabu search algorithm is proposed to solve the hydro thermal scheduling problem. A three thermal and one hydro unit system has been taken for the study the prohibited operating zones also included as one of the constraint. The example problem has been solved by the proposed algorithm and the results have been compared with other methods from the comparison results, the solution quality and computational efficiency of the proposed algorithm is demonstrated.

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