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Grey wolf optimization for combined heat and power dispatch with cogeneration systems

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ABSTRACT

The Combined Heat and Power Dispatch (CHPD) is an important optimization task in power system operation for allocating generation and heat outputs to the committed units. This paper presents a Grey Wolf Optimization (GWO) algorithm for CHPD problems. The effectiveness of the proposed method is validated by carrying out extensive tests on three different CHPD problems such as static economic dispatch, environmental-economic dispatch and dynamic economic dispatch. Valve-point effects, ramp-rate limits and spinning reserve constraint along with network loss are considered. Standard test systems containing 4, 7, 11 and 24 units are used for demonstration purpose. To validate the performance of the GWO, statistical measures like best, mean, worst, standard deviation, epsilon, iter and sol-iter over 50 independent runs are taken. The simulation experiments reveal that GWO performs better in terms of solution quality and consistency.

Introduction

General

Nowadays the energy conservation has been globally highlighted due to an expected sharp increase in energy demands and the resultant increased pollution. Also the conversion of electric energy into heat energy needs efficient process because most of the energy is wasted during conversion process. In order to improve the efficiency of the existing system, cogeneration is introduced which refers to the simultaneous production of electric and heat energy from a single source. Cogeneration minimizes the energy loss during aforesaid conversion process and can significantly reduce a facility's energy use by decreasing the amount of fuel to meet the facility's electrical and thermal base loads. This reduction in energy use can produce a number of benefits, including energy cost savings; reducing gas emissions, and other environmental impacts, especially when renewable fuel sources are used.

In Combined Heat and Power Economic Dispatch (CHPED) problem, the cogeneration units, heat-only units and power-only units are combined together and their outputs are optimized. This problem is a complex, non-linear optimization problem and the main issue in this formulation is finding the feasible operating point of cogeneration units. The complexity of the problem increases further considering the valve point effects and pollutant emissions. This formulation can be extended to dynamic load patterns, in which the units are scheduled according to load demands over a certain period of time. In this formulation, Spinning Reserve Requirements (SRRs) is considered along with ramp rate limits, is called as Reserve Constrained Combined Heat and Power Dynamic Economic Dispatch (RCCHPDED) problem.

Literature survey

The solution methods can be categorized into two groups: mathematical and heuristic. The mathematical approaches including Lagrangian multiplier, linear programming, quadratic programming, dynamic programming, etc., were applied to solve this problem [1–3]. These methods require approximations in the modeling of the cost curves and are not practical as the actual cost curves are highly non-linear, non-monotonic and sometimes contain discontinuities.

Genetic Algorithm (GA) and its modified versions including Genetic Algorithm based Penalty Function (GA-PF), Improved Genetic Algorithm (IGA), Self Adaptive Real Coded Genetic Algorithm (SARGA) have been reported for the solution of CHPED problems [4–6]. Basu suggested Non-dominated Sorting Genetic Algorithm-II (NSGA-II) [7] but the major drawback of this method is crowded comparison that restricts the convergence. The distributed autocatalytic process had been included in the

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conventional Ant Colony Search (ACS) in order to enhance its solution quality namely Improved ACS was applied to CHPED problems [8]. Evolutionary programming [9,10] was applied to solve CHPED problem considering environmental factors but suffers with premature convergence to a local extremum. Harmony Search Algorithm (HSA) and Economic Dispatch with Harmony Search (EDHS) problems which uses a stochastic random search but it suffer with the premature convergence [11,12]. Particle Swarm Optimization (PSO) and its modified versions including Time Varying Acceleration Coefficients Particle Swarm Optimization (TVAC-PSO), Selective Particle Swarm Optimization (SPSO) were applied for solving CHPED problems [13–15]. Differential Evolution (DE), Artificial Immune System (AIS) and Bee Colony Optimization (BCO) were applied for the optimal solution of CHPED system [16–18]. A new mutation strategy was introduced in the firefly algorithm to enhance its search capability called Enhanced Firefly Algorithm (EFA) and was applied to find the optimal solution in dynamic environment [19].

The decomposition approaches such as Lagrangian relaxation with the surrogate sub gradient multiplier updating technique [20] and Bender's decomposition [21] were used to solve the CHPED problem. Self Adaptive Learning Charged System Search Algorithm (SALCSSA) was applied to find the optimal dispatches in dynamic environment [22]. Multi-objective line up competition algorithm was applied to solve CHPED problem [23] but Abdollah Ahmadi and Mohammad Reza Ahmadi commented that the algorithm was implemented on test system which contains erroneous data; hence the reported results were inaccurate [24]. Group Search Optimization (GSO), Improved Group Search Optimization (IGSO) [25], Teaching Learning Based Optimization (TLBO), Oppositional Teaching Learning Based Optimization [26] and a hybrid harmony – genetic approach was also been reported to solve CHPED problem [27].

