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# An effective Lightning Flash Algorithm solution to large scale non-convex economic dispatch with valve-point and multiple fuel options on generation units

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Generation units with multiple fuel options and valve-point loading effects on the generators are fundamental parts of power system generation. However, economic dispatch (ED) of these units have non-convex, non-continuous generation cost functions. In this paper, a new Lightning Flash Algorithm (LFA) is proposed to solve complex non-convex ED problems in large scale power systems considering multiple fuel options and valve point effects on the generators. Five case study systems including 10-units, 40-units, 80-units, 160-units and 640-units are conducted to validate the applicability and effectiveness of the proposed LFA method for solving ED problems. The results are compared with other published methods in literature and confirm the applicability and effectiveness of LFA against other existing methods. LFA can successfully conduct the best fuel types of the generators and adjust the optimum settings to allocate load demand to the online generation units in power system. The results demonstrate that using proposed LFA method can minimize the total generation costs and optimally satisfy the load demands in the power grid.



## 1. Introduction

Economic Dispatch (ED) is considered to be an important optimization problem in power system operation. The objective of ED is to minimize the fuel costs of generators in power system in order to obtain an optimum scheme with maximum efficiency and minimum operation costs. This is achieved by optimally allocating load dispatch among available generation units in a system while satisfying various constraints. Scheduling the output power of generators subject to the practical constraints on the generators and the grid involves mathematical modelling of optimization. This model contains valve-point effects, ramp rate limits and prohibited zones of operation on the generators and also transmission losses in the grid. In traditional ED problem, the fuel cost function of each thermal generation unit is often defined by a single quadratic function and the valve-point effects are ignored which would introduce inaccuracy into the dispatching output.

However in practical power system, numerous thermal units are supplied with multiple fuels such as natural gas, coal and oil. Based on this fact, representation of cost function in ED as a single quadratic function is no longer an accurate model. Instead, multiple fuel options and valve-point effects must be considered in case of practical applications which is a goal in this paper.

These practical characteristics form a complex non-convex model of ED optimization. The classical or artificial intelligence based methods are used for solving traditional ED. The classical approaches fail to solve complex non-smooth practical models. The incremental cost functions based on these methods are assumed monotonous and also the excessive computational time and memory space requirement make these methods infeasible. The lambda iteration method, the base point and participation factor method, the gradient method [1–3] and nonlinear programming [4,5] are some of these classical techniques.

Metaheuristic and evolutionary methods have been reported in literature as an alternative solution for solving non-convex ED problems. Most of them only consider valve point effects with single fuel cost such as chaotic bat algorithm (CBA) [6], particle swarm optimization (PSO) [7–9], hybrid grey wolf optimizer (HGWO) [10], harmony search algorithm (HS) [11], chaotic particle swarm optimization algorithm and sequential quadratic

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programming techniques (CPSO-SQP) [12], integer coded differential evolution-dynamic programming [13], pattern search and sequential quadratic programming techniques (GA-PS-SQP) [14], firefly algorithm (FA) [15], particle swarm optimization with time varying acceleration coefficients (IPSO-TVAC) [16], modified shuffled frog leaping algorithm (MSFLA) [17], artificial bee colony algorithm [18], shuffled differential evolution algorithm (SDE) [19], chaotic self-adaptive particle swarm optimization algorithm (CSAPSO) [20], multi-strategy ensemble biogeography-based optimization (MsEBBO) [21], etc. Other research works such as enhanced augmented Lagrange Hopfield network (EALHN) [22], adaptive hopfield neural networks (AHNN) [23], augmented Lagrange Hopfield network (ALHN) [24] only address multiple fuel cost functions without considering valve-point effects. However, in real power system operation, both multiple fuel cost and valve-point effects need to be considered in order to achieve a more realistic and accurate power dispatch in the grid.

