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Hydro-thermal-wind scheduling employing novel ant lion optimization technique with composite ranking index

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ABSTRACT

A solution to the combined hydro-thermal-wind scheduling problem of multi reservoir cascaded hydro plants is presented employing a novel ant lion optimization (ALO) algorithm. Five objectives, cost, various emissions and power loss, are simultaneously optimized. The optimal schedules of thermal, hydro and wind power (WP) units are determined for continuously varying load subject to a large number of practical operational constraints. The effect of reserve and penalty coefficients and WP uncertainty is also investigated for the multi-objective (MO) problem. The newly proposed ALO algorithm has unique features like random walk, roulette wheel, and boundary shrinking. These operations provide a judicious balance between exploration and exploitation, and create a powerful optimization technique for complex real-world problems.

Finding the best compromise solution (BCS) is a tedious task when multiple objectives are involved. A composite ranking index (CRI) is proposed as a performance metrics for MO problems. The CRI helps the decision maker in ranking the large number of Pareto-optimal solutions. The developed model is tested on three standard systems, having a mix of hydro, thermal and wind generators. The performance is found to be superior to published results and comparable with established algorithms like artificial bee colony (ABC) and differential evolution (DE).

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1. Introduction

With increasing focus on climate change and clean energy, more and more wind power (WP) is being integrated in the power system. However, wind intermittency requires effective policies and dispatch strategies to maintain economy with reliability and security. Cheap and pollution free hydro power complements wind uncertainty and reduces dependence on thermal power for reserve, lowering emissions as well as cost. The pumped storage technology is quite reliable to serve as a reserve [1]. Recently hydro-wind coordination, for balancing shortfall is proposed [2]. A mix of thermal, wind, photovoltaic, and hydropower is the environment friendly answer for a reliable and secure power system in future [3].

In view of this, the combined dispatch of hydro-thermal-wind generators is the need of the hour. The initial papers on short-term hydro-thermal scheduling included a single objective (SO) [4–7]. Later, regulations forced utilities to minimize emissions along with cost and MO models came into existence [8–22]. Both, SO [23–25] as well as MO [26,27] models can be found for wind integrated thermal scheduling problems. However, very few researchers have addressed the joint dispatch of hydro-thermal and wind units [28–30].

The goal of hydrothermal scheduling is to minimize the cost of thermal generation subject to various linear and non-linear equality/inequality constraints. The problem becomes complex when WP is integrated as WP uncertainty needs to be modelled using wind curtailment penalty and cost of thermal reserve to represent under and over estimation of WP respectively [31].

Hydrothermal scheduling using dynamic programming [4], Lagrange relaxation [5] etc. do not work satisfactorily for complex practical problems. Lately, nature inspired (NI) methods have gained popularity against gradient based algorithms, due to their numerous advantages [10,27] such as (i) Non dependence on nature of optimization problem (ii) Non dependence on initial solution (iii) Global search capability due to population based direct search (iv) Simple implementation and (v) Effective constraint handling. Among popular NI techniques, EP [9], PSO [10,15], DE

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[8,11,12], ABC [13,18,32], GS [14,17] PPO [15], and cultural algorithm with PSO [16], are successfully implemented. In Ref. [19] normal boundary intersection method, a MO fuzzy optimization model [20] and Lexicographic optimization technique [21] are proposed for hydro-thermal scheduling.

In this paper a novel ALO algorithm [33], based on the hunting activity of ant lions found in nature, is employed for solving the MOHTWS problem. The six step hunting activity is formulated into mathematical operations to build the ALO algorithm.

In this paper, five objectives consisting of cost, various emissions and power loss are simultaneously optimized taking into consideration WP uncertainty cost, cascading, water transport delays, reservoir limits, dynamic water discharge limits, hydraulic balance constraints, prohibited zones of hydro units, ramp rate limits and valve point loadings of thermal units, power balance, and capacity limits of hydro-thermal-wind units. To the best of authors' knowledge, all these complexities have not yet been included together in any one paper so far. Three standard test cases have been used to analyse the performance of the proposed approach.

The BCS is determined by the decision maker using different indices such as TOPSIS [34], fuzzy rank [35], satisfaction/coordination degree approach [36] etc. In this paper, a new composite ranking index (CRI) has been proposed as a performance measure for MO problems. The performance of the ALO algorithm is compared and validated with other established NI algorithms to demonstrate its applicability for complex real-world problems.

