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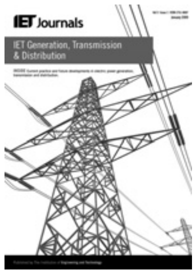

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Solving economic load dispatch problem with valve-point effects using a hybrid quantum mechanics inspired particle swarm optimisation

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Abstract: Economic load dispatch (ELD) performs an important part in the economic operation of power system. The ELD problem is considered as a non-linear constrained optimisation problem. The problem becomes non-convex and non-smooth when the generators' prohibited zones and valve-point effect are considered. The purpose of this work is to present a solution strategy to solve ELD problem in an efficient way while considering several aspects of ELD. The strategy employs a hybrid mechanism involving a quantum mechanics inspired particle swarm optimisation (PSO). The conventional PSO is modified by integrating quantum mechanics theory that redefines the particles positions and velocities in more diverse manner and therefore explores more search space. The PSO is further upgraded from a single population-based to a multi-population one. Such feature of the method delivers a fine balance between the local and global searching abilities. The simulations are carried by considering several cases of thermal units by varying different combinations of system configurations such as with/without valve-point effect, with/without network loss and for one or several hours of load demand. The results are quite promising and effective compared with several benchmark methods.

1 Introduction

The economic operation in power system planning plays a major role deciding the electricity price in both regulated and deregulated market. The economic load dispatch (ELD) allocates the generators' powers to meet certain demand while minimising the generating cost under various systems and units'-related constrained environment. ELD is a non-linear constrained optimisation problem whose complexity increases when constraints such as valve-point effect and generators' prohibited zones are undertaken [1]. ELD has been studied by numerous researchers and engineers. These efforts include mathematical programming based on several optimisation techniques. As the bibliographical study on ELD suggests, recently as opposed to mathematical approaches, several heuristic optimisation strategies like genetic algorithm (GA) and its variant real-coded GA (RCGA) [2, 3], simulated annealing (SA) [4], tabu search [5], fuzzy systems [6], ant colony optimisation [7], particle swarm optimisation (PSO) [8–12], neural network [13], hybrid evolutionary programming (EP) [14] and biogeography-based optimisation (BBO) [15] are capable of producing high-quality ELD solutions. Although the heuristic methods do not always guarantee discovering globally optimal solutions in finite time, they usually provide fast and reasonable solutions. After analysing the existing methods such as Hopfield neural network [13] which do consider piecewise quadratic fuel cost and prohibited zones, the convergence rate are very slow due to usage of sigmoid function. GA method is usually faster than SA method due to its parallel search capabilities. However, when the objective parameters are highly correlated to each other (e.g. in case of ELD), the chromosomes are tend to exhibit similar structure and the average fitness becomes higher. Although PSO is also capable of producing good solution, however, the performance is highly dependent on the parameter sensitivity and balancing between local and global search capabilities. Again most of the methods mentioned above used approximated quadratic fuel cost, which is an approximation of higher order fuel cost.

The concepts of quantum mechanics and computation have been applied in different fields of optimisation [16]. The applicability of quantum-inspired PSO in continuous optimisation problems is proven in previous studies such as [17] and so on. The fundamental theory of PSO, where the particles are moved according to the knowledge achieved by social and inter-personal communication is integrated and somewhat transformed into quantum mechanical-oriented theories such as use of Schrodinger equation and potential field distribution. Such augmentation works as the main principle of quantum inspired PSO. Particles' movements are redefined using quantum mechanical analogies of velocity and position. This approach has a wide search ability which is mandatory for any sophisticated global search algorithms. The application of quantum-inspired PSO (based on the quantum evolutionary algorithm) in ELD problem has been researched [18]. However, the effects of several constraints such as ramp rate, generators' prohibited zones were not shown and only single-hour ELD cases were reported.

The proposed method minimises the fuel cost of generators using a hybrid quantum-inspired PSO. To incorporate with practical power system, the valve-point effects are included while forming the objective function. The generators ramp rate and prohibited zones are also included in the considered constraints. Inclusion of such constraints presents ELD as a non-smooth and non-convex optimisation problem. The proposed method uses a multi-population-based PSO instead of trivial PSO with single population. As of previous work of the authors [10], this method can also be extended to higher order and multiple fuel cost function for better curve fitting, less approximation and more practical result.

