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Short Term Hydrothermal Scheduling Using Dynamic Programming and Genetic Algorithm

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Abstract

Short-term hydrothermal scheduling (STHTS) is a very complicated optimization problem. Many successful and powerful optimization methods and algorithms have been employed to solve this problem. In this paper Dynamic programming algorithm and Genetic algorithm are used to solve the short term hydrothermal scheduling problem. It is a dynamic non-linear problem and requires solving unit commitment and economic power load dispatch problems. The main purpose of hydrothermal coordination is to minimize the cost of operation subject to attainment of a certain level of security and reliability. Also, owing to environmental considerations, operation at absolute minimum cost cannot be the only objective of optimal thermal unit commitment in the recent year. The environmental effect of thermal power generation is also becoming a major concern in most countries.

Index terms: dynamic programming, genetic algorithm, hydro thermal scheduling, optimal solution.

Introduction

A modern power system consists of a large number of thermal and hydel plants connected at various load centers. The main objective in the operation of such a power system is to meet the system load demand at minimum fuel cost by an optimal mix of various types of plants. The study of the problem of optimum scheduling of power generation at various plants in a power system is of more importance, particularly where the hydel sources are scares and high cost of thermal generation has to be depend upon to meet the power demand. The hydel resources being extremely limited, the worth of water is greatly increased. If optimum use is made of their limited resource in conjunction with the thermal sources, huge saving in fuel and the associated cost can be made.

Different methods have been proposed to solve these hydrothermal scheduling problems in the past. Pontryagin's maximum principle [5], Variational methods [7], the dynamic programming [2, 17, 18] and general mathematical programming [1, 9] have been used to solve the problem in different formulations. Methods based on Lagrangian multiplier and gradient search techniques [13] for finding the most economical hydrothermal generation schedule under practical constraints have been well documented. The stochastic search algorithms like Simulated Annealing (SA) [15], Genetic Algorithm (GA) [16], Dynamic Strategy (DS) [4] and Dynamic Programming (DP) may prove to be very efficient in solving highly nonlinear HS problems since they do not place any restriction on the shape of the cost curves and other non-linearities in model representation.

In certain sectors, however, the hydel source is sufficiently large, particularly in rainy season as the inflows into the hydel reservoirs exhibits an annual cyclicity. Furthermore, there may be a seasonal variation in power demand on the system, and this too exhibits an annual cylicity. The solution to the scheduling problem in this case consists of determination of amount of water quantities to be drawn from the reservoirs for hydel generation in each sub-interval and the corresponding thermal generations to meet the load demand over each interval utilizing the entire quantity of water available for power generation during the total interval.

The short range problem usually has an interval of a day or a week. For scheduled purposes this period is normally divided in to sub-intervals. Here, the load, water inflows and unit availabilities are assumes to be known. A set of starting conditions (i.e. reservoirs levels) being given, the optimal hourly schedule can be prepared that minimizes a desired objective while meeting system constraints successfully.

Problem Formulation

The short term hydrothermal coordination (1 Day to 1 week) involves the hour-by-hour scheduling of a generation on a system to achieve minimum production cost for the given time period. Therefore, it accepts the result of a unit commitment program and assumes that the unit commitment will not be changed throughout the study time period. In this paper, the study time range is assumed to be one day broken into 24 h. The formulation is given as in the following section.

Objective function

The main objective of the present work is:

1. To find solution of short term hydrothermal scheduling (HS) problem so that the total fuel cost is minimized while satisfying the constraints.
2. To develop and study the performances of dynamic programs and genetic algorithm in solving HS problem.

3. Introduction of HS problem followed by a clear description of DP and GA for solution of HS problem and finally reporting of the results.

