

Economical Operation of Hydro-Thermal Power System based on Multi-path Adaptive Tabu Search

J. Kluabwang

Abstract—An economic operation scheduling problem of a hydro-thermal power generation system has been properly solved by the proposed multipath adaptive tabu search algorithm (MATS). Four reservoirs with their own hydro plants and another one thermal plant are integrated to be a studied system used to formulate the objective function under complicated constraints, eg water managements, power balance and thermal generator limits. MATS with four sub-search units (ATs) and two stages of discarding mechanism (DM), has been setting and trying to solve the problem through 25 trials under function evaluation criterion. It is shown that MATS can provide superior results with respect to single ATS and other previous methods, genetic algorithms (GA) and differential evolution (DE).

Keywords—Hydro-thermal scheduling problem, economic dispatch, adaptive tabu search, multipath adaptive tabu search

I. INTRODUCTION

THE general short-term hydro-thermal generation scheduling problems investigated under a general hypothesis that the hydro units do not pose any cost constraints on the generation of electric power [1] have the objective function to minimize the operation cost of thermal units in given period of time while preserving all constraints, prohibited operating zone, valve-point loading, power balance, water discharge rate limit, water storage volume limit, reservoir end limit and capacity limit in both hydro plants and thermal plants. Under these constraints, the difficulty to bring optimal solution for this problem has arisen and meta-heuristic search methods have been applied to solve this problem, [1],[2],[6]-[8].

This paper is composed of five topics, firstly introduction, problem formulation, proposed multipath adaptive tabu search algorithm, computational results and finally conclusion.

II. PROBLEM FORMULATION

A. Hydropower plantss

This paper has studied an hydraulic network depicted in Fig.1. It consists of four reservoirs which act as huge energy storages, both receiving water from four channels, I_1 - I_4 , and discharging water, Q_1 - Q_4 , into each turbine of hydro power generators to produce electricity.

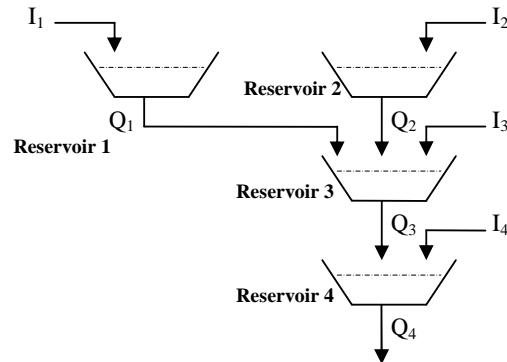


Fig. 1 Hydraulic network for studies

Output power from hydroplants, $P_{h,i}$ of i^{th} hydro power plant, can be obtained by the frequently used equation (1) in terms of reservoir volume, $V_{h,i}$, and water discharge, $Q_{h,i}$,

$$P_{h,i}(t) = c_{1,i}V_{h,i}^2(t) + c_{2,i}Q_{h,i}^2(t) + c_{3,i}V_{h,i}(t)Q_{h,i}(t) + c_{4,i}V_{h,i}(t) + c_{5,i}Q_{h,i}(t) + c_{6,i} \quad (1)$$

where c_k are coefficients of hydro power plants given by [2].

B. Thermal power plant

The aim for solving this problem is to minimize the fuel cost of the only one thermal plant in this system. But the cost has highly complex relation with hydraulic network management [2] through the hydro power plants which has been described in previous topic. The thermal power generation, $P_s(t)$, can be achieved from power demand, $P_D(t)$, hydro power generation, $P_h(t)$ and power loss, $P_L(t)$ within this equation,

$$P_s(t) = P_D(t) + P_L(t) - P_h(t) \quad (2)$$

$P_L(t)$ is assigned to zero here. $P_s(t)$ is bounded the range 500 to 2500 MW. The fuel cost in dollars (\$) from a thermal power plat can be written in the general quadratic form,

$$F_s(P_s(t)) = \gamma + \beta P_s(t) + \alpha P_s^2(t) \quad (3)$$

where γ is 5000, β is 19.2 and α is 0.002.

C. Objective function

The main scheme of this problem is to find what set of hourly water discharge over 24 hour interval to meet power demand under restricted constraints. The objective function

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has been formulated as optimization problem in equation (4)

$$\begin{aligned} \min J(Q_1, Q_2, Q_3, Q_4, t) \\ \text{subject to } 5 \leq Q_1 \leq 15 \\ 6 \leq Q_2 \leq 15 \\ 10 \leq Q_3 \leq 30 \\ 13 \leq Q_4 \leq 25 \end{aligned} \quad (4)$$

where

$$J = P_s(Q_1, Q_2, Q_3, Q_4, t) + \sum_{i=1}^5 \sum_{j=1}^4 \alpha_i L_i(t) \quad (5)$$

