Pumped-Storage Scheduling Using Glowworm Swarm Algorithm

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Received 27 July 2017; received in revised form 17 August 2017; accepted 21 August 2017

Abstract

This paper presents new solution methods and results based on a glowworm swarm algorithm for solving the 24-hour pumped-storage generation scheduling problem. Complete solution algorithms and encoding/decoding techniques are proposed in the paper. The optimal schedules of both pumped-storage and thermal units are concurrently obtained within the evolutionary process of evaluation functions. Significantly, no hydro-thermal iteration is needed. The proposed approach is applied with success to an actual utility system, which consists of four pumped-storage units and 34 thermal units. The results indicate the attractive properties of the glowworm swarm algorithm in practical application, namely, a highly optimal solution cost and more robust convergence behaviour.

Keywords: pumped-storage, glowworm swarm algorithm, hydro-thermal iteration.

1. Introduction

The exact optimal solution to the P/S scheduling problem can be obtained by exhaustive enumeration of all P/S and thermal unit combinations at each time period. However, the burden of computation makes it unacceptable for realistic applications. Conventional methods for solving the P/S scheduling problem are based on decomposition approaches that involve a hydro and a thermal subproblem [1-3]. These two subproblems are usually coordinated by LaGrange multipliers, and then the optimal generation schedules of both P/S and thermal units are obtained via repetitive hydro-thermal iterations. A well-recognized difficulty is that the solutions to these two subproblems may oscillate between maximum and minimum generations with slight changes of the multipliers [4]. As a result, the solution cost usually gets stuck at a local optimum rather than at the global optimum. However, the optimality of solution is very important to electric utility. Even a small reduction in percentage production cost may lead to large saving of money. Obviously, a complete and efficient algorithm for solving the P/S scheduling problem is still in demand.

Recently, a global optimization technique known as glowworm swarm algorithm (GSA) has emerged as a candidate for many optimization applications due to its flexibility and efficiency [5-6]. GSA has been successfully applied in various areas such as economic dispatch [7], multimodal functions optimization [8], optimal power flow [9], and so on.

In this paper, a new GSA approach is developed for solving the P/S scheduling problem for the coming 24 hours. One of the advantages of the new approach is the use of stochastic operators rather than deterministic rules to obtain the global optimum in order to escape from local optimums where other methods might land. A representative test example based on the actual Taipower system is presented and analyzed to illustrate the capability of the proposed approach in practical applications.

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2. Problem Formulation

2.1. List of symbols

P_{si}^t	power generation of thermal unit i in hour t	V_j^t	water volume of the upper reservoir of plant j at the ending of hour t
P_{hj}^t	power generating (positive) or pumping (negative) of P/S plant j in hour t	$V_{j,l}^t$	water volume of the lower reservoir of plant j at the ending of hour t
$F_i^t(P_{si}^t)$	production cost for P_{si}^t	I_j^t	natural inflow into reservoir j in hour t
T	number of scheduling hours	Q_j^t	water discharge of P/S plant j in hour t
N_h	number of P/S plants	$Q_{j,p}^t$	water pumping of P/S plant j in hour t
N_s	number of thermal units	S_j^t	water spillage of P/S plant j in hour t
P_L^t	system load demand in hour t	UR_{si}	up ramp rate limit of thermal unit i
P_{loss}^t	system transmission network losses in hour t	DR_{si}	down ramp rate limit of thermal unit i

2.2. Modeling of a pumped-storage plant

A P/S plant, which consists of an upper and a lower reservoir, is designed to save fuel costs by generating during peak load with water in the upper reservoir, which would be pumped up during light load hours.