Thermal Model

The objective function is to minimize the total operating cost (C) represented by the fuel cost of thermal generation over the optimization interval (T).

$$C = \sum_{k=1}^{T} \sum_{i=1}^{N} t_k F_t(P_{tk}) \tag{1}$$

Where the problem is to schedule the power generation of all units over t_k time sub-intervals in order to minimize the fuel cost which is given as:

$$F_i\,(P_{ik}) = a_i P^2_{ik} + b_i\, P_{ik} + c_i \tag{2}$$

$k = 1.......T,\ i = 1......N$

Where a_i, b_i and c_i are cost coefficients of the i^{th} generating unit.

Hydro model

In hydro system, there is no fuel cost incurred in the operation of hydro unit. According to Glimn-krichmayer model, discharge is a function of power output and the head. For large capacity reservoir it is practical to assume that the effective head is constant over the optimization interval. Thus q_{jk} is the rate of discharge from the j^{th} unit in the interval k and is represented by the quadratic equation:

$$q_{ik} = X_j\, P^2_{j+N.k} + Y_j\, P_{\,j+N.k} + Z_j \tag{3}$$

Where $x_j\, y_j$ and z_j are the discharge coefficients of the hydro units.

Constraints

Load Demand Equality Constraints

$$\sum_{i=1}^{N+M} P_{ik} = P_{dk} + P_{loss\,k} \tag{4}$$

Where P_{dk} is the load demand during the k^{th} sub-interval and P_{lossk} are the transmission losses during the k^{th} interval.

Minimum and Maximum Power Generation Limits from View Point of Economy and Capacity of Generating Units

$$P_{imin} < P_{ik} < P_{imax} \tag{5}$$

Where P_{ik} Power output of the generating units in MW during the k^{th} interval, P_{max} is the maximum power of a generating unit in MW and P_{min} is the minimum power of a generating unit in MW.

Transmission Losses

The transmission losses during k^{th} interval are given by the Kron's loss formula in terms of B- coefficients.

$$P_{loss\,k} = \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} P_{ik}B_{ij}\,P_{ik} + B_{i0}\,P_{ik} + B_{00} \tag{6}$$

The fixed head hydro thermal problem can be defined considering the optimization interval to meet the load demand in each interval. Each hydro plant is constrained by the amount of water available for draw-down in the interval.

Dynamic programming

The basis for Dynamic Programming (DP) is the theory of optimality elucidated by Bellman in 1957. This method can be used to explain crises in which many chronological conclusions are to be taken in defining the optimum operation of a system, which consists of distinct number of stages. The searching may be in forward or backward direction**.** Within a time period the combinations of units are known as the states. In Forward DP an excellent economic schedule is obtained by commencing at the preliminary stage amassing the total costs, then retracing from the combination of least accumulated cost starting at the last stage and finishing at the initial stage. The stages of the DP problem are the periods of the study horizon. Each stage usually corresponds to one hour of operation i.e., combinations of units steps forward one hour at a time, and arrangements of the units that are to be scheduled are stored for each hour. Finally, by backpedaling from the arrangement with smallest amount of total cost at the final hour throughout the finest path to the arrangement at the preliminary hour the most economical schedule is acquired. The estimation of each and every combination is not convenient evidently. Additionally, several of the combinations are prohibited due to insufficient existing capacity.

DP solution to the hydrothermal scheduling problem

Dynamic programming may be applied to the solution of the hydrothermal scheduling problem. The multi plant hydraulically coupled systems offer computational difficulties that make it difficult to use those types of system to illustrate the benefits of applying DP to this problem. Here we will illustrate the application of DP with a single hydro plant operated in conjunction with a thermal system. Figure.1 shows a single, equivalent steam plant, P_s, and a hydro plant with storage, P_H, serving a single series of loads; P_L. Time intervals are denoted by j, where j runs between 1 and j_{max}.