2. Multi-objective hydro-thermal-wind power scheduling (MOHTWS)

In the MOHTWS problem, five objectives, which are cost, NO_X, SO_X, CO_X and power loss are simultaneously optimized subject to complex equality/inequality constraints of hydro-thermal and WP units.

2.1. Cost of thermal and wind units with wind uncertainty

$$F_1 = \sum_{t=1}^{T}\left\{\sum_{i=1}^{Ns}[f_{it}(P_{sit})] + \sum_{k=1}^{N_w}[f_{wkt}(P_{wkt})]\right\} \tag{1}$$

$$f_{it}(P_{sit}) = \left\{a_{si} + b_{si}P_{sit} + c_{si}P_{sit}^2 + \left|d_{si}\times Sin\left[e_{si}\times\left(P_{si}^{\min} - P_{sit}\right)\right]\right|\right\} \tag{2}$$

The cost of WP consists of three terms, a direct cost, an under estimation penalty and a reserve cost due to over estimation of WP as given in (3). A penalty cost function is used for cases when *more* WP is available than scheduled; conversely, the reserve cost function represents the cost of thermal reserve to meet the deficit, when available WP is *less* than the scheduled WP.

Based on above, the WP cost of kth wind turbine at t^{th} time can be computed as [31]:

$$f_{wkt}(P_{wkt}) = \left\{(K_k\times P_{wkt}) + C_{pkt}(W_{kt,av} - P_{wkt}) + C_{rkt}(P_{wkt} - W_{kt,av})\right\} \tag{3}$$

The under estimation penalty will be proportional to the unutilized WP whereas the reserve cost will depend on the WP deficit. The penalty and reserve costs can be expressed as [31]:

$$C_{pkt}(W_{kt,av} - P_{wkt}) = k_p\times(W_{kt,av} - P_{wkt}) = k_p\times\int_{P_{wkt}}^{w_r}(w - P_{wkt})f_w(w)dw \tag{4}$$

$$C_{rkt}(P_{wkt} - W_{kt,av}) = k_r\times(P_{wkt} - W_{kt,av}) = k_r\times\int_{0}^{P_{wkt}}(P_{wkt} - w)f_w(w)dw \tag{5}$$

$$f_w(w) = \frac{khv_{in}}{P_{wR}c}\left[\frac{\left(1 + hw/P_{wR}\right)v_{in}}{c}\right]^{k-1}\times exp\left\{-\left[\frac{\left(1 + hw/P_{wR}\right)v_{in}}{c}\right]^{k}\right\} \tag{6}$$

The WP characterization is done using Weibul pdf, $f_w(w)$. Here $h = (v_r/v_{in}) - 1$. Further details can be found in Refs. [26,31].

2.2. Minimization of NO_X, SO_X and CO_X emissions [32]

$$F_2 = \sum_{t=1}^{T}\left\{\sum_{i=1}^{Ns}\left[\alpha_{ni}P_{sit}^2 + \beta_{ni}P_{sit} + \gamma_{ni}\right]\right\} \quad (\text{Kg/h}) \tag{7}$$

$$F_3 = \sum_{t=1}^{T}\left\{\sum_{i=1}^{Ns}\left[\alpha_{si}P_{sit}^2 + \beta_{si}P_{sit} + \gamma_{si}\right]\right\} \quad (\text{Kg/h}) \tag{8}$$

$$F_4 = \sum_{t=1}^{T}\left\{\sum_{i=1}^{Ns}\left[\alpha_{ci}P_{sit}^2 + \beta_{ci}P_{sit} + \gamma_{ci}\right]\right\} \quad (\text{Kg/h}) \tag{9}$$

2.3. Minimization of real power loss

If total number of units is $N_T = N_S + N_H + N_W$ and P_{it} represents the respective thermal, hydro and WP generation, then the total transmission loss P_{Lt} at tth interval can be calculated using B -loss coefficient as [4].

$$F_5 = P_{Lt} = \sum_{i=1}^{N_T}\sum_{j=1}^{N_T}P_{it}B_{ij}P_{jt} + \sum_{i=1}^{N_T}B_{0i}P_{it} + B_{00} \tag{10}$$

2.4. Equality constraint for maintaining power balance

$$\sum_{i=1}^{Ns}P_{sit} + \sum_{j=1}^{N_H}P_{Hit} + \sum_{k=1}^{N_w}P_{wkt} = P_{Dt} + P_{Lt} \tag{11}$$

The jth hydro unit output can be expressed in terms of hydro power coefficients as given below. The storage volume of the j^{th}

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