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Scheduling short-term hydrothermal generation using predator prey optimization technique

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Paper presents predator–prey based optimization (PPO) technique to obtain optimal generation scheduling of short-term hydrothermal system. PPO is a part of the swarm intelligence family and is capable to solve large scale non-linear optimization problems. PPO based algorithm combines the idea of particle swarm optimization concept with predator effect that helps to, maintain diversity in the swarm and preventing premature convergence to local sub-optimal. In this paper first of all feasible solution is obtained through random heuristic search and then thermal and hydro power generations are searched for optimum hydrothermal scheduling problem using PPO. Variable elimination method is implemented to handle the equality constraint by eliminating variable explicitly. These eliminated variables are considered by penalty method restricts slack units with in limits. Slack thermal generating unit for each sub-interval handles power balance equality constraint and slack hydro units handle water equality constraint. The performance of the proposed approach is illustrated on, fixed-head and variable-head hydrothermal power systems. The results obtained from the proposed technique are compared with the existing technique. From the numerical results, it is experienced that the PPO based approach is able to provide a better solution.

1. Introduction

In the electric power supply system, there exist a wide range of problems involving optimization processes. Among them, hydrothermal scheduling is an important optimization task in power system operation. Optimization methods are classified based on the type of search space and the objective function along with equality and inequality constraints. In general, the objective function or constraints or both contains nonlinearity giving rise to nonlinear problem. The optimal scheduling of hydrothermal power system is basically a complex programming problem involving nonlinear objective function and a mixture of linear and nonlinear constraints. The objective of hydrothermal scheduling is to generate the power economically, whereas satisfying various constraints. The equality constraints include generation-demand balance and balance of available volume-water discharge. The inequality constraints include generation limit on thermal and hydro power unit, limit on water discharge rate and reservoir storage level limit. The hydrothermal scheduling problem is broadly classified as convex and non-convex optimization problem. In convex hydrothermal scheduling problem the input–output characteristics are assumed piecewise linear and monotonically increasing, optimization algorithms that are based on mathematical programming can be applied. Several conventional methods have been used in hydrothermal scheduling for finding the economical hydrothermal generation schedule under practical constraints such as dynamic programming [1], mixed integer programming [2], Lagrange relaxation method [3], Lagrangian multiplier and gradient search techniques [4]. Most of the applied methods make a number of assumptions to simplify the optimization problem, but that may lead to a suboptimal solution.

The recent trend is to apply more realistic models for hydro and thermal units. The non-convex hydrothermal model presents the complete, realistic problem having non-smooth characteristics. Such problem requires a fast, accurate and robust solution methodology as it cannot be handled effectively by mathematical programming based optimization methods. Generally, heuristic

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search methods are used as tool for the solution of complex optimization problems because of their strength to overcome the shortcomings of the traditional optimization methods. Heuristic search techniques has a number of exclusive advantages like robust and reliable performance, global search capability, little information requirement, ease of implementation, parallelism, no requirement of differentiable and continuous objective function. In the past decades, several heuristics search techniques such as genetic algorithm [5–7], evolutionary programming [8,9], simulated annealing and particle swarm optimization (PSO) [10,11] have been proven to be very efficient in solving complex power system problem. Various heuristic search techniques have been reported in the literature pertaining to short-term fixed-head hydrothermal scheduling. Basu has applied evolutionary programming technique [12], simulated annealing technique [13] and real-coded genetic algorithm [14] for solving fixed-head hydrothermal scheduling. Chiang [15] has applied improved genetic algorithm (IGA) equipped with an improved evolutionary direction operator and a migration operation for solving hydrothermal generation scheduling. The artificial immune system technique has been applied for optimal scheduling of thermal plants in coordination with fixed-head hydro units [16]. Petcharaks and Ongsakul [17] have proposed a hybrid enhanced Lagrangian relaxation and quadratic programming based technique for hydrothermal scheduling. Gil et al. [18] have proposed a method to deal with short-term generation scheduling problem for hydrothermal system using genetic algorithm. Sasikal and Ramaswamy [19] have presented an optimal gamma based algorithm for fixed-head hydrothermal problems using genetic algorithm. Mandal and Chakraborty [20] have developed an efficient and reliable PSO based algorithm to solve combined economic-emission scheduling of hydrothermal power systems with cascaded reservoirs. PSO technique has been applied to solve short-term hydrothermal scheduling by Mandal et al. [21]. A biogeography based optimization methodology combined with predator prey approach has been proposed and validated for economic load dispatch by Silva and Coelho [22]. Brabazon et al. [23] have constructed a simulation model using swarm metaphor, to examine the impact of strategic inertia on the adaptation of the strategic fitness of a population.