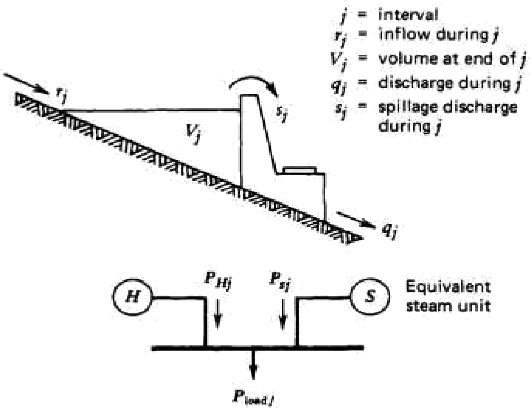

Figure.1 Hydrothermal system

Both starting and ending storage volumes, V_O and V_{jmax}, are given, as are the period loads. The steam plant is assumed to be on for the entire period. Its input-output characteristic is

$$F_j = a + b\,P_{sj} + c\,P_{sj}^2 \tag{7}$$

The water use rate characteristics of the hydroelectric plant is

$q_j = d + g\,P_{Hj} + h\,P_{Hj}^2$, acre-ft/h for $P_{Hj} > 0$

and

$q_j = 0$ for $P_{Hj} = 0$

The coefficients a through h are constants. Take the units of water flow rate acre-ft/h. If each interval, j is n_j hours long, the volume in storage changes as

$$V_j = V_{j-1} + n_j(r_j - q_j - s_j) \tag{8}$$

Spilling water will not be permitted (i.e., all s_j=0)

If V_i and V_K denote two different volume states, and

$$V_{j-1}\text{-}1 = V_i \tag{9}$$

$$V_j = V_K \tag{10}$$

Then, the rate of flow through the hydro-unit during interval j is

$$q_j = ((V_i - V_K) / n_j) + r_j \tag{11}$$

where, q_j must be non-negative and is limited to some maximum flow rate, q_{max}, which corresponds to the maximum power output of the hydro -unit.

The scheduling problem involves finding the minimum cost trajectory (i.e the volume at each stage).

The DP algorithm is quite simple. Let

{i}= the volume states at the start of the period j

{k}=the states at the end of j

$TC_K(j)$= the total cost from the start of the scheduling period to the end of period j for the reservoir storage V_k

PC(i,j-1:k,j)= production cost of the thermal system in period j to go from an initial volume of V_i to an end of period volume V_k.

Genetic Algorithm

Genetic algorithms have been widely applied to power systems since they were introduced by John Holland in his book in 1975. GA is a search technique that searches for a solution points starting from an initial arbitrary solution within the feasible region. Genetic algorithms have become one of the most popular approaches because of the many advantages such as their ability to handle any objective function with any constraints. Moreover, they are less likely to converge to local minima since their population-based search is a probabilistic transition strategy. On the other hand, their main weakness is the high computational time required for convergence.

Various power system planning and operation problems have been solved using genetic algorithms such as economic dispatching, unit commitment and hydrothermal coordination problems. One of the earliest applications of GA to solve the STHTS problem was presented in this paper. In this work, a GA-based method was applied to the 24h ahead generation scheduling of hydrothermal units. The GA was used to solve the hydro sub-problem considering the water balance as well as the effects of net head and water travel time delays. A test system was employed to test the method and compare its performance to a dynamic programming approach. Results showed the good performance with good solution quality and robustness of GA especially for avoiding local minima as it was theoretically stated. A good overview on GA was presented and applied to determine the optimal short-term scheduling of hydrothermal systems.

Solution Procedure

The performance is evaluated for the following case:

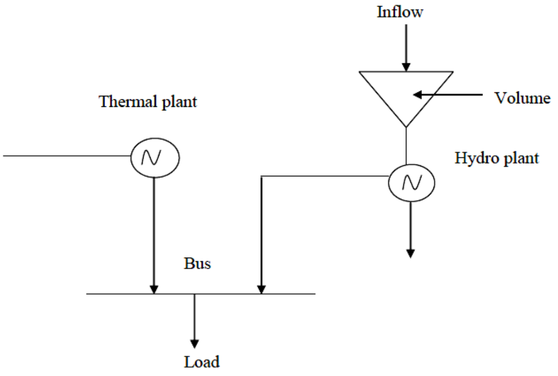

Figure 2: Test System

The test system consists of one thermal and one hydro generating station as shown in figure 2. The operating cost is given by