The equivalent plant model can be obtained using an off-line mathematical procedure which maximizes the total plant generation output under different water discharge rates [2]. The generation output of an equivalent hydro plant is a function of the water discharge through the turbine and the net head (or the content of reservoir). The general form is expressed by:

$$P_{hj}^t = f(Q_j^t, V_j^{t-1}) \quad (1)$$

The quadratic discharge-generation function to be used in this paper as a good approximation of the hydro plant generation characteristics, considering the net head effect, is given below:

$$P_{hj}^t = \alpha_j^{t-1} Q_j^{t^2} + \beta_j^{t-1} Q_j^t + \gamma_j^{t-1} \quad (2)$$

where coefficients α_j^{t-1}, β_j^{t-1}, and γ_j^{t-1} depend on the content of the upper reservoir at the ending of hour *t-1*. In this work, the read-in data include five groups of α, β, γ coefficients that relate to different storage volumes, from minimum to maximum, for the upper reservoir. Then, the corresponding coefficients for any reservoir volume are calculated by using a linear interpolation [3] between the two closest volumes, as shown in the first quadrant of Fig. 2.

In pumping mode, since all P/S units of Taipower are designed for constant power pumping, the characteristic function of a P/S plant is a discrete distribution as shown in the third quadrant of Fig. 1.

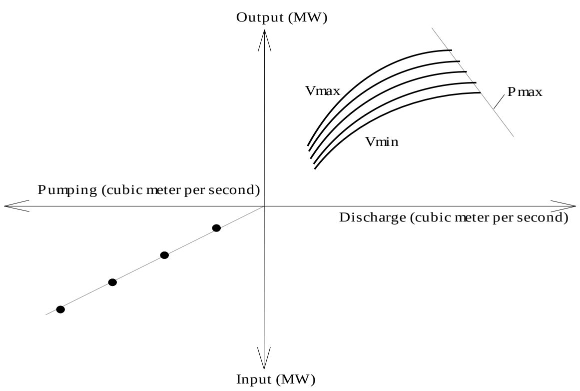

Fig. 1 Typical input-output characteristic for a P/S plant

2.3. Objective function and constraints

The scheduling of P/S units deals with the problem of obtaining the optimal generations both for P/S and thermal units. It aims to minimize the production costs of thermal units while satisfying various constraints. With discretization of the total scheduling time into a set of shorter time intervals (say, one hour as one time interval), the scheduling of P/S units can be mathematically formulated as a constrained nonlinear optimization problem as follows:

$$\textbf{Problem:} \quad Minimize \sum_{t=1}^{T}\sum_{i=1}^{N_s} F_i^t(P_{si}^t) \tag{3}$$

Subject to the following constraints:

System power balance

$$\sum_{i=1}^{N_s} P_{si}^t + \sum_{j=1}^{N_h} P_{hj}^t - P_L^t - P_{loss}^t = 0 \tag{4}$$

Water dynamic balance

$$V_j^t = V_j^{t-1} + I_j^t - Q_j^t + Q_{j,p}^t - S_j^t \tag{5}$$

$$V_{j,l}^t = V_{j,l}^{t-1} + Q_j^t - Q_{j,p}^t + S_j^t \tag{6}$$

Thermal generation and ramp rate limits

$$Max(\underline{P_{si}}, P_{si}^{t-1} - DR_{si}) \le P_{si}^t \le Min(\overline{P_{si}}, P_{si}^{t-1} + UR_{si}) \tag{7}$$

Water discharge limits

$$\underline{Q_j} \le Q_j^t \le \overline{Q_j} \tag{8}$$

Water pumping limits

$$\underline{Q_{j,p}} \le Q_{j,p}^t \le \overline{Q_{j,p}} \tag{9}$$

Reservoir limits

$$\underline{V_j} \le V_j^t \le \overline{V_j} \tag{10}$$

$$\underline{V_{j,l}} \le V_{j,l}^t \le \overline{V_{j,l}} \tag{11}$$

3. Glowworm Swarm Algorithm Solution Methodology

3.1. Review of glowworm swarm algorithm

The basic glowworm swarm algorithm (GSA) technique was firstly introduced by Krishnanand and Ghose in 2009 [5, 6]. The GSA is a swarm intelligence optimization technique based on the behavior of glowworms. The behavior of glowworms which is used for GSA is the apparent capability of the glowworms to change the intensity of the luciferin emission and thus appear to glow at different intensities [5].