The organisation of this paper is briefed as follows: the problem formulations with objective function and considered constraints will be shown in Section 2. Section 3 describes the hybrid quantum-based particle swarm optimisation (HQPSO) with a little discussion about traditional PSO and its transformation towards HQPSO. The algorithm steps with associated concerns are detailed in Section 4. The conducted simulation and result analyses will be elucidated in Section 5. Finally, concluding remarks are briefed in Section 6.

2 ELD formulation

2.1 Objective function

The objective of ELD operation is to minimise the generation cost which mainly comprises fuel cost. This study considers the valve-point effects as a complementary component of objective function. Therefore the objective function is described as the superposition of sinusoidal functions and quadratic function. The cost function curve is shown in Fig. 1.

The quadratic fuel cost function (approximation of bold line in Fig. 1) can be shown as

$$\mathrm{FC}_i(P_i) = a_i + b_iP_i + c_iP_i^2 \tag{1}$$

where FC_i is the fuel cost function of generation i; a_i, b_i and c_i are the cost coefficients of generator i and P_i represents the power of ith generator. The dotted-line shown in Fig. 1 is generated considering the valve-point effects. The sharp increase in losses due to wire drawing effects results in such phenomena. In order to incorporate such effects, sinusoidal functions are added with fuel cost function. Therefore instead of using (1), the modified cost function is used, which is

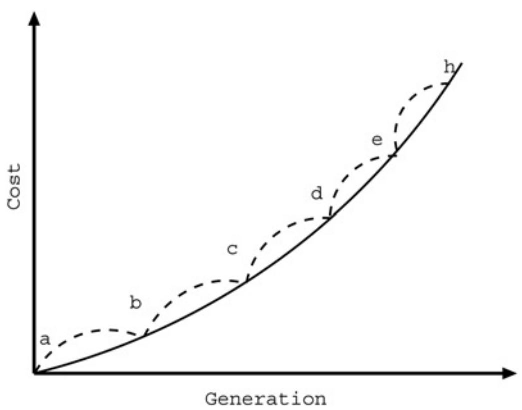

Fig. 1 *Cost function curve for ELD operation with valve-point effect*

$$\mathrm{FC}_i(P_i) = a_i + b_iP_i + c_iP_i^2 + |e_i \times \sin(h_i \times (P_i^{\min} - P_i))| \tag{2}$$

e_i and h_i are valve-point effects coefficients of fuel cost for ith generator. Since the generation planning extends over a particular period of time (say N number of generators operating over T time intervals), the actual objective of ELD is to minimise the total production cost, which is shown as (3)

$$F = \min \sum_{t=1}^{T} \sum_{i=1}^{N} \mathrm{FC}_i(P_i(t)) \tag{3}$$

However, these formulations can be extended to produce more accurate result with less approximation by considering higher order (i.e. more than two) of fuel cost function. This scenario is achievable simply reforming (1) in generalised fashion as shown in (4)

$$\mathrm{FC}_i(P_i) = \sum_{j=1}^{\phi} \alpha_i^j P_i^j \tag{4}$$

where ϕ is the order of fuel cost function. Equation (1) can be derived from (4) by replacing α_i^0, α_i^1 and α_i^2 with a_i, b_i and c_i, respectively.

2.2 Constraints

The objective of ELD problem is subjected to the following constraints.

2.2.1 System power balance: The total generators' power output should be able to satisfy the load demand and transmission loss. For a particular time interval t, mathematically this constraint can be defined as

$$\sum_{i=1}^{N} P_i(t) = P_{\mathrm{D}}(t) + P_{\mathrm{L}}(t) \tag{5}$$

where $P_{\mathrm{D}}(t)$ is the load demand at time t and $P_{\mathrm{L}}(t)$ is the system's transmission loss. The system transmission network loss is computed by the Kron's loss formula, which represents loss as a function of the output level of the system-generating units. The matrix formulation is shown in (6).

$$P_{\mathrm{L}}(t) = \boldsymbol{P}^{\mathrm{T}}[\boldsymbol{B}]\boldsymbol{P} + \boldsymbol{B}_0\boldsymbol{P} + \boldsymbol{B}_{00} \tag{6}$$

Here $\boldsymbol{B}$ is the matrix of loss coefficients. The above equation