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A differential evolution particle swarm optimizer for various types of multi-area economic dispatch problems

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A B S T R A C T

This paper proposes a new, efficient and powerful heuristic-hybrid algorithm using hybrid DE (differential evolution) and PSO (particle swarm optimization) techniques DEPSO (differential evolution particle swarm optimization) designed to solve eight optimization problems with benchmark functions and the MAED (multi-area economic dispatch), RCMAED (reserve constrained MAED) and RCMAEED (reserve constrained multi area environmental/economic dispatch) problems with reserve sharing in power system operations. The proposed hybridizing sum-local search optimizer, entitled HSLSO, is a relatively simple but powerful technique. The HSLSO algorithm is used in this study for solving different MAED problems with non-smooth cost function. The effectiveness and efficiency of the HSLSO algorithm is first tested on a number of benchmark test functions. Experimental results showe the HSLSO has a better quality solution with the ability to converge for most of the tested functions.

1. Introduction

ELD (Economic load dispatch), OPF (optimal power flow) and ORPD (optimal reactive power dispatch) nonlinear problems are some of the most important optimization problems in power system operation and planning for allocating generation to the committed units [1,2], which have been resolved using many proposed optimization mathematical methods and modern heuristic algorithms such as Hopfield neural network [1,3], a MHSA (modified harmony search algorithm) [4], GA (genetic algorithm) [5], RCGA (real-coded GA) [6], PSO (particle swarm optimization) [7], a proposed efficient scheme in Ref. [8] for clearing of energy and reserves in multi-area markets, an IA (immune algorithm) with power redistribution [9], a new MDE (modified differential evolution) [10], CSA (cuckoo search algorithm) [11], iteration PSO with time varying acceleration coefficients [12], a hybrid DE algorithm based on PSO algorithm DEPSO (differential evolution particle swarm optimization) [13], PSO for dynamic ELD problem [14], IGDT (information gap decision theory) to help the DNOs (distribution network operators) [15], risk-constrained self-scheduling of GenCos (GenCos generation companies) optimizers [16], a new continuous method of QGSO (quick group search optimizer) [17], ICA (imperialist competitive algorithms) for multi-objective OPF problems [18], Tribe-MDE (tribe-modified DE) for solving multi-objective EED (environmental/economic dispatch) [19], RCCRA (real coded chemical reaction algorithm) [20], stochastic programming [21], FFA (firefly algorithm) for multi-objective EED considering wind power penetration [22], HIC-SQP (hybrid ICA algorithm with sequential quadratic programming) [23], a new hybrid method for OPF problem with non-smooth cost functions [24], Combinination of chaotic DE and QP (quadratic) [25], BFA (bacterial foraging algorithm) [26], quantum PSO method [27], multi-objective CSA [28], a novel stochastic approach [29], DE based dynamic decomposed strategy [30], a new hybrid algorithm for practical optimal DLD (dynamic load dispatch) [31], SALCSSA (self-adaptive learning charged system search algorithm) [32], solving stochastic OPF incorporating electric vehicles and offshore wind farm [33], CCDE (colonial competitive differential evolution) technologies [34], and etc. The main objective of ELD and OPF problems is the effective management of electrical energy generation by minimizing the total fuel cost of power generation units of a single area, while satisfying various system and operating

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constraints [35–37]. The MAED (multi-area economic dispatch), RCMAED (reserve constrained multi-area economic dispatch) and RCMAEED (reserve constrained environmental/economic dispatch) problems [38–41] are an extension of ELD problems in practical power systems, whose main objective is to determine the generation levels and the power interchange between areas to minimize the operation cost (fuel cost function) of thermal generating units in all areas of power systems while satisfying generating units power limits, system power balance, and power transmission capacity constraints of network lines [42,43].

The DE [44,45] and PSO [46] techniques are population-based optimization evolutionary algorithms. Enhanced versions of DE, PSO and hybrid DEPSO techniques have been successfully applied to different engineering optimization problems with the PSO techniques with combines the positive features of Constrained PGS-COM (Particle Swarm, Generating Set Search, and Complex) for black-box optimization problems [47], a global review of PSO techniques for power systems [48], and DEPSO techniques for different engineering optimization problems [49].

