ADAPTIVE SELECTIVE CUCKOO SEARCH ALGORITHM FOR MULTI-OBJECTIVE SHORT-TERM HYDROTHERMAL SCHEDULING

ÁP DỤNG THUẬT TOÁN CUCKOO SEARCH CHỌN LỌC THÍCH NGHI ĐIỀU ĐỘ TỐI ƯU HỆ THỐNG THỦY NHIỆT ĐIỆN NGẮN HẠN ĐA MỤC TIÊU

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ABSTRACT

This paper proposes an Adaptive Selective Cuckoo Search Algorithm (ASCSA) for solving the multi-objective short-term hydrothermal scheduling (MOSTHTS). The main objective of the MOSTHTS problem is to minimize both total power generation cost and emission of thermal generators over a scheduling period while satisfying power balance, hydraulic, and generator operating limit constraints. The proposed ASCSA method is developed for the problem based on improvements from the conventional CSA method to improve the optimal solution and speed up the computational process. The result comparisons from different test systems have indicated that the proposed method can obtain higher quality solution and shorter computational time than many other methods. Therefore, the proposed ASCSA method can be a new efficient method for solving multi-objective short-term HTS problem.

Keywords: *Adaptive selective random walk; new selection technique; multi-objective; short-term hydrothermal scheduling; fitness function.*

TÓM TẮT

Bài báo này đề xuất thuật toán Adaptive Selective Cuckoo Search (ASCSA) để giải bài toán phối hợp hệ thống thủy nhiệt điện ngắn hạn đa mục tiêu (MOSTHTS). Mục tiêu chính của bài toán là cực tiểu chi phí phát điện và khí thải từ các nhà máy nhiệt điện trong thời gian lên kế hoạch phát điện tối ưu giữa các nhà máy thủy điện và nhiệt điện trong khi vẫn đảm bảo được các ràng buộc từ hồ thủy điện, ràng buộc cân bằng công suất và giới hạn các tổ máy phát. Phương pháp đề xuất ASCSA được xây dựng từ phương pháp cổ điển Cuckoo search (CCSA) nhằm cải thiện chất lượng nghiệm tối ưu và đẩy nhanh quá trình hội tụ của CCSA. Kết quả so sanh từ các hệ thống khác nhau cho thấy ASCSA có thể đạt được chất lượng nghiệm tốt và thời gian tính toán nhanh. Từ đó có thể kết luận được rằng phương pháp đề xuất ASCSA là một phương pháp rất hiệu quả cho điều phối hệ thống thủy nhiệt điện ngắn hạn đa mục tiêu.

Từ khóa: *Kỹ thuật chọn lọc thích nghi; kỹ thuật chọn lọc mới; đa mục tiêu; điều độ thủy nhiệt điện ngắn hạn;hàm thích nghi.*

1. INTRODUCTION

The short term hydrothermal scheduling (HTS) problem is to determine power generation among the available thermal and hydro power plants so as the total fuel cost of thermal units is minimized over a scheduled time of a single day or a week satisfying both hydraulic and electrical operational constraints such as power balance, the quantity of available water and limits on generation [1]. However, thermal power generating station is one of the most important sources of carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NO_x) which cause the atmospheric pollution [2]. Therefore, the short-term HTS problem can be extended to minimize the gaseous emission as a result of the recent environmental requirements in addition to the minimization the fuel cost of thermal power plants, forming the multi-objective short-term HTS problem [2]. A simulated annealing-based goal-attainment (SA-BGA) method [3] has been applied to the multi-objective short-term HTS problem with nonsmooth fuel cost function. This study has only obtained a few solutions corresponding to a few different values of weight factors and then the best compromise solution has been found based on the goal-attainment method. Therefore, the best emission could be reasonable but the best fuel cost was so far the reasonable value. Contrary to ref. [3], three larger systems considering both fuel cost and emission have been employed to test a proposed method based on PSO and Lagrange multipliers in [4]. Similar to LGM in [2], a particle swarm optimization and gamma based (γ-PSO) method [4] has utilized the coordination equations in the iterative algorithm to obtain the optimal solution. In order to apply the coordination, a Lagrange function has first been constructed consisting of Multi-objective and constraints of power balance constraint and available water constraint. Secondly, PSO has been carried out to search optimal gamma, which was Lagrange multiplier associated with available water constraint. Finally, the optimal gamma would be substituted into the coordination equations to calculate hydro and thermal generations. Non-dominated sorting genetic algorithm-II (NSGA-II) [5] has been implemented to deal with the economic environmental dispatch problem with non-smooth fuel cost and emission functions of thermal power generators in coordination with fixed head hydro units. This method was considered superior to other methods since it could determine the compromise solution without using fuzzy mechanism. To investigate the performance, other methods such as Real-coded genetic algorithm (RCGA) and Multi-objective differential evolution (MODE) have also been implemented to run on two different systems in which the smaller system has ignored valve point loading effects and the larger system has considered valve effects. The comparisons have mainly focused on fuel cost and emission whereas the execution time comparison has not led to any conclusion because all the methods have used identical population and identical iterations. As a result, NSGA-II has been considered very good for the problem when its fuel cost and emission have been lower than those from others. However, this method still suffered long execution time for obtaining optimal solution due to the characteristic of conventional GA. Chiang has proposed an approach based on the improved genetic algorithm, multiplier updating and the ε-constraint technique (IGA-MU) to solve the optimal economic emission dispatch of hydrothermal power systems [6]. The improved GA had a high performance by using multiplier updating for handling all constraints and the ε-constraint technique for managing the Multi-objective problem. Therefore, this method was more efficient than the conventional GA although the result comparison between the two methods has not been given. Another method based on the integration of predator-prey optimization and Powell search method (PPO-PS) [7] has been implemented for solving the economic emission dispatch for fixed-head hydrothermal systems. Predator-prey optimization (PPO) has been used as a global search tool meanwhile Powell's method has played focused on local search ability. Predator-prey has been constructed based on particle swarm optimization configuration. In addition to several advantages of PSO such few control parameters, easy implementation, it had to suffer some main drawbacks such as local optimal trapping and lack of effective capability to deal with the constraints. PPO model includes both predator and prey particles in initial population. The prey target is to escape from the predators whilst the purpose of predator is to capture the prey in order to improve exploration and exploitation capability of PSO. Furthermore, Powell's method has played a crucially important role searching around the solutions obtained from PPO. In addition, a penalty handling method for dealing with the equality constraints and inequality constraints has also been integrated into the PPO-PS to form a more potential method, called PPO-PS-PM.

An improved regularity model-based multi-objective estimation of distribution algorithm (IRM-MEDA) [8] has been successfully applied for solving the HTS problem with nonconvex fuel cost function of thermal units. The result comparison has revealed that the IRM-MEDA was not more effective and robust than MODE , NSGA-II and IGA-MU since it could not get better solutions than the two methods for all cases. Furthermore, the improved version has not been demonstrated efficient compared to original methods because RM-MEDA has not been implemented for comparison.

In this paper, an adaptive selective cuckoo search algorithm is proposed for solving the MOSTHTS problem. The results from the methods compared to those from other methods see that ASCSA is a very efficient method for solving the considered problem.

2. PROBLEM FORMULATION

2.1 Objective function

The fuel cost of thermal units is approximately represented as a quadratic function [1]:

$$F_{im} = \left[a_{si} + b_{si} P_{si,m} + c_{si} P_{si,m}^2 \right] \tag{1}$$

The fuel cost curves with and without valve-point loading effects are depicted in Figure 4.1.

$$F_{im} = \begin{bmatrix} a_{si} + b_{si} P_{si,m} + c_{si} P_{si,m}^2 \\ + \left| d_{si} \times \sin\left(e_{si} \times \left(P_{si}^{\min} - P_{si,m} \right) \right) \right| \end{bmatrix} \tag{2}$$