There are few research works that address ED with both multiple fuel costs and valve-point effects. Among them, crisscross optimization (CSO) [25], PSO [29], biogeography-based optimization (BBO) [26], differential evolution (DE) [27], cuckoo search algorithm (CSA) [28], genetic algorithm (GA) [29], group search optimizer (GSO) [30], differential HS (DHS) [31], tabu search algorithm (TSA) [29], seeker optimization algorithm (SOA) [32] and auction-based algorithm (AA) [33] have been deployed as original methods. However, convergence stagnancy and performance of these methods are easily affected in large scale systems. Improved and hybrid version of these algorithms are used in order to improve the convergence and global optimum search capabilities including real-coded genetic algorithm (RCGA) [34], adaptive RCGA (ARCGA) [35], new adaptive PSO algorithm (NAPSO) [36], chaotic modified shuffled frog leaping algorithm (CMSFLA) [37], improved PSO (IPSO) [38], anti-predatory PSO (APSO) [39], distributed Sobol PSO and TSA (DSPSO−TSA) [29], incorporating a real-valued mutation operator into the PSO algorithms (PSO-RVM) [40], PSO with both chaotic sequences and crossover operation (CCPSO) [41], rank CSA (ORCSA) [42], global-best HSA (GHS) [43], estimation of distribution and differential evolution cooperation (ED-DE) [44], combined DE and PSO algorithms (DEPSO) [45], oppositional real coded chemical reaction algorithm (ORCCRO) [46], real coded chemical reaction algorithm (RCCRO) [47], colonial competitive DE (CCDE) [48], synergic predator-prey optimization algorithm (SPPO) [49], new PSO with local random search (NPSO_LSR) [50]. The quoted methods have been applied to solve multiple fuel option and valve-point effect in ED problem. However, they still suffer from the premature convergency and curse of dimensionality. In fact, the majority of them are tested and validated on small scale systems with 10 units [25,51] while only very few of these methods have been tried on bigger test systems. The results of these methods published in literature show that there is a necessity to find a solution to large scale non-convex ED problems with multiple fuel options and valve-point effects and to overcome the curse of dimensionality and premature convergence.

In this paper, a new evolutionary method called Lightning Flash Algorithm (LFA) is proposed to solve large scale non-convex ED problems in power system considering both multiple fuel options and valve-point effects on the generators. The proposed LFA is developed based on the action and reaction of cloud to ground lightning strikes in a thunderstorm phenomenon. The novelty and contribution of this paper is summarized as follows: 1) The LFA is proposed as a new optimization tool for solving power system related problems. Mathematical framework of this method is developed in MATLAB software. Three branches of lightning is associated to the proposed method to enhance the searching ability of the algorithm for finding global optimum values in large scale complex systems. 2) Proposed LFA method is employed to solve large scale non-convex ED problem with both multiple fuel options and valve-point effects. It is tested on five test systems and the results validate the applicability and effectiveness of LFA method. 3) The obtained results of LFA are compared with results of other methods in literature to confirm its effectiveness against quoted algorithms. 4) There is only one research work in literature that addresses large scale system of more than 200 units. Therefore, application of the proposed method on large scale systems is another innovative part of this paper.

The rest of the paper is organized as follows. Section 2 describe the ED problem with multiple cost function and valve-point constraints. Section 3 introduces the proposed LFA method and explains its intrinsic differences with other algorithms. In section 4, ED problem is solved with the proposed LFA method in five case study systems and the results are compared with literature. Section 5 discusses the outcomes. Based on the results and discussions, the conclusion is provided in section 6.

## 2. ED problem formulation

In a practical ED optimization, the generator constraints and network limits are considered. The practical constraints of spinning generators are the ramp rate limit, the prohibited zones of operation, generation capacity constraints and valve point effects. The traditional ED optimization problem is formulated with a single quadratic equation:

$$\min F_t = \sum_{i=1}^{m} F_i(P) = \sum_{i=1}^{m} \alpha_i + \beta_i P_i + \gamma_i P_i^2 \tag{1}$$

where $\alpha_i$, $\beta_i$ and $\gamma_i$ are the cost equation coefficients of unit $i$, $P_i$ is the output power in (MW) while $F_i(P)$ is the cost function of that unit in ($/h). The indice $m$ denotes the number of generators in a system. Multiple fuel options and valve-point effects are considered and represented in (2):

$$F_i(P) = \begin{cases} \alpha_{i1} + \beta_{i1}P_i + \gamma_{i1}P_i^2 + \left| e_{i1}\sin\left[ f_{i1}\left(P_i^{min} - P_i\right)\right]\right|, & P_i^{min} \le P_i \le P_{i,1}\ \textit{fuel type } 1 \\ \alpha_{i2} + \beta_{i2}P_i + \gamma_{i2}P_i^2 + \left| e_{i2}\sin\left[ f_{i2}\left(P_i^{min} - P_i\right)\right]\right|, & P_{i,1} \le P_i \le P_{i,2}\ \textit{fuel type } 2 \\ \vdots & \\ \alpha_{iN} + \beta_{iN}P_i + \gamma_{iN}P_i^2 + \left| e_{iN}\sin\left[ f_{iN}\left(P_i^{min} - P_i\right)\right]\right|, & P_{i,N-1} \le P_i \le P_i^{max}\ \textit{fuel type } N \end{cases} \tag{2}$$

where $e_i$ and $f_i$ are the valve-point coefficients of unit $i$ and each generation unit has up to N types of fuel options. Each fuel type has a production limit. ED optimization provides a feasible dispatching schedule to minimize the generation costs, satisfy the demand and keep the operation of the grid in a stable operation mode. An