In the GSA, glowworms can automatically subdivide into subgroups and thus can find multiple global solutions simultaneously, and thus GSA is very suitable for multimodal problems. However, in GSA, there is no sufficient number or neighbors limit and there is no perception limit based on distance, but it can still have a cognitive limit which allows swarms of glowworms to split into sub-groups and converge to high function value points. This property of GSA allows it to be used to identify multiple peaks of a multi-modal function [6].

3.2. Solution methodology

For ease of exposition, consider a P/S plant consisting of four units. The encoding scheme that translates the encoded parameter-water discharges of each plant into their binary representation is shown in Fig. 2.

Using a plant's water discharge, instead of the plant's generation output, the encoded parameter is more beneficial for dealing with the difficult water balance constraints. Each chromosome string contains 24 genes to represent the solution for the hourly discharge/pumping schedules of the P/S plant in a 24-hour period. Each gene is assigned by the same number of five bits. The first bit is used to identify whether the plant is in generating or in pumping mode. The other four bits are used to represent a normalized water discharge q_j^t in generating mode, or to represent the number of pumping units in pumping mode. The resolution is equal to $1/2^4$ of the discharge difference from minimum to maximum in generating mode.

Hour		1		2	.....		24
	1	0 0 0 1	0	0 0 1 1	.....	1	0 0 1 0

Fig. 2 The encoding scheme for a P/S plant with four units

3.3. Decoding

Evaluation of a chromosome is accomplished by decoding the encoded chromosome string and computing the chromosome's fitness value using the decoded parameter. The detailed decoding procedure is summarized in the following steps :

(1) Decode the first bit to identify whether the plant is in generating or pumping mode.

(2) If in pumping mode, go to step 3, else in generating mode, then go to step 6.

(3) Decode the other four bits of the gene to calculate the number of pumping units and the total volumes of water pumping.

(4) Calculate the upper boundary of the water pumping.

(5) Calculate the MW power for pumping.

(6) Decode the other four bits of the gene to obtain the normalized discharge in decimal values.

(7) Calculate the upper boundary of the discharge.

(8) Translate the normalized value to the actual value.

(9) Calculate the generation output using (2).

(10) Calculate the remaining thermal load.

(11) Continue the computation of the above 10 steps from hour 1 to hour 24.

(12) Do thermal unit commitment for the remaining thermal load profile, and return the corresponding thermal cost to the main program.

(13) Translate the corresponding thermal cost to the fitness function.

(14) Repeat the above 13 steps from the first chromosome to the last chromosome.

4. Test Results

The proposed GSA approach was implemented in software and tested on a portion of the Taipower generation system, which consists of 34 thermal units and the Ming-Hu P/S plant with four units. This software package was written in Matlab and executed on a personal computer.

Detailed characteristic data of the Ming-Hu P/S plant are given in Table 1. The thermal system consists of 34 thermal units involving six large coal-fired units, eight small coal-fired units, seven oil-fired units, ten gas turbine units, and three combined cycle units. For data on the characteristics of the 34-unit thermal system please refer to [10].

The software is tested on a summer weekday. The load profile is obtained by subtracting the expected generation output of other hydro plants and nuclear units from the actual system load profile. The optimal schedules of both P/S units and thermal units are obtained within 5 minutes, well satisfied the Taipower's requirement. Test results are schematically shown in Fig. 3. Fig. 3 shows the total generating/pumping profile created by the proposed approach.

Table 1. Characteristics of the Ming-Hu P/S plant.

