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# Species-based Quantum Particle Swarm Optimization for economic load dispatch

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ABSTRACT

Economic load dispatch (ELD) is one of the important optimization problems in the operation of power systems which can be helpful to create effective generating management plans. In this paper, the ELD problem is discussed considering transmission network losses and practical constraints of plants such as generation ramp rate, prohibited operation zones, and valve-point effects. A new method called Species-based Quantum Particle Swarm Optimization (SQPSO), which is based on the Quantum Particle Swarm Optimization (QPSO), is proposed and applied in order to solve this problem possessing non-smooth and smooth cost functions. In the proposed intelligent technique, the particles are classified according to the output results and they explore the answers in each iteration in-group form. The new method has just one control parameter. The simulation results and the numerical investigations of various examples are compared with other conventional techniques to assess the efficiency of the proposed method. The results of the numerical investigations well depict that in spite of its simplicity, the proposed method is superior over the other techniques from standpoint of optimum answer exploitation as well as possessing appropriate and acceptable speed and stability.



## Introduction

ELD is one of the fundamental issues in power system analysis. Determination of the optimal scheduling of power generations to match total power demand at minimal possible cost along with satisfying the power generators and system constraints is the main purpose of ELD. The generation cost particularly in thermal plants is excessive and therefore, the unit outputs' suitable planning can result in considerable operation costs saving.

It is not simple to solve this problem according to the non-linear nature of its objective function and presence of hard constraints due to practical limitations of power plants. Over the years, a wide variety of optimization techniques have been adapted to solve ELD problems. Some of these techniques use conventional optimization methods, whereas others are based on artificial intelligence methods. Linear and non-linear programming techniques are presented in [1,2]. Linear programming technique is fast and reliable but it approximates the cost functions in piecewise form. Therefore, the optimality of its output answer is not certain. Similarly, the non-linear programming technique faces with the complexity and convergence problem. The dynamic programming solution of economic load dispatch is presented in [3]. Although this method is able to solve some types of economic load dispatch problems, it is not able to solve the large dimensioned problems or requires too long time to obtain the answers. Techniques such as Lagrangian technique are also presented, the operation basis of which is derivation [4]. These techniques are not able to take into account the plants' operational constraints such as ramp rate, prohibited zones, and valve-point effects due to the non-differentiable nature of constraints. Generally, the mathematical nature of the problem disables the analytical mathematic approaches to solve this problem appropriately.

Therefore, it is proposed to utilize evolutionary algorithms in which there is no worry about the non-differentiability and the non-linear nature of the objective functions and constraints. The genetic algorithm [5], particle swarm optimization [6], artificial neural networks [7], and simulated annealing algorithm [8] are some of the mentioned evolutionary methods. The ELD problem is one of the most practical subjects in electrical power engineering and is always under high attention of several researchers. Therefore, in addition to the mentioned methods, large numbers of new techniques, which differ from accuracy and implementation speed viewpoint, are presented to solve this problem [9–35].

In this paper, a new intelligent QPSO technique based method called Species-based QPSO is proposed. In this new intelligent