In addition to the quadratic function representation of emission gas, the amount of emission from each thermal unit can be also expressed in form of a quadratic and exponential function as follows [7]:

$$F_2 = \sum_{m=1}^{M} \sum_{i=1}^{N_1} t_m \begin{bmatrix} \alpha_{si} + \beta_{si} P_{si,m} + \gamma_{si} P_{si,m}^2 \\ + \eta_{si} \exp(\delta_{si} P_{si,m}) \end{bmatrix} \tag{3}$$

where α_{si}, β_{si}, γ_{si}, η_{si}, and δ_{si} are emission coefficients of thermal unit *i*.

The objective function is to minimize both fuel cost and emission as below

$$Min\, F = \psi_1 F_1 + \psi_2 F_2 \tag{4}$$

Where F_1 and F_2 are respectively the total fuel cost and the total emission from the set of working thermal units; ψ_1 and ψ_2 are two weight factors corresponding to respectively fuel cost and emission, and the two factors must be subject to [9]:

$$\psi_1 + \psi_2 = 1 \tag{5}$$

$$0 \le \psi_1, \psi_2 \le 1 \tag{6}$$

2.2 Hydraulic and System constraints

- *Power balance constraint*:

$$\sum_{i=1}^{N_1} P_{si,m} + \sum_{j=1}^{N_2} P_{hj,m} - P_{L,m} - P_{D,m} = 0 \qquad (7)$$

where $P_{L,m}$ is the power loss in transmission lines

- *Available Water constraint*:

$$\sum_{m=1}^{M} t_m q_{j,m} = W_{aj}\, ; j = 1, \ldots, N_2 \qquad (8)$$

Where W_{aj} is the amount of water available for j^{th} hydropower plant over scheduled horizon; $q_{j,m}$ is the water discharge and obtained by[2].

$$q_{j,m} = a_{hj} + b_{hj} P_{hj,m} + c_j P_{hj,m}^2 \qquad (9)$$

- *Generator operating limits*:

$$P_{si,\min} \le P_{si,m} \le P_{si,\max} \qquad (10)$$

$$P_{hj,\min} \le P_{hj,m} \le P_{hj,\max} \qquad (11)$$

3. ADAPTIVE SELECTIVE CUCKOO SEARCH ALGORITHM

3.1 Levy flight random walk

When a new solution for nest *d*, X_d^{new} is generated the Lévy flight random walk is performed[10]

$$X_d^{new} = X_d + \alpha\left(X_d - G_{best}\right) \oplus Lévy(\beta) \qquad (12)$$

3.2 Adaptive selective random walk

Conventional Cuckoo search algorithm (CCSA) has used the selective random walk to produce the second new solution generation as follows.

$$X_d^{new} = \begin{cases} X_d + rand.(X_{randper1} - X_{ranper2}) & if\ RN < Pa \\ X_d & otherwise \end{cases} \qquad (13)$$

Where P_a is the probability of alien egg to be abandoned; RN is a random number; X_{r1} and X_{r2} are two random solutions withdrawn from the population.

The updated step-size used in Eq. (13) is called the two points based factor and written as follows

$$\Delta X_{d,new1} = rand.(X_{randper1} - X_{randper2}) \qquad (14)$$

As shown in Figure 1, if a current best solution G_{best} is still far from a real optimal value and the old solution is very close to the Gbest, a new solution X_{new1} will be very close to the old solution and the algorithm will end with a local optimum when using only the two point factor. To overcome the mentioned circumstance, a new equation is proposed as

$$\Delta X_{d,new2} = rand.\begin{pmatrix} X_{randper1} - X_{randper2} \\ +X_{randper3} - X_{randper4} \end{pmatrix} \qquad (15)$$

It is clear that X_{new2} can be far away from the old solution, and the local optimum can be avoided.