Installed Capacity	Maximal Discharge (m3/s)	Maximal Pumping (m3/s)	Lower Reservoir		Efficiency
			Maximal Storage (k×m3)	Minimal Storage (k×m3)	
250MW×4	380	249	9,756	1,478	0.74

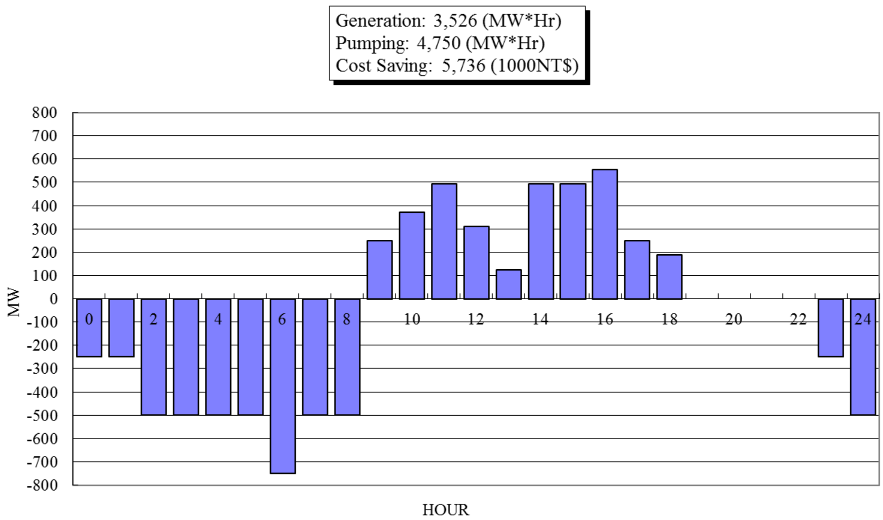

Fig. 3 Hourly MW generating/pumping schedules

5. Conclusions

This paper presents a new methodology based on a GSA for solving the P/S units scheduling problem in the daily hydro-thermal coordination. One of the advantages of the proposed approach is the flexibility of GSA for modeling various constraints. The difficult water dynamic balance constraints are embedded and satisfied throughout the proposed encoding and decoding algorithms. The effect of net head was also considered. Numerical results from an actual utility system indicate the attractive properties of the GSA approach in practical application, which are a highly optimal solution and more robust convergence behavior.

References

[1] A. J. Wood and B. F. Wollenberg, Power generation, operation, and control, 3rd ed., John Wiley & Sons, New York, 2013.

[2] M. E. El-Hawary, “An overview of scheduling functions in hydro-thermal electric power systems,” Proc. the 1991 IASTED International Conference, pp. 1-37, March 1991.

[3] S. Ruzic, , et al., “A flexible approach to short-term hydro-thermal coordination,” IEEE Transactions on Power Systems, vol. 11, no. 3, pp. 1564-1578, August 1996.

[4] P. H.Chen, “Two-level hierarchical approach to unit commitment using expert system and elite PSO,” IEEE Transactions on Power Systems, vol. 27, no. 2, pp. 780-789, May 2012.

[5] K. N. Krishnanand and D. Ghose, “Glowworm swarm optimization: a new method for optimizing mufti-model functions,” International Journal of Computational Intelligence Studies, vol. 1, no. 1, pp. 93-119, May 2009.

[6] K. N. Krishnanand and D. Ghose, “Glowworm swarm optimization for simultaneous capture of multiple local optima of multimodal functions,” Swarm Intelligence, vol. 3, no. 2, pp.87-124, June 2009.

[7] D. N. Jayakumar and P. Venkatesh. “Glowworm swarm optimization algorithm with topsis for solving multiple objective environmental economic dispatch problem,” Applied Soft Computing, vol. 23, pp. 375-386, October 2014.

[8] Y. Q. Zhou, G. Zhou, and J. L. Zhang, “A hybrid glowworm swarm optimization algorithm to solve constrained multimodal functions optimization,” Optimization, vol. 64, no. 4, pp. 1057-1080, 2015.

[9] S. S. Reddy and C. S. Rathnam, “Optimal power flow using glowworm swarm optimization,” International Journal of Electrical Power & Energy Systems, vol. 80, pp. 128-139, September 2016.

[10] P. H. Chen, “Pumped-storage scheduling using evolutionary particle swarm optimization,” IEEE Transactions on Energy Conversion, vol. 23, no. 1, pp. 294-301, March 2008.