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A new hybrid bacterial foraging and simplified swarm optimization algorithm for practical optimal dynamic load dispatch

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ABSTRACT

This paper presents a novel approach to depict the practical constraints of generator units such as reserve constraints, prohibited operating zones and valve-point effects in the optimal dynamic dispatch problem. Determining the power generation output of units at minimum total fuel cost a dynamic environment with ramp rate limits to satisfy load demand and transmission losses is too complicated and has a lot of local optima in its search space. In addition, the proposed problem has a non-linear, non-convex, non-smooth, multi-modal, non-separable, and non-differentiable nature. In order to overcome above problems a new hybrid technique, based on bacterial foraging and simplified swarm optimization algorithms combined with a new mutation operator and opposition-based initialization is proposed to restraint the premature convergence of the solutions. Therefore, the bacteria in chemo-tactic procedure are moved in short or long steps as well as swimming movements. Furthermore, to increase the diversity of the solution of the search space a novel self-adaptive mutation strategy which profits from four mutation rules is implemented. For more validation the simulation results are applied on four small, medium and large scale systems with 5-unit, 10-unit, 30-unit and 100-unit and compared with those of other methods in the area.

1. Introduction

The operational conditions of the transmission networks are determined to supply the varying consumers load demand, transmission losses over a short-term time span. In essence, to reach the optimal generation dispatch of the generating unit, Optimal Dynamic Dispatch (ODD) is done by the System Operator (SO), of which, the latter is the topic of this paper. It is necessary to note that ODD is the extension of the conventional Economic Dispatch (ED). The main purpose of solving the ED problem is to determine the optimal thermal unit generation dispatch in 1 h for the economic operation, while at the same time satisfying various equality and inequality constraints [1]. Although there is a vast body of work on the static ED problem such as chaotic and Gaussian particle swarm optimization [2], hybrid multi-agent based particle swarm optimization algorithm [3], EP based SA algorithm [4], and particle swarm optimization with time varying acceleration coefficients [5], little attention has been paid to the ODD problem. According to [6], the first stage in the ODD problem is to minimize the total fuel cost as an objective function. The second stage in the ODD problem is to satisfy equality, inequality and dynamic constraints, i.e. load demand balance, ramp rate limits, generation capacity, Spinning Reserve Requirement (SRR), and Prohibited Operating Zones (POZs) constraints. The third stage is to select an efficient and powerful optimization technique which obtains a global solution or near the global solution with satisfactory execution time.

There are two groups of optimization-based methods which were solved the ODD problem: (*i*) mathematical programming-based optimization techniques; and (*ii*) meta-heuristic-based optimization methods [7]. The choice of optimization methods is strongly dependent on the nature of objective function and constraints [8]. The ODD problem can be solved with the first group, if the cost function and constraints have smooth and convex nature and can be modeled with linear equations. Some of the mathematical programming-based optimization methods which solve the ODD problem are linear programming [9], nonlinear programming [10], mixed integer quadratic programming [11], Lagrangian relaxation [12], and dynamic programming [13]. These techniques have been presented to solve ODD neglecting valve-point effects, POZs and SRRs. Recently, a Maclaurin Series based Lagrangian (MSL) method is proposed in [14] to only handle the valve-point effects. Although the simulation time of the MSL method is acceptable, but the achieved operation cost by MSL is not satisfactory. Since it is very hard to attain the global optima or near the global optima of the ODD problem and meanwhile handling all the aforementioned constraints is so challenging, many researchers have been gravitated to the second group.

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Nomenclature

Indices

i	thermal unit index
j	chemo-tactic step index
k	reproduction step index
l	elimination–dispersal event index
$iter$	iteration index
m, n	bacterium index

Constants

a_i, b_i, c_i, d_i, e_i	cost coefficients of thermal unit i
$B_{i,j,t}$	loss coefficient relating the productions of thermal units i and j (MW^{-1})
$B_{0,i,t}$	loss coefficient associated with the production of thermal unit i
$B_{00,t}$	loss coefficient parameter (MW)
DR_i	ramp-down rate of thermal unit i (MW/h)
K_i	number of POZs for thermal unit i
Nb	number of bacteria in the population of MBF-SSO algorithm
Nc	number of chemo-tactic steps of the MBF-SSO algorithm
Ned	number of elimination–dispersal events of the MBF-SSO algorithm
Nk	number of reproduction steps of the MBF-SSO algorithm
NTU	number of units
$P_{D,t}$	expected load demand (MW)
$P_{i,\max}$	power capacity of thermal unit i (MW)
$P_{i,\min}$	minimum power output of thermal unit i (MW)
$P_{i,k}^{L}$	lower boundary of the kth POZ for thermal unit i
$P_{i,k}^{U}$	upper boundary of the kth POZ for thermal unit i
$rand(.)$ and $rand_Q(.)$	$Q = 1, \ldots, 3$ random function generator in the range [0,1]
SR_t	10 min spinning reserve requirements (MW)
$SR_{i,t}$	10 min spinning reserve requirements related to the ith thermal unit (MW)
T	number of time intervals
UR_i	ramp-up rate of thermal unit i (MW/h)