$$F_1(P_{1k}) = a_1 P_{1k}^2 + b_1 P_{1k} + c_1 \tag{12}$$

The rate of discharge of hydro generating station is given by

$$q_{1k} = X_1 P^2_{2k} + Y_1 P_{2k} + Z_1 \tag{13}$$

Table 1: Cost coefficient

Plant	a1	b1	c1
P_S	700	4.8	0.0005

Table 2: Discharge coefficient

Plant	x1	y1	z1
P_H	260	10	0

Table 3: Power Generation Limit

Limits	Maximum	Minimum
P_S	1200	200
P_H	200	0

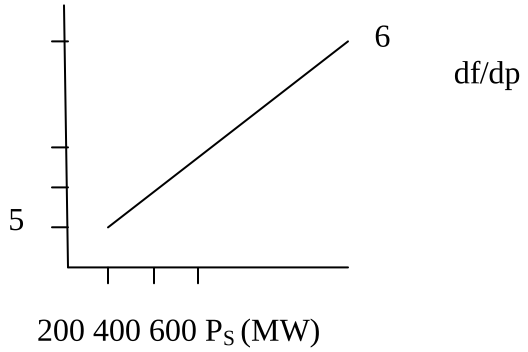

Figure 3. Steam plant incremental cost function

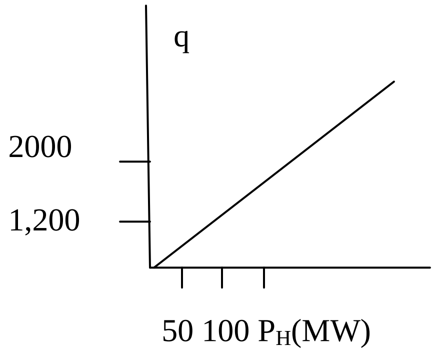

Figure 4.Hydroplant q versus P_H function

The scheduling problem is for a 24-H day with individual period taken as 4 h each (n_j=4.0 h).

The loads and natural inflows into the storage pond are:

Table 4: Load and Natural inflow

Period J	$P_{Load\ j}$ (MW)	Inflow Rate r(j) (arce-ft/h)
1	600	1000
2	1000	1000
3	900	1000
4	500	1000
5	400	1000
6	300	1000

Procedure

For the above scheduling program, start the search using a coarse grid on both the time interval and the volume states. This would permit the future refinement of the search for the optimal trajectory after a crude search had established the general neighborhood. Finer grid steps bracketing the range of the coarse steps around the initial optimal trajectory could then be used to establish a better path. The method will work well for problems with convex function. For this problem, limit our effort to 4-h time steps and storage volume steps that are 2000 acre-ft apart.

During any period, the discharge rate through the hydro-unit is

$$q_j = (V_{j-1} - V_j) + \frac{1000}{4}$$

The DP procedure for two intervals is as follows.

1. Take the storage volume steps at 6000,8000,10000......18000 acre-ft.
2. The initial set of volume states is limited to 10000 acre-ft.
3. No need to compute the data for greater volume states since it is possible to do no more than shut the unit down and allow the natural inflow to increase the amount of water stored. The table here summarizes the calculation for j=1.

Table 5 Calculation for j=1

j=1 $P_L(1)$= 600MW {i}=10				
V_k	Q	P_H	P_S	$TC_K(j)$
14	0	0	600	15040
12	500	24	576	14523
10	1000	74	526	13453
8	1500	124	476	12392
6	2000	174	426	11342

The tabulation for second and succeeding interval is more complex since there are a number of initial volume states to consider.