Heuristic search techniques often provide a fast and reasonable solution, but do not ensure global optimal solutions in finite time, so these search techniques belong to the group of approximate algorithm. Several literatures have reported some major shortcomings of different heuristic search technique. Evolutionary programming (EP) is a powerful search technique; however, it is having slow converging characteristics, near optimum solution for some problems [24]. Genetic algorithm (GA) ensures that solutions are changing continually, but sometimes it is deficient of producing better offspring and causes slow convergence near global optimum [25,26]. Differential Evolution (DE) has limited ability to move its population to large distances across the search space if the population is clustered in a limited portion of it [27]. In GA, the worse solutions are discarded and only the good ones are saved. Particle swarm optimization maintains the diversity of the swarm, since all the particles share the information related to the most successful particle in the swarm. PSO converges very fast compared to other search techniques such as Genetic algorithm, Evolutionary programming, etc. [26]. Mahamed et al. [25] have shown that the convergence behavior of PSO depends upon their parameters. Wrong choices of values for these parameters may result in divergent particle trajectories and it causes trapping into local minimum value; so no algorithm can always, surpass the others in all possible optimization problems. The predator–prey model is inspired in the hunt of birds (prey) grouped in swarms attacked by predators. Predators' effects include additional capability to escape from local minimum position as compared to PSO algorithm [28]. Predators play the role of searching around global best in a concentrated manner, whereas preys explore on a solution space escaping from predators, so predators prevent pre-mature convergence and preys play the role of diversification. Predator prey optimization has been successfully applied to various test problems [28,29]. Silva et al. [28] have presented experimental results of four benchmark multimodal functions solved using standard PSO and its other variants and PPO. They have concluded that PPO performed better than the standard PSO and its other variants. Since optimal scheduling of a hydrothermal power system is also a multimodal problem, so use of a PPO technique may be best suited for this problem. In this paper, PPO technique has been applied on fixed and variable-head scheduling problem and implemented on number of test systems and achieved numerical results. The paper is organized with the introduction of a short-term hydrothermal model followed by elaborative description of a PPO algorithm to achieve the solution. Finally, results are reported and after performing comparison with existing methods the conclusions are outlined.

2. Mathematical formulation of the short-term hydrothermal scheduling

The basic problem is to find optimum active power generation in the system as a function of time. Total generation should meet load demand in each interval and each hydro unit is constrained by the amount of water available for draw down in the planning period. Both fixed and variable-head hydrothermal generation scheduling problems are taken into consideration. Short and long period of time subinterval classify the whole planning period problem as short-term and long-term scheduling period.

2.1. Thermal model

The objective function to be minimized is the total system operating cost of thermal generating unit for the planned time horizon. The generator operating cost is usually approximated using quadratic function. However, it is more practical to consider the valve-point loading for fossil–fuel-based unit. In this context, a cost function is obtained based on the ripple curve for more accurate modeling. This curve contains higher order nonlinearity and discontinuity due to the valve-point loading effect. One way of representing this effect is to use a rectified sinusoidal function in the cost function [30]. Operating cost function for thermal unit is expressed over the optimization interval given as:

$$F = \sum_{k=1}^{T}\sum_{i=1}^{N}(a_i P_{ik}^2 + b_i P_{ik} + c_i + \left| d_i \ \sin\{e_i(P_i^{\min} - P_{ik})\}\right|) \tag{1}$$

where a_i, b_i, c_i, d_i and e_i are cost coefficients of ith thermal unit, P_{ik} is real power generation of ith unit during kth subinterval; N is the number of thermal generators, T is total time duration for scheduling, $P_i^{\min}$ is the lower limit of ith thermal unit.

2.2. Short-term hydro model

In short-term hydrothermal scheduling problem, an insignificant fuel cost is incurred in the operation of hydro-units. The input-output characteristic of a hydro-generator is expressed by the variation of water discharge, q_{jk} which is a function of power output, P_{mk} and net head, h_{jk}. According to Glimn–Kirchmayer model [31] the discharge rate of jth hydro unit at kth subinterval is given by

$$q_{jk} = K_j \varphi(P_{mk}) \psi(h_{jk}) \quad (j = 1, 2, \ldots, M; m = j + N; k = 1, 2, \ldots, T) \tag{2}$$