The P_s is an thermal power output which indirectly depend upon all water discharge Q_i . Penalty terms- L_i and weighting factors- α_i , can be described as follows,

1) Discharge rate limit can be represented in equation (6)

$$L_1 = \sum_{t=1}^{24} \sum_{i=1}^4 \left(\left| Q_{i,t} - Q_{\min} \right| - (Q_{i,t} - Q_{\min}) \right) + \left(\left| Q_{\max} - Q_{i,t} \right| - (Q_{\max} - Q_{i,t}) \right) \quad (6)$$

2) Storage volume limit can be calculated by equation (7)

$$L_2 = \sum_{t=1}^{24} \sum_{i=1}^4 \left(\left| V_{i,t} - V_{\min} \right| - (V_{i,t} - V_{\min}) \right) + \left(\left| V_{\max} - V_{i,t} \right| - (V_{\max} - V_{i,t}) \right) \quad (7)$$

3) Capacity of hydro plant limit can be formulated here,

$$L_3 = \sum_{t=1}^{24} \sum_{i=1}^4 \left(\left| P_{h,i,t} - P_{h,\min} \right| - (P_{h,i,t} - P_{h,\min}) \right) + \left(\left| P_{h,\max} - P_{i,t} \right| - (P_{h,\max} - P_{h,i,t}) \right) \quad (8)$$

4) Capacity of thermal plant limit can be formulated here,

$$L_4 = \sum_{t=1}^{24} \sum_{i=1}^4 \left(\left| P_{s,i,t} - P_{s,\min} \right| - (P_{s,i,t} - P_{s,\min}) \right) + \left(\left| P_{s,\max} - P_{s,i,t} \right| - (P_{s,\max} - P_{s,i,t}) \right) \quad (9)$$

5) Reservoir end limit can be calculated by equation (10)

$$L_5 = \sum_{t=1}^{24} \sum_{i=1}^4 \left(\left| V_{storage,i,t} - V_{start,i,t} \right| \right) + \left(\left| V_{storage,i,t} - V_{stop,i,t} \right| \right) \quad (10)$$

These weighting factors are $\alpha_1 = \alpha_3 = \alpha_4 = 10^4$, $\alpha_2 = 10^5$ and $\alpha_5 = 10^6$.

The objective function is hard to solve problem via classical method, many meta-heuristic search methods have been applied to solve it [1],[2],[7],[8]. As an alternative search method, the proposed multipath adaptive tabu search algorithm is described in next topic [5].

III. MULTIPATH ADAPTIVE TABU SEARCH (MATS)

Tabu search (TS) is a widely used metaheuristics search, firstly proposed by F. Glover in 1989 [3]. TS based on two main strategies, intensification and diversification. To improve search performance, adaptive tabu search (ATS) of a research team in Thailand [4] has been launched with two additional mechanisms, back-tracking mechanism for escaping deadlock situation and adaptive search radius for accelerating search speed. Currently, multipath adaptive tabu search (MATS) has just been proposed for solving any difficult engineering problems [5]. MATS is designed to act as a manager administrating many search cores, ATSs, under an approach to improve search performance with respect to the original single ATS. MATS consists of three key mechanisms, firstly, at the beginning, partitioning mechanism (PM), to provide initial solutions which come from different sub-search spaces for each sub-ATSs, second, sequencing mechanism (SM) to allow all sub-ATSs working in sequential order, lastly discarding mechanism (DM) to remove the weak sub-ATS(s) out of the main iterative loop for saving overall computational time.

IV. COMPUTATIONAL RESULTS

According to IEEE-CEC 2011 competition on real-world optimization problems [6] and the code of problem 11 case 3, ATS and MATS have been tested randomly 25 trials with 150,000 function evaluations limit in each trial on a PC with dual core CPU 2.6 GHz, RAM 1 GBytes and HDD 40 GBytes. Sub-ATSs in MATS have identical properties liked a single ATS but they have been efficiently managed by MATS's mechanisms. Test results have been collected and illustrated in Table I. Considering the best objective function values in Table I, the single ATS's value, 9.391×10^5 \$ is lowest, then of the MATS's, 9.395×10^5 \$, and of previous works, genetic algorithm (GA), 9.466×10^5 \$ and differential evolution (DE), 9.476×10^5 \$ respectively. In case of average values, MATS's is the lowest value and next are of ATS, DE's and GA's, respectively. From these statistic data included median, worst and standard deviations, it can interpret that MATS can frequently obtained higher-quality solution than the single ATS and also the other methods, GA and DE.

TABLE I
COMPARATIVE RESULTS FROM 25 TRIALS UNDER 150,000 FES LIMIT [6].