Table 6: Calculation for j=2

j=2 $P_L(1)$= 1000MW {i}=[6,8,10,12,14]					
V_k	V_i	Q	P_H	P_S	$TC_K(j)$
18	14	0	0	1000	39040[a]
16	14	500	24	976	38484[a]
16	12	0	0	1000	38523
14	14	1000	74	926	37334[a]
14	12	500	24	976	37967
14	10	0	0	1000	37453
12	14	1500	124	876	39194[a]
12	12	1000	74	926	39818
12	10	500	24	976	36897
12	8	0	0	1000	36392
.	.	.			
.	.	.			
.	.	.			
6	10	2000	174	826	33477[a]
6	8	1500	124	876	33546
6	6	1000	74	926	33636

[a] Denotes the minimum cost path.

Finally, in the last period, the following combination:

Table 7.Calculation for Final stage j=6 feasible combination

j=6 P_L=3600MW {i}=[6,8,10,12,14]					
V_k	V_i	q	P_H	P_S	$TC_K(j)$
10	10	1000	74	226	82240.61
10	8	500	24	276	82260.21
10	6	0	0	300	81738.46

These are the only feasible combinations since end volume is set at 10 and the minimum loading for the thermal plant is 200MW.

Matlab Program Output

Hydrothermal scheduling of power generation unit using dynamic programming

Sorted Results for Time Period - 6
Load during this Time Period in MW= 800

V_k	V_i	q	P_H	P_S	PC	$TC_K(j)$
0.0800	0.0800	0	0	0.0080	0.1944	1.2749

HYDRO-THERMAL Scheduling Results for Time Period 1 – 6

Hydrothermal scheduling of power generation unit using genetic algorithm

Period	Load	P_S	P_{h1}	Unit 1	P_{h2}	Unit2
0.0010	1.1000	0.9010	0	0	0.1990	0.0010
0.0020	1.2000	0.9020	0.1115	0.0010	0.1865	0.0010
0.0030	0.9000	0.9000	0	0	0	0
0.0040	1.1000	0.9135	0.1865	0.0010	0	0
0.0050	1.0000	0.8635	0	0	0.1365	0.0010
0.0060	0.8000	0.8000	0	0	0	0

Total Generation Cost = 6412.02 $/hr

Period	Load	P_{S1}	P_{s2}	P_{S3}	P_{h1}	P_{h2}
0.0010	1.0000	0.3702	0.3161	01148	0	0.1990
0.0020	1.2000	0.3824	0.3259	0.1187	0.1740	01990
0.0030	0.7000	0.3227	0.2779	0.0994	0	0

0.0040	0.5000	0.2288	0.2023	0.0690	0	0
0.0050	1.0000	0.4636	0.3913	0.1451	0	0
0.0060	0.9000	0.3002	0.2597	0.0921	0.1240	0.1240

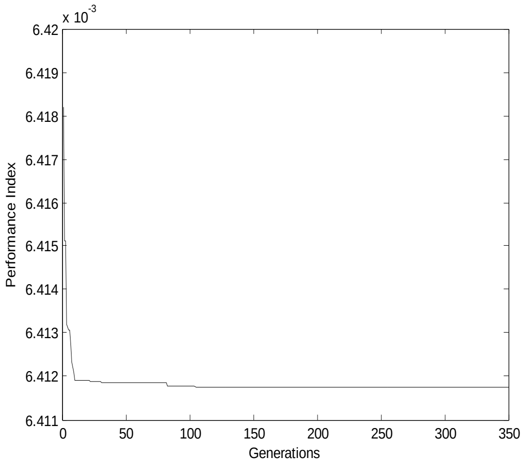

Figure 5. Generation versus Performance index

The final, minimum cost trajectory for storage volume is plotted.

Conclusion

A Dynamic programming and Genetic based approach has been proposed and demonstrated to solve the short term hydrothermal scheduling problem. Numerical results show that highly near-optimal solutions can be obtained by DP and GA. The effectiveness of the developed program is tested for the system having one hydro and one thermal unit for 24 hour load demand. The GA-based algorithm is faster in searching the optimal solution.

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