Different optimization algorithms have been proposed for solving the MAED problem of electrical energy generation in the literature. Basu solved the MAED problem in different practical power systems using ABCO (artificial bee colony optimization) [38] and TLBO (teaching-learning-based optimization) [39] with prohibited operating zones, valve-point loading, multiple fuels and tie line constraints considering transmission losses. Manoharan et al. [40] solved MAED problems using evolutionary programming methods such as the DE, PSO, RGA (real-coded genetic algorithm) and CMAES (covariance matrix adapted evolution strategy) for 4-, 10- and 120-unit power systems. Sudhakar et al. [41] applied Secant method to solve the MAED problem. In Ref. [42], the EP-LMO (evolutionary programming with Levenberg–Marquardt optimization) method is proposed to solve the MAED problem of a 10-unit power generation system with multi-fuel options. In Ref. [43], a PSO-based method is proposed to solve the MAED problem of a large 120-unit power system. Sharma et al. solved the MAED and RCMAED (reserve constrained MAED) problems using various DE methods enhanced with time-varying mutation [50] and the improved PSO method with a parameter automation strategy having PSO_TVACparticle swarm optimization_time varying acceleration coefficients [51]. Many other heuristic search techniques have been proposed for solving economic dispatch problem, such as a PS (pattern search) algorithm [52], an improved MOPSO (multi-objective PSO) for solving MAEED (multi-area environmental/economic dispatch) problem [53], the DSM (direct search method) [54], a new RDE (recurrent DE) method [55], PSO algorithm [56], a PF-HDSM (penalty function-hybrid direct search method) for solving MWCD (multi-area wind-thermal coordination dispatch) problem [57], EDSM (enhanced direct search method) [58], a novel approach based on HS (harmony search) algorithm [59], the OCD (optimality condition decomposition) for solving MA-DED (multi-area dynamic economic dispatch) problem [60], and different novel search approaches for solving multi-area generation scheduling such as neural networks approach [61], traditional economic dispatch method [62], modification of MAED [63], a new DE algorithm [64], an embedded MA-OPF (multi-area optimal power flow) [65], a new proposed technique [66], a decomposition methodology [67,68], a practical approach [69], a generalized unified power flow controller [70], and evolutionary programming [71].

2. Multi-area economic dispatch problems

The main purpose of the MAED optimization problem in power systems is to minimize the total electrical energy generation cost for supplying loads of all areas with or without minimizing the total pollutant emissions (such as NO_x and SO_2 emissions) while satisfying electrical power balance constraints, electrical power generating constraints and transmission (tie-line) capacity constraints. The objective functions of minimizing system operation (energy generation) cost and pollutant emissions [38,60] with VPL (valve point loading) effects and multiple fuel options [38,39] can be written in the following form:

- Minimizing system operation cost

$$\text{Min} \sum_{i=1}^{N} (F_i(P_i)) \tag{1}$$

where:

$$1: F_i(P_i) = \begin{cases} a_{i1}P_i^2 + b_{i1}P_i + c_{i1} + \left|e_{i1} \times \sin(f_{i1} \times (P_{i,\min} - P_i))\right|, & \text{fuel } 1, P_{i,\min} \le P_i \le P_{i1} \\ a_{i2}P_i^2 + b_{i2}P_i + c_{i2} + \left|e_{i2} \times \sin(f_{i2} \times (P_{i,\min} - P_i))\right|, & \text{fuel } 2, P_{i1} \le P_i \le P_{i2} \\ \dots & \\ a_{uk}P_i^2 + b_{ik}P_i + c_{ik} + \left|e_{ik} \times \sin(f_{ik} \times (P_{i,\min} - P_i))\right|, & \text{fuel } k, P_{ik-1} \le P_i \le P_{i,\max} \end{cases}$$

2: N is the number of generation units.
3: k is the fuel type.
4: P_i is the active power generation of the i-th unit, $P_{i,min}$ and $P_{i,max}$ are the minimum power generation and maximum power generation limits of the i-th unit.
5: $a_{ik}P_i^2 + b_{ik}P_i + c_{ik}$ is the quadratic fuel cost function for fuel type k of the i-th unit.
6: a_{ik}, b_{ik} and c_{ik} are the fuel cost-coefficients for fuel type k of ith unit.
7: $\left|e_{ik} \times \sin(f_{ik} \times (P_{i,\min} - P_i))\right|$ is the sinusoidal fuel cost function of VPL effects for fuel type k of the i-th unit.
8: e_{ik} and f_{ik} are the fuel cost-coefficients of model VPL effects for fuel type k of the i-th unit.

Tie-line power transfer among all areas of the network plays a very important role in deciding the operating cost in multi-area networks. Taking into consideration the cost of active power transmission through each tie-line of the power system, the final objective function of the MAED optimization problem becomes [40,50]:

$$\text{Min } F_T = \text{Min}\left(\sum_{i=1}^{N}(F_i(P_i)) + \sum_{j=1}^{M}\Big(f_j(T_j)\Big)\right) \tag{2}$$