Methods	Objective function value (x 10^5 \$)				
	Best	Median	Mean	Worst	Std.
GA [7]	9.46598	9.75758	9.75109	9.95007	0.11849
DE [8]	9.47654	9.56271	9.58791	9.70009	0.05992
ATS	9.39131	9.46218	9.46548	9.55447	0.03676
MATS	9.39504	9.43414	9.44364	9.52591	0.03528

Alternative pattern to demonstrate the comparative results between ATS and MATS in histogram has been elaborated through in Fig. 2. Obviously, if we count the number of trials which is less than 9.44×10^5 \$. There are fifteen trials (80%) of MATS and only three trials (12%) of ATS. It means that the solution from MATS is probably superior than of ATS's do.

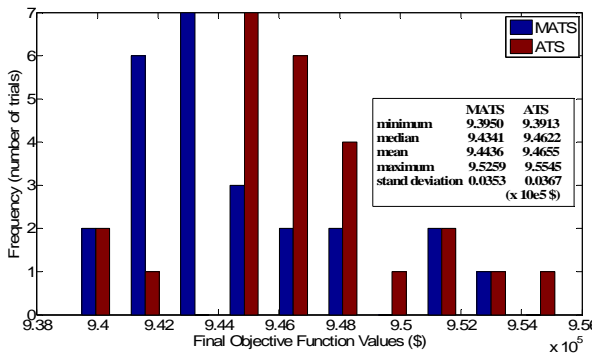


Fig. 2 Comparative results between MATS and ATS

The solution of MATS from the best trial ($J=9.395 \times 10^5$ \$) consists of 96 values (4 hydro plants x 24 hours) and also has been plotted to be trajectories of hourly water discharge shown in Fig.3.

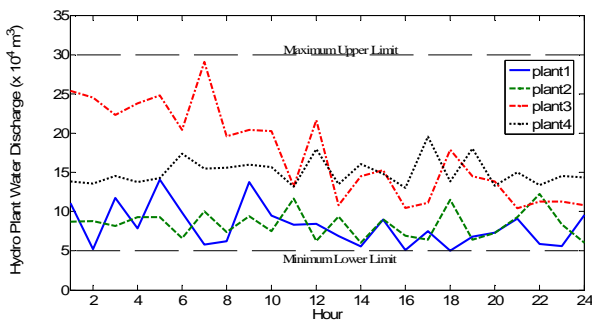


Fig. 3 Trajectories of hourly water discharges

In Fig.3, all trajectories are with their own specification [2], the water discharge of plant1, Q_1 (blue line) is bounded between 5×10^4 m³ to 15×10^4 m³, Q_2 (green line) is between 6×10^4 m³ to 15×10^4 m³, Q_3 (red line) is between 10×10^4 m³ to 30×10^4 m³ and Q_4 (black line) is between 13×10^4 m³ to 25×10^4 m³.

Convergence property of the proposed MATS on solving the hydrothermal power scheduling problem can be seen from a best trial (for sample), in Fig. 4. At the beginning, PM provided different initial solutions and then, SM has forced all of sub-ATS, namely MATS#1, MATS#2, MATS#3 and, MATS#4, to operate in sequential manner. At a moment later, DM has been firstly invoked at the 1000th iteration to discard two the weak sub-ATS (MATS#1 and MATS#2 at that time) and secondly invoked at the 4000th iteration to stop another low qualified MATS#3 out of the MATS's iterative loop.

Let's the left MATS#4 go on searching until the maximum function evaluation limit (150,000) found. Finally MATS#4 has reported the final solution, $J=9.395 \times 10^5$ \$, at the 9,000th iteration within 422.1219 seconds.

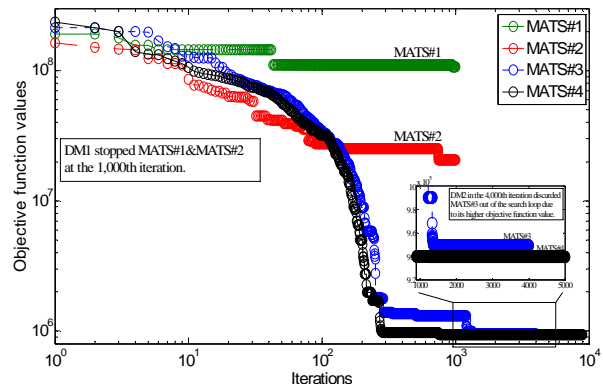


Fig. 4 Convergence curves of MATS from the best trial

V. CONCLUSION

Multi-path adaptive tabu search (MATS) approach is applied to solve the complicated hydro-thermal scheduling problem. The problem characterized by four reservoirs with hydro generators and a thermal generator have been described. Computational tests are based on 150000 FES limit. MATS with four sub-ATSs and suitable parameters can obtain better results, mean than of the single ATS and other previous methods, GA and DE.

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