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**Nomenclature**

| | |
|---|---|
| $a_i$, $b_i$, $c_i$ | cost coefficients of *i*th generator; \$/h, \$/MW h, \$/MW$^2$ h, respectively |
| $A_{ai}$ | feasible operating zones of *i*th generator |
| $B$ | symmetric loss coefficient matrix |
| $B_{00}$ | constant loss coefficient |
| $B_{ij}$ | *ij*th element of $B$ |
| $B_{0i}$ | *i*th element of the loss coefficient vector |
| $\beta$ | contraction–expansion coefficient |
| $c_1$, $c_2$ | cognitive and social parameters, respectively |
| $D$ | dimension size |
| *dif* | power mismatch; MW |
| $\varepsilon$ | maximum power mismatch; MW |
| $F_i$ | cost function of the *i*th generator; \$/h |
| $F_t$ | total generation cost; \$/h |
| $\phi_1$, $\phi_2$ | random numbers in (0,1) |
| *gbest* | total population best position |
| $g_i$, $h_i$ | coefficients of the *i*th generator to model valve point effect; \$/h, MW$^{-1}$, respectively |
| $j$ | index of prohibited zones |
| *lbest* | best-fit particle in a species |
| $L_{sorted}$ | a sorted list of particles |
| $m$ | number of generators |
| *Mbest* | mean best position |
| $n_i$ | number of prohibited zones in the *i*th generator curve |
| $ns_1^*$, $ns_2^*$ | initial and final desired number of groups, respectively |
| $ns^*$, $ns$ | desired and generated number of groups, respectively |
| $P_D$ | load demand; MW |
| $P_i$ | power output of the *i*th generator; MW |
| $P_L$. | line losses; MW |
| $P_{i,j}^l$, $P_{i,j}^u$ | the lower and upper bounds of *j*th prohibited zone of generator *i*, respectively |
| $P_i^{max}$, $P_i^{min}$ | minimum and maximum output of *i*th generator, respectively; MW |
| $P_i^0$ | output power of *i*th generator in the previous hour; MW |
| $p_a$ | local attractor |
| $p_b$ | *pbest*; particles best positions |
| $p_g$ | best position among a group of particles (it denotes *gbest* in the basic QPSO and *lbest* in the SQPSO) |
| $r_1$, $r_2$ | random numbers in (0,1) |
| *rs* | radius of species |
| $S$ | population size |
| *Se* | species seed set |
| *sei* | seed of *i*th species |
| $t$ | iteration number |
| $t_{max}$ | maximum iteration number |
| $UR_i$, $DR_i$ | up ramp limit and down ramp limits of the *i*th generator, respectively; MW/time-period |
| $u$, $k$ | random numbers in (0,1) |
| $v_i$ | velocity of particle *i* at iteration *t* |
| *vrs* | variation amount of *rs* in iterations |
| $w$ | inertia weight |
| $x_i$ | position of particle *i* at iteration *t* |
| *XM* | maximum domain of search space |
| $\chi$ | penalty coefficient |

proposed method, the particles are classified according to the output results and they search the answers in each iteration in the group form. The new technique possesses just one control parameter and considerably improves the exploration ability of the basic QPSO in addition to maintain the simplicity of it. Based on the new method, an algorithm is proposed to solve economic load dispatch problem in which the practical considerations and the constraints of power plants such as valve-point effects, prohibited operational zones, ramp rates of plants' generated power, and the transmission power losses are under consider.

Some sample systems with different dimensions are used to investigate and depict the efficiency of the proposed algorithm. The results of numerical evaluations and comparing them with the results obtained applying other techniques well show the superiority of the proposed technique over the other methods in solving ELD problem.

## Problem description

ELD tries to minimize power system's total generation cost during a definite time interval (typically 1 h) as well as satisfying the operating constraints of a power system. Therefore, it can be formulated mathematically as an optimization problem possessing an objective function and two constraints (equality and inequality).

### *Objective function*

In simple form, the total generation costs are usually expressed by a quadratic function of the power output from the generating units. Hence, the objective function of the ELD problem can be mathematically described as follows:

$$\text{Minimize} \quad F_t = \sum_{i=1}^{m} F_i(P_i) = \sum_{i=1}^{m} a_i P_i^2 + b_i P_i + c_i \tag{1}$$

However, it is more practical to consider the valve-point loading in the cost model. If the valve-point effect is under consider in power units, the generation cost function takes a non-smooth nature due to the associated mechanical effects of it. This effect is modeled usually in mathematical form as follows adding a sinusoidal term to the plants' cost function:

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + |g_i \sin(h_i(P_i - P_i^{min}))| \tag{2}$$

### *Equality constraint*

This class of constraints consists of the power balance constraint, which indicates that it is necessary to satisfy the following equality constraint to face with the balance between the generation and consumption:

$$\sum_{i=1}^{m} P_i - P_D - P_L = 0 \tag{3}$$

Parameter $P_L$ depicts the system losses that can be calculated applying the *B*-coefficients as follows:

$$P_L = \sum_{i=1}^{m}\sum_{j=1}^{m} P_i B_{ij} P_j + \sum_{i=1}^{m} B_{0i} P_i + B_{00} \tag{4}$$

### *Inequality constraints*

#### *Generation capacity constraint*

The generation power of each generator-*i* should not exceed the upper and lower limits. This constraint is expressed as the following inequality: