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Cuckoo search algorithm for combined heat and power economic dispatch

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ABSTRACT

This paper proposes a cuckoo search algorithm (CSA) for solving for the combined heat and power economic dispatch (CHPED) problem considering valve point loading effects on fuel cost function of pure power generation units and electrical power losses in transmission systems. The main objective of the CHPED problem is to minimize the total fuel cost for producing electricity and heat supplying to a load demand. The proposed CSA method inspired from the reproduction behavior of cuckoo birds has attracted many researchers implementing to engineering optimization problems since it has showed several advantages of few control parameters, high solution quality and fast computational time. The effectiveness and robustness of the proposed CSA have been validated on five different systems including three systems with quadratic fuel cost function of pure power units neglecting transmission losses and two systems with nonconvex fuel cost function of pure power units. The result comparisons between the CSA method and other methods for the test systems have revealed that the CSA method can obtain higher quality solution with faster computational time than many other methods. Therefore, the proposed CSA method can be a very efficient method for solving the CHPED problem.

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Introduction

Over decades, the economic load dispatch has become one of the most important problems in electrical power system operation as it can enable the system with thermal units to produce electricity with the possibly minimum generation fuel cost. However, there is a fact that the benefit can be higher as heat from the electrical generation process released into the air is used to supply to industrial zones or manufacturers [1]. The best way to maximize the benefit or minimize the operating cost of the thermal units is the use of both heat and electricity as they are under working condition. Consequently, optimal operation of the combined heat and power units has played a very important role in power systems. The generation process of both electricity and heat, called cogeneration, can reduce emission releasing into the air, avoiding greenhouse effect [2].

In the 1990s, several conventional methods were employed to solve the combined heat and power economic dispatch (CHPED) problem including Newton method [3] and Lagrange relaxation (LR) [4]. The two methods are effective for application to the CHPED problem since they converge with a small number of iterations. However, the general disadvantage of these methods is the restriction for application on problems with large-scale, non-differential objective functions and complicated constraints. In fact, the Newton's method mainly depends on the inversion of Jacobi matrix which owns all terms obtained via the partial derivative of functions with respect to variables. A large-scale and complex system will lead to a very large size of the Jacobian matrix and it is time consuming for inversing this matrix. Moreover, once non-differential functions are considered the matrix fails to be obtained. Similarly, the LR is also a deterministic method based on the derivative of constraints and objective functions. On the other hand, the number of Lagrange multipliers is directly proportional to the number of equality constraints in addition to the mutual influence among the multipliers. Therefore, LR method cannot deal with nonconvex problem similar to the Newton's method. In this paper, CHPED problem is ranged from simplicity to complex once the fuel cost function of pure power units changes from quadratic into nonconvex and the number of cogeneration units is from low to high value. Equally, the feasible operating zone of the cogeneration units is with the boundary of a polygon. These complicated characteristics of CHPED restrict the application of the two conventional methods. To tackle the drawback of these conventional methods, many meta-heuristic and artificial intelligent algorithms have been used for solving the CHPED problem such

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Nomenclature

F_{pi}	cost function of power only unit i
F_{cj}	cost function of cogeneration unit j
F_{hk}	cost function of heat only unit k
a_{pi}, b_{pi}, c_{pi}	cost function coefficients of power only unit i
e_{pi}, f_{pi}	nonconvex cost function coefficients of power only unit i
$a_{cj}, b_{cj}, c_{cj}, d_{cj}, e_{cj}, f_{cj}$	cost function coefficients of cogeneration unit j
a_{hk}, b_{hk}, c_{hk}	cost function coefficients of heat only unit k
N_p, N_c, N_h	number of power only units, cogeneration units and heat only units.
$P_{pi,d}$	power output of power only unit i corresponding to host nest d
$P_{cj,d}$	power output of cogeneration unit j corresponding to host nest d
$H_{cj,d}$	heat output of cogeneration unit j corresponding to host nest d
$H_{hk,d}$	heat output of heat only unit k corresponding to host nest d
$P_{pi,min}$	lower power output of power only unit i
$P_{pi,max}$	upper power output of power only unit i
$P_{cj,min}$	lower power output of cogeneration unit j
$P_{cj,max}$	upper power output of cogeneration unit j
$H_{hk,min}$	lower heat output of heat only unit k
$H_{hk,max}$	upper heat output of heat only unit k
$H_{cj,min}$	lower heat output of cogeneration unit j
$H_{cj,max}$	upper heat output of the cogeneration unit j
P_L	power loss on the transmission line
B_{ij}, B_{0i}, B_{00}	power loss coefficients
P_D	power load demand
H_D	heat load demand