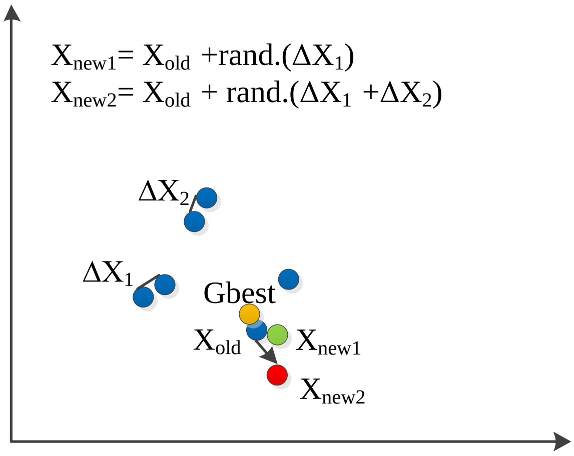

***Figure 1.** Solutions at the last iterations of the search process*

If RN is less than Pa, the adaptive selective random walk will use either $\Delta X_{d,new1}$ or $\Delta X_{d,new2}$ to generate new solution d as follows:

$$X_{d,new1} = X_d + \Delta X_{d,new1} \qquad (16)$$

$$X_{d,new2} = X_d + \Delta X_{d,new2} \qquad (17)$$

To determine either $X_{d,new1}$ or $X_{d,new2}$ is used, a new criterion based on FDR is proposed in Eq. (18) in which FT_d and FT_{best} are thefitness values of the d^{th} solution and the best solution among the population, respectively.When FDR_d is less than a threshold, Eq. (17) is used. Otherwise, Eq. (16) is employed. The threshold is a predetermined value ranging in [10^{-5}, 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}].

$$FDR_d = \frac{FT_d - FT_{best}}{FT_{best}} \qquad (18)$$

3.3 New selection technique

In CCSA, each old solution and each new solution at the same nest are compared to keep better one; however, in the ASCSA, all old solutions and all new solutions are integrated and then the population with lower fitness are retained while others with higher fitness are abandoned.

4. FUZZY METHOD

As shown in Eq. (4), the objective function is a sum of both fuel cost functionand emission in which the two individual objectives are related to their weight factor, Ψ_1 corresponding to fuel cost function and Ψ_2 corresponding to emission function. As mentioned, three dispatch cases are considered where the first two cases, independent fuel cost optimization ($\Psi_1 = 1$ and $\Psi_2 = 0$) and independent emission optimization ($\Psi_1 = 0$ and $\Psi_2 = 1$) are easily carried out but the last case, economic-emission dispatch is much more complicated. Consequently, the section introduces a mechanism, called Fuzzy technique so as to determine the best solution among the set of solutions for the economic-emission dispatch case [9] and [11]. The best compromise obtained by the method can be influenced by the set of non-dominant solutions. Consequently, the selection of the solution sets can enable the Fuzzy method to determine a high quality solution, which can be better than others in terms of both fuel cost and emission.

5. NUMERICAL RESULTS

In the section, two systems with different form of fuel cost function and emission function are employed to test the performance of the ASCSA. System 1 with convex form for both fuel and emission functions while system 2 with nonconvex form for fuel cost function and exponential form for emission function can challenge the effectiveness of the ASCSA. The detailed results are as follows.

5.1 Result comparisons for system 1

In this section, system 1 with quadratic fuel cost function and quadratic emission function are employed to implement Conventional CSA (CCSA) and the proposed ASCSA. The system has two thermal units and two hydro units scheduled in three subintervals. The obtained results from CCSA and ASCSA are given in Table 1 to compare with other methods. As observed from the fuel cost and emission, ASCSA has obtained better solutions than all methods in [5] and [7]. Compared to CCSA, ASCSA has found better solution for emission dispatch while there is a trade-off for the compromise case. However, the execution time from ASCSA is always faster than CCSA.The fitness convergence characteristic for economic dispatch of system 1 is piloted in Fig.2.

5.2 One system considering valve point effects on thermal units

In this section, system 2 with nonconvex fuel cost function of thermal units and an exponential emission function consisting of two hydro plants and four thermal plants scheduled in four twelve-hour subintervals is considered [6]. For implementation of the CSA methods the population and the maximum number of iterations are respectively set to 50 and 300 for CCSA, and 50 and 200 for ASCSA. The result comparisons reported in Table 2 for the system see that ASCSA has obtained the best fuel cost and emission for all cases. In addition, the execution time from ASCSA is the fastest; therefore, ASCSA is the fastest convergence method. The methods in [3] and [6] have been run on a Pentium 3 PC and there is no computer reported for the methods in [5], [7].

6. CONCLUSIONS

In this paper, an adaptive selective cuckoo search algorithm has been proposed for solving the multi-objective hydrothermal scheduling problem. The ASCSA has been implemented for dealing with two systems with different fuel cost functions and different emission functions. In the first system, the objectives are represented quadratic fuel cost and emission function but the objective are represented as nonconvex fuel cost function and exponential emission function in the second system. The performance of ASCSA compared to CCSA has indicated that ASCSA is superior to CCSA in terms of optimal solution and convergence speed. The comparisons with other methods have also sent a message that ASCSA is very efficient for solving the considered problem since it has obtained better optimal solution and faster convergence.

