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Synergic predator-prey optimization for economic thermal power dispatch problem

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ABSTRACT

This paper introduces a synergic predator-prey optimization (SPPO) algorithm to solve economic load dispatch (ELD) problem for thermal units with practical aspects. The basic PPO model comprises prey and predator as essential components. SPPO uses collaborative decision for movement and direction of prey and maintains diversity in the swarm due to fear factor of predator, which acts as the baffled state of preys' mind. In the SPPO, the decision making of prey is bifurcated into corroborative and impeded parts. It comprises four behaviors namely inertial, cognitive, collective swarm intelligence, and prey's individual and neighborhood concern of predator. The prey particle memorizes its best and not-best positions as experiences. In this research work, to improve the quality of prey swarm, which influence convergence rate, opposition based initialization is used. To verify robustness of proposed algorithm general benchmark problems and small, medium, and large power generation test power system are simulated. These test systems have non-linear behavior due to multi-fuel options and practical constraints. The constraints of prohibited operating zone and ramp rate limits of power generators' are handled using heuristics. Newton–Raphson procedure is exploited to attain the transmission losses using load flow analysis. The outcomes of SPPO are compared with the results described in literature and are found satisfactory.

1. Introduction

Economic load dispatch is a constrained optimization task in power system to schedule committed generating units for economical power generation. Practical ELD problem exhibits nonlinear characteristics, because of the multi-fuel options [1], valve-point loading effect, ramp-rate limits, prohibited operating zone (POZ) constraints [2] and transmission losses [3]. Further the spinning reserve requirements are introduced in the ELD problem [4].

The conventional optimization techniques [5,6] require completely differentiable and continuous objective function and constraints [7] to solve optimization problems. In the last decade, various researchers have solved ELD problem by conventional techniques after simplifying the ELD problem with number of assumptions. Because of this, conventional techniques are unable to search global optimal solution. The dynamic programming can handle the non-linear and discontinuous optimization problems, but requires large computational time and suffers from the curse of dimensionality [8]. To overcome disadvantages of conventional techniques, various global optimization techniques *i.e.* genetic algorithm (GA) [9], particle swarm optimization (PSO) [10], simulated annealing algorithm [11], evolutionary programming (EP) [12], biogeography based algorithm (BBO) [13], differential evolution (DE) [14], *etc.* and their variants are applied to solve the ELD problem. Recently the ELD problem is solved using teaching learning algorithm [15], particle diffusion algorithm [16], social spider algorithm [17], modified artificial bee colony algorithm [18], chaotic teacher learning algorithm [19], *etc.*

Among population based techniques, the PSO introduced by Kennedy and Eberhart [20], is found to be robust in solving nonlinear optimization problems. PSO caught attention of power system community and succeeded to solve many complex power system optimization problems. de Oca et al. [21], presents the basic concepts and variants of PSO [21]. In brief, the advantages of PSO are concluded as: simple concept, easy implementation, computational efficiency in comparison to other heuristic techniques [8,22]. At the same time, the unresolved issues of PSO are: lack of mathematical background, large computational time compared to mathematical approaches, initial point and parameter dependency, optimal

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design parameters setup, stochastic nature of final solution, inability to handle scattering and premature convergence/partial optimism [22] due to homogeneity of particles.

One of a major concern for PSO performance is diversity of particles. The attempts to tackle this crucial issue includes neighborhood topologies [23], adjustment of parameters in standard PSO [24], parameter adaptation mechanism [25], modified models [26]. In another effort to ameliorate the performance of PSO, it is blended with local/global search techniques. The examples are a combination of genetic algorithm and PSO [27], hybrid PSO [28]. These approaches improved the solution quality and convergence behavior, but lead to the drawbacks of algorithmic complexity, computationally onerous [29], and problem specific approach, *etc.*

In the hunt of betterment, usually the existing solution procedures are complexed, although simple natural biological approches exists for such problems, which are often ignored. These approaches usually lacks theoratical background, but are effective in obtaining solution. Among these the introduction of multi-swarm systems [30], bio-inspired PSO [31] and predator effects [32] based mechanism are also proposed to improve the performance of PSO. The predator prey optimization (PPO) introduces a second population, called predator, to ensure population diversity. The predator and prey are responsible for convergence and diversification respectively [33]. The predator always targets the best position of the swarm and the preys avoid it by its individual decision. The PPO has better convergence and solution accuracy than PSO [34].