GWO as an optimization tool

Mirjalili et al., developed a bio-inspired optimization algorithm, the so called Grey Wolf Optimization (GWO), which mimics the leadership hierarchy and hunting mechanism of grey wolves in nature [28]. This algorithm has few parameters and easy to implement, which makes it superior than earlier ones. The GWO is effectively proposed in CHPD problems. The proposed method is tested on different scale of test systems. The obtained results are compared with the earlier reports and GWO emerges out to be a stout optimization technique for solving CHPD problem for linear and nonlinear models.

Remainder of the article

The remainder of this paper is organized as follows. RCCHPDED problem along with operational constraints is introduced in next section. GWO considered in section 'Grey Wolf Optimizer (GWO)'. Implementation for CHPD is addressed in section 'GWO based CHPD'. Section 'Constraint handling by GWO' describes the constraint handling strategy. In section 'Verification via test systems' CHPD problems are considered as follows:

(a) Linear single objective optimization problem.
(b) Non-linear multi-objective optimization problem.
(c) Non-linear single objective large scale optimization problem.
(d) Reserve constraint combined heat and power dynamic economic dispatch (RCCHPDED) problem, numerical results are compared to the meta-heuristic and classical optimization techniques.

Conclusion of this paper is conducted in the last section.

Problem formulation

Nomenclature

h, i, j	heat-only (HU), power-only (PU) and cogeneration (CHP) units indices
k, t	iteration and time index
a_i, b_i, c_i, d_i, e_i	cost coefficients of power-only unit i
$B_{i,j,t}, B_{o,i,t}, B_{oo,t}$	transmission loss coefficients
DR_i^{PU}, DR_j^{CHP}	down-ramp rate of ith power-only unit and jth CHP unit (MW/h)
$H_{D,t}, P_{D,t}$	heat and power demands at time t
$H_{h,max}^{HU}, H_{h,\min}^{HU}$	maximum and minimum heat outputs of heat-only unit h (MWth)
$H_{j,max}^{CHP}, H_{j,\min}^{CHP}$	maximum and minimum heat outputs of CHP unit j (MWth)
N_{CHP}, N_{HU}, N_{PU}	number of CHP units, heat-only units and power-only units
NT	number of time intervals
$P_{j,max}^{CHP}, P_{j,\min}^{CHP}$	maximum and minimum power outputs of CHP unit j (MW)
$P_{i,max}^{PU}, P_{i,\min}^{PU}$	maximum and minimum power outputs of power-only unit i (MW)
SR_t	10 min spinning reserve requirements at time t (MW)
UR_i^{PU}, UR_j^{CHP}	up-ramp rate of ith power-only unit and jth CHP unit (MW/h)
UR_{ii}	up-ramp rate of power generating unit ii (MW/h)
α_j, β_j, ζ_j,γ_j,λ_j,φ_j	cost coefficients of CHP unit j
σ_h, μ_h, ρ_h	cost coefficients of heat-only unit h
F_T	total operational costs at time span NT ($)
$f_1(P_t^{PU})$	total fuel cost of power-only units at time t ($)
$f_2(P_t^{CHP}, H_t^{CHP})$	total fuel cost of CHP units at time t ($)
$f_3(H_t^{HU})$	total fuel cost of heat-only units at time t ($)
$H_{h,t}^{HU}$	output of heat-only unit h at time t (MWth)
$P_{j,t}^{CHP}, H_{j,t}^{CHP}$	power and heat outputs of CHP unit j at time t
$H_{Loss,t}, P_{Loss,t}$	heat and power losses at time t
H_violet, P_violet	heat and power mismatch vector
$P_{i,t}^{PU}$	power output of power-only unit i at time t (MW)
$P_{ii,,t}^{PU}$	power output of electric power generation unit ii at time t (MW)
$P_{ii,max}$	power capacity of electric power generation unit ii, respectively (MW)

Considering a system, that consists of power-only units, cogeneration units and heat-only units. The outputs of power-only unit and heat-only unit are limited by their own upper and lower limits. Fig. 1 illustrates the heat-power Feasible Operation Region (FOR) of a cogeneration unit which is enclosed by the boundary curve ABCDEF. In the system under consideration, power is generated by power-only and cogeneration units while heat is produced by cogeneration and heat-only units. The CHPD problem is concerned to determine the power and heat production of each unit so that the fuel cost and the pollutant emissions of system are minimized simultaneously while the power and heat demands and other constraints are met.