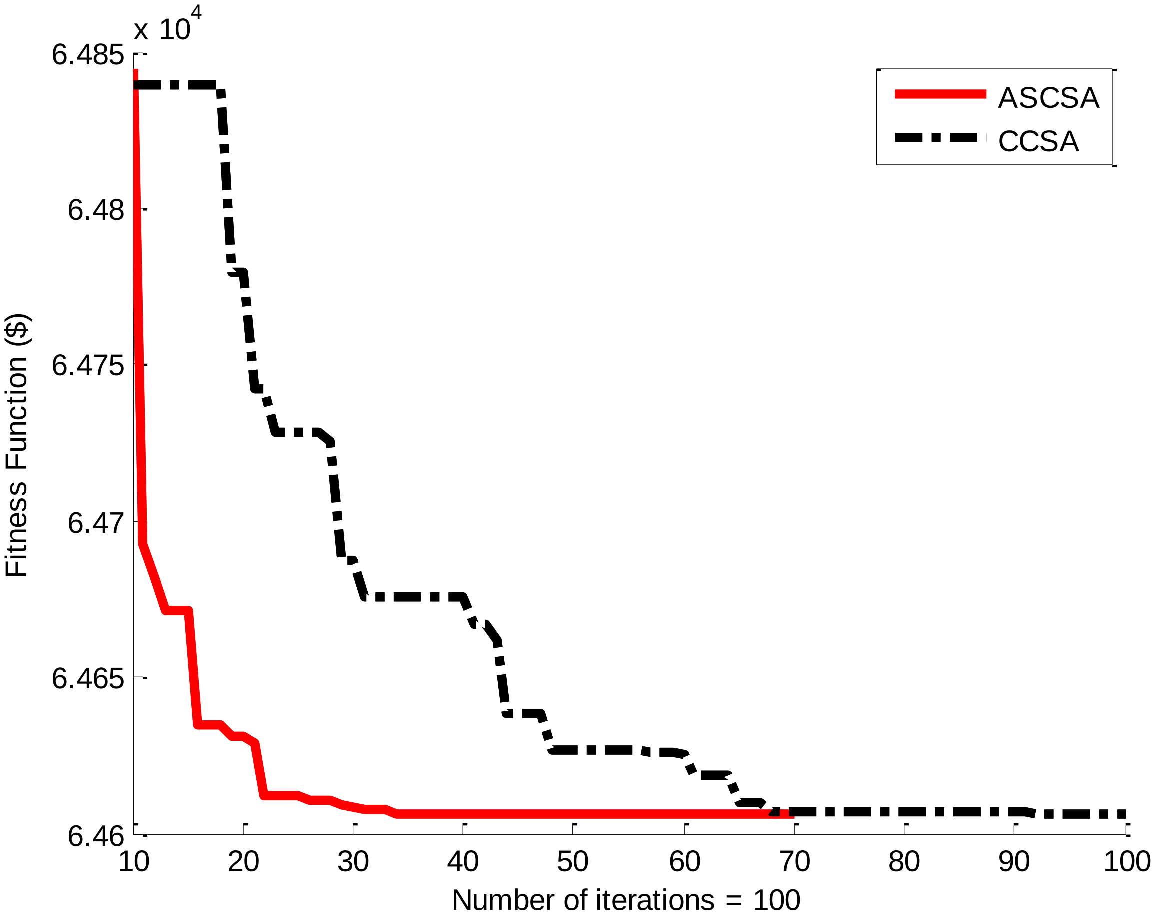

Figure 2. *The fitness convergence characteristic for economic dispatch of system 1*

Table 1. *Result comparisons for system 1 with quadratic fuel cost and emission functions*

Method	Economic dispatch		Emission dispatch		Compromise dispatch		
	Cost ($)	CPU (s)	Emission (lb)	CPU (s)	Cost ($)	Emission (lb)	CPU (s)
RCGA [5]	66,031	21.63	586.14	20.27	-	-	-
NSGA-II [5]	-	-	-	-	66,331	618.08	27.85
MODE [5]	-	-	-	-	66,354	619.42	30.71
SPEA-2 [5]	-	-	-	-	66,332	618.45	34.87
PSO-PM [7]	65,741	18.25	585.67	18.00	65,821	620.78	18.98
PSO [7]	65,241	18.32	579.56	18.31	65,731	618.78	19.31
PPO-PM [7]	64,873	16.14	572.71	15.93	65,426	612.34	16.53
PPO [7]	64,718	15.99	569.73	15.18	65,104	601.16	16.34
PPO-PS-PM[7]	64,689	15.98	568.78	15.92	65,089	600.24	16.15
PPO-PS [7]	64,614	15.89	564.92	15.45	65,058	594.18	16.74
CCSA	64,606	0.24	564.88	1.2234	65,055	593.93	0.33
ASCSA	64,606	0.24	564.72	0.39	65,052.2	594.16	0.23

Table 2. *Result comparisons for system 1 with nonconvex fuel cost and exponential emission functions*

Method	Economic dispatch		Emission dispatch		Economic emission dispatch		
	Cost ($)	CPU (s)	Emission (lb)	CPU (s)	Cost $)	Emission (lb)	CPU (s)
SA-BGA [3]	70,718	-	23,200	-	73,612	26,080	1492
RCGA [5]	66,516	40.36	23,222	41.98	-	-	-
NSGA-II [5]	-	-	-	-	68,333	25,278	45.42
MODE [5]	-	-	-	-	68,388	25,792	46.76
SPEA-2 [5]	-	-	-		68,392	26,005	57.02
GA-MU [6]	67,751	90.15	23,223	78.27	68,521	26,080	96.10
IGA-MU [6]	66,539	51.63	23,223	42.87	68,492	26,080	53.54
PSO-PM [7]	66,349	33.14	23,167	33.63	67,994	25,902	34.11
PSO [7]	66,223	32.15	23,112	32.34	67,892	25,773	34.52
PPO-PM [7]	65,912	21.03	23,078	21.18	67,211	25,606	22.04
PPO [7]	65,885	21.45	22,966	21.56	67,170	25,601	22.11
PPO-PS-PM [7]	65,723	21.12	22,912	24.74	67,092	25,600	24.90
PPO-PS [7]	65,567	22.00	22,828	21.98	66,951	25,596	22.76
IRM-MEDA [7]	68,000	-	23,031.57	-	-	-	-
CCSA	65,243	1.54	22,821.3	1.6	66,733	24,667	1.6
ASCSA	64,728	0.96	22,818.3	0.97	66,536	24,644	0.99

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