Variables

$\mathbf{Gbest}^{iter(j)}$	best solution in iteration $iter$ or chemo-tactic step j
$\mathbf{Worst}^{iter(j)}$	worst solution in iteration $iter$ or chemo-tactic step j
$F(\mathbf{P}_G)$	total operational costs at time span T ($)
$FF(\mathbf{P}_G(m, j, k, l))$	fitness function of the mth bacterium in chemo-tactic step i at kth reproduction step for lth elimination–dispersal event
$AFF(m)$	accumulated fitness function of the mth bacterium
$\mathbf{P}_G$	generating unit vector
$P_{i,t}$	power generation output of thermal unit i (MW)
$P_{i,t}(m, j, k, l)$	position of ith thermal unit in the jth chemo-tactic step, kth reproduction step and lth elimination–dispersal event (MW)
$P_{Loss,t}$	total real power losses (MW)
$\overline{P}_{i,t}$	upper limit of the ith thermal unit output power (MW)
$\underline{P}_{i,t}$	lower limit of the ith thermal unit output power (MW)
$P\_violate_t$	power mismatch (MW)
Δ_t	spinning reserve requirements violation (MW)

Subscript

t	tth time interval (h)

The meta-heuristic-based methods exact no restriction on the ODD formulation. On the other hand, these methods cannot guarantee obtaining of the global optimal solution but they find more desirable solutions than mathematical-programming-based approaches. The main problem related to these methods refers to stagnation of solution especially for the high-dimensional, high-constraints, multi-modal, non-differentiable, and non-separable ODD problems. To remove these flaws, hybrid meta-heuristic methods are introduced in recent years in the several literatures such as Self Adaptive Modified Firefly Algorithm (SAMFA) [7], Enhanced Adaptive Particle Swarm Optimization (EAPSO) [8], hybridization of Bee Colony Optimization and Sequential Quadratic Programming (BCO–SQP) [15], θ-Teaching–Learning-Based Optimization (θ-TLBO) [16], PSO with Bacterial Foraging effect (PSO–BF) [17], Bacterial foraging PSO–Differential Evolution (BPSO–DE) [18], Hybrid Quantum inspired PSO (HQPSO) [19], Enhanced Bee Swarm Optimization (EBSO) [20], Modified Teaching–Learning Algorithm (MTLA) [21], and Artificial Immune System [22]. Most of the above mentioned methods consider entire of the aforesaid constraints of ODD problem except SRRs and POZs. The SRRs constraint has been formulated in [5,21] over the recent years. The SRRs constraint is an additional power which the SO must be considered in the formulation for preparing proper reliability and avoiding from sudden generator outages, major load forecast errors and generation shortfalls affect. Other POZs constraint should be added to the ODD problem in order to keep these units from the vibrations in a shaft bearing [23]. However, no economic dispatch approach considering all of the above constraints in a multi-period ODD optimization problem is currently available in the technical literatures.

This paper proposed a new hybrid Modified Bacterial Foraging-Simplified Swarm Optimization algorithm (MBF-SSO) for the proposed ODD problem. Bacterial Foraging Algorithm (BFA) is a most recent nature inspired algorithm which imitates the foraging behavior of the microbial creatures and tries to remove the species with poor foraging strategies and propagate the successful foraging behaviors [3,24]. The BFA accounts as the swarm intelligent algorithm which profits from the features of the famous optimization algorithms, i.e. PSO and ACO [24]. The optimization trends in this algorithm have four processes: chemo-tactic, swarming, reproduction, and elimination and dispersal. The SSOA is an evolutionary population-based technique which is overcome to the drawback of the PSO algorithm [25]. Until now the SSO has successfully been applied to various optimization problems to show its capability and superiority with respect to the PSO algorithm. Here, several modifications are carried out on the optimization steps of the BFA and SSOA and the ODD problem as well as several test functions such as Rosenbrock, Rastrigin, Ackley, and Griewank is considered as benchmarks for testing the enactment of the proposed MBF-SSO. The step size of bacteria movement in chemo-tactic step has a critical role in BFA convergence. The too small steps may entangle the bacteria in the local minima while the too big steps can miss the global optimum. Taking this into account, the suggested modifications involve short and long tumbles as well as swimming movement which help the bacteria to search the entire solution search space thoroughly. In addition, a Self Adaptive Mutation Strategy (SAMS) is utilized along with the BF-SSO to eliminate the problem of the stagnation of the solution The basic idea behind the SAMS is to simultaneously select adaptively four effective strategies from the candidate strategy pool on the basis