as genetic algorithm (GA) [5], improved ant colony search (IACS) [6], evolutionary programming (EP) [7], improved genetic algorithm with multiplier updating (IGA-MU) [8], Lagrange relaxation and sequential quadratic programming (LR-SQP) method [9], self-adaptive real-coded genetic algorithm (SARGA) [10], augmented Lagrange Hopfield network (ALHN) [11], bee colony optimization (BCO) [12], harmony search (HS) [1,13,14], mesh adaptive direct search algorithm (MADSA) [15], novel direct search (NDS) [16], artificial immune system (AIS) [17], Lagrangian relaxation with surrogate subgradient multiplier updates (LR-SSMU) [18], conventional particle swarm optimization (CPSO) [19], particle swarm optimization with time varying acceleration coefficients (TVAC-PSO) [19], and oppositional teaching learning based method (OTLBO) [2]. In [5], several versions of GA combing with some trials of an improved penalty function have been proposed to solve the CHPED problem. The results have revealed that the optimal solution has been improved due to the change of the improved penalty function. However, these GAs with the penalty terms have suffered from local optimal solution although its value has been set to from small value to large value. To overcome this drawback, the combination of the augmented Lagrange function and the Lagrange function and penalty terms has been proposed to update multiplier in [8], forming IGA_MU method. As a result, the solution was significantly improved compared to that from GAs in [5]. Nevertheless, the IGA_MU [8] is still slow for obtaining optimal solution. In IACS, the incorporation of constructive greedy heuristic with several search techniques has been proposed, leading to quick search of optimal solution. However, the method tends to obtain near global optimum solution even though it has been applied to small-scale and simple CHPED problems. Moreover, the method has the same drawback as IGA_MU; that is long computational time. The EP method [7] can handle heat balance constraint and power balance constraint and determine dispatch order of units by using several other techniques when applying to the CHPED problem. Nevertheless, the EP method has some disadvantages when dealing with the CHPED problem such as near global optimum and long computational time. In the LR-SQP method, sequential quadratic programming (SQP) algorithm has been proposed to solve nonlinear optimization problems and verify the feasible operating zone of each unit. Although this method is capable of solving more complicated problem than LR method, it is not effective for the problem with nonconvex objective function. In SARGA, the combination of tournament selection and simulated binary crossover performed on real-coded GA enables the method to achieve fast computation with low computational burden. On the other hand, there has been also a penalty approach without parameters used to successfully handle equality and inequality constraints. The ALHN method [11] is the combination of the augmented Lagrange function and Hopfield network. The advantages of the ALHN method are easy implementation, fast computation, and global optimum. However, this method still suffers difficulty when dealing with the problems with nonconvex functions. BCO has been successfully applied for solving CHPED problem considering valve point effect on pure power generation units. The result comparison has revealed that the BCO is superior to EP, particle swarm optimization (PSO), and real coded GA in terms of high solution quality and execution time. However, the effectiveness and robustness of the BCO method has not been evaluated on the large-scale systems. Several improvements of HS [1,13,14] have been proposed for solving the CHPED problem. The improved HS methods have obtained better solution quality than the original one. However, the convergence characteristic of the HS has revealed that the method is still slow for obtaining optimal solution. In [15], the combination of each of the three search techniques including Latin hypercube sampling (LHS), particle swarm optimization (PSO) and design and analysis of computer experiments (DACE) with MADS algorithm forms different improvements of the MADS method such as MADS-LHS, MADS-PSO and MADS-DACE. Among these improvements, MADS-DACE is superior to others for obtaining better solution quality. In [16], NDS along with a successive refinement search technique has been employed to speed up the convergence with a small number of iterations and short computational time. The AIS method has been considered superior to EP and PSO through the result comparison for the CHPED problem with valve point effects off pure power generation units. The AIS method has some advantages such as few parameters and low number of iterations for obtaining optimal solution. However, the method may suffer the premature convergence if the application of the aging operator to eliminate the bad antibodies is not successful. In the LR-SSMU method [18], the Lagrange function is established to search for the optimal solution. In addition, two proposed rules are successfully applied to update the Lagrange multiplier including constant step size (CSS) rule and square summable but not summable (SSBS) rule. The obtained results from the two methods, LR-SSMU-CSS and LR-SSMU-SSBS, in terms of cost and characteristic rate have indicated that there is no method superior to another. TVAC-PSO in [19] is also an improved version of CPSO by modifying two acceleration coefficients. The TVAC-PSO in [19] has been tested on many

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