The PPO has the capability to solve large scale non-linear optimization problems. The numerical result comparison shows the supremacy of PPO over PSO and its variants [35,36]. In another effort, Costa e Silva et al. [37] have proposed biogeography-based optimization method combined with PPO technique for designing a brushless DC wheel motor. The success of search algorithm requires balanced exploration and exploitation. The PPO's exploitation capability is uncertain as the predator's effect is a random process. In spite of various successful applications of PPO to solve complex optimization problems, the psychology aspect of prey particles lacks exploration. The prey being a part of the swarm, its individual decision-making is partial. The decision of prey for new place must be a group activity as the swarm together influences decision-making. A group tends to make decisions, that are more extreme than those of its individual members, in the direction of the individual inclinations [38].

In optimization algorithms, the convergence rate of algorithm is highly corelated to the quality of initial population. The proximity of starting point to the optimal solution, results in a faster convergence and contrary [39]. In the worst-case initialization, the convergence will take much more time or the solution can be intractable. Looking simultaneously for a better candidate solution, in both current and opposite directions may help to solve this problem quickly and efficiently. In opposition-based learning research field, a variety of new models have been studied for dealing with significant problems. Xu et al. [39] provides a detail survey of opposition-based meta-heuristics recently used in engineering applications.

In the light of various observations of the literature survey, the author's contributions to ELD solution methodology are summarized as follows:

- This paper proposes a new version of the PPO model called Synergic PPO (SPPO). The SPPO blends the psychology of preys along with the mathematical model of the PPO. This results in collaborative intelligence that drives the search variables. The proposed SPPO divides the self-intelligence of the prey into two evolutionary elements, *i.e.*, best and non-best experiences. These elements help in information exchange at a steady rate, which ensures uniform diversity. The prey movement will be guided by the best and non-best experiences along with the predator's effect. The predator always chases the global best prey and the predator's effect depends on the swarm's realization of predator. In this research work, the collaborative predator effect is introduced as a gizmo to counteract search in the initial and final phase. In the initial phase, the predator's effect being small, the search will be more explorative and in the final juncture as the predator's effect will dominate and the search will shift to exploitation.
- An opposition based initialization of prey particle positions is utilized to start with good candidates of prey particles. As the priori information about the solution is ambiguous, it is better to check the quality of their opposite solutions instead of using random guess.
- The ELD problem having multi-fuel options considering non-linearity's of generators is solved. A variant of the multi-fuel system with transmission losses is proposed and analyzed. The transmission losses are obtained using Kron's relations as well as load flow analysis.
- In this paper, five generalized benchmark problems and six power test systems with different cases are considered to prove the supremacy of proposed SPPO based ELD solution approach.

The paper is organized into six sections. Section 2 presents the ELD problem. Section 3 presents the constraint handling procedures used in the search process, Section 4 explains the SPPO based solution procedure to solve the ELD test problems. The comparison of results is presented in Section 5. Finally, Section 6 concludes this paper.

2. Economic load dispatch problem

The ELD problem is defined as to minimize the entire operating cost of a power system and simultaneously meet the system operational constraints. Mathematically, the multi-fuel ELD with generators' constraints and power generation limits $P_j^{\min}$ and $P_j^{\max}$ is stated as below:

Minimize the operating cost

$$f(P_j) = \sum_{j=1}^{N_g} (a_{jk}P_j^2 + b_{jk}P_j + c_{jk} + |d_{jk}\sin\{e_{jk} \times (P_{jk}^{\min} - P_j)\}|);$$
$$P_{jk}^{\min} \le P_j \le P_{jk}^{\max} \quad (k = 1, 2, \ldots, N_f) \tag{1.a}$$

Subjected to:

(i) Power balance, equality constraint

$$\sum_{j=1}^{N_g} P_j - (P_D + P_L) = 0 \tag{1.b}$$

(ii) Generators' operating lower and upper boundaries

$$P_j^{\min} \le P_j \le P_j^{\max} \quad (j = 1, 2, \ldots, N_g) \tag{1.c}$$

(iii) Ramp rate limit constraint
  (a) As generation increases

$$P_j - P_j^0 \le UR_j \quad (j = 1, 2, \ldots, N_g) \tag{1.d}$$

  (b) As generation decreases

$$P_j^0 - P_j \le DR_j \quad (j = 1, 2, \ldots, N_g) \tag{1.e}$$