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# Exchange market algorithm for economic load dispatch

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ABSTRACT

This paper presents exchange market algorithm for solving economic load dispatch problems. Exchange market algorithm (EMA) is a new, robust, and strong algorithm to extract the optimal point for global optimization. Inspired by the stock exchange trading method, EMA strives to solve optimization problem. Meticulous investigation of the stock exchange methods employed by the elites in such markets has yielded to shape this algorithm. This algorithm has two searcher operators as well as two absorbent operators for individuals to be absorbed to the elite person, which leads to creation and organization of random numbers in the best way. In order to show the abilities of the EMA, this algorithm has been implemented on four test systems in different dimensions (3, 6, 15 and 40 units) with convex and nonconvex cost functions. The numerical results have been compared with the results of some new and strong algorithms. The results prove the robustness and effectiveness of the proposed algorithm and show that it could be used as a reliable tool for solving practical ELD problems.



## Introduction

Economic load dispatch (ELD) is one of the most important optimization problems in power system operation and planning. The main objective of economic dispatch problem of electric power generation is to schedule the output power of committed generating units so as to meet the required load demand at minimum operating cost, while satisfying system equality and inequality constraints. In the ELD problem, the cost function for each generation unit is approximately represented by a single quadratic function and the problem is solved using mathematical programming based on optimization techniques such as lambda iteration method, gradient method, Newton's method, linear programming, interior point method and dynamic programming [1,2]. However, many mathematical assumptions such as convexity, quadratic, differentiable or linear objectives are required to simplify the problem. In these numerical methods for solving the ELD problem, an essential assumption is that the incremental cost curves of the units are piecewise-linear monotonically increasing functions. Unfortunately, the input–output characteristics of power generating units are inherently highly nonlinear because of prohibited operating zones, valve-point loadings, etc. Furthermore, they may lead to multiple local minimum points of the cost function. Classical dispatch algorithms require that these characteristics be approximated, even though such approximations are not desirable as they may lead to suboptimal [3,4]. Due to the non-convergence behavior of generation units' input/output characteristics the practical ELD problem should be a non-convex problem with constraints, which cannot be solved directly through the mathematical approaches. Dynamic programming (DP) method can solve such types of problems, but it suffers from so-called the curse of dimensionality [5]. From the last decades, advanced heuristic techniques such as genetic algorithm [6,7], evolutionary programming (EP) [8,9], differential evolution (DE) [10–13], particle swarm optimization (PSO) [14–19], and Biogeography-based optimization (BBO) [20,21] are developed to solve these problems.

Exchange Market Algorithm (EMA) is a meta-heuristic algorithm appropriate to solve the optimization problems. This algorithm is inspired by the stock market in which the shareholders buy and sell any types of shares under different market conditions. In this algorithm, it is assumed that the shareholders compete to introduce themselves as the most successful shareholder in the ranked list. In the EMA, shareholders with lower ranks tend to do logical risks to gain more profits and generally it is assumed that the shareholders are intelligent persons and behave similar with the successful traders of the stock market. Unlike the other algorithms, this algorithm has two searcher operators as well as two absorbent operators for individuals to be absorbed to the elite person, which leads to creation and organization of random numbers in the best way. These operators make EMA able to overcome the usual limitations of other algorithms such as local optimal trapping due to premature convergence (i.e. exploration problem), insufficient

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capability to find nearby extreme points (i.e. exploitation problem) and lack of efficient mechanism to treat the constraints (i.e. constraint handling problem). Less execution time, the ability in selecting search area and in turn the ability for optimization of various problems, convergence to the identical solutions in each program iteration, high ability in extraction of global optimum points, are some advantages of EMA [22].

In order to reveal the capabilities of EMA, it is applied to optimize several convex and nonconvex ELD problems aim to decrease the system fuel costs. In order to investigate the performance of the EMA in facing problems with several type of constraints, the ELD problem is optimized considering the existence of system power losses, system equality and inequality constraints, ramp rate limits, valve-point effects, and prohibited operational zones. This algorithm is implemented successfully on systems with 3, 6, 15, and 40 units. The obtained results are compared with other advanced techniques. The results well demonstrate the practical advantage of the exchange market algorithm over the other approaches.

The rest of this paper is organized as follows. Section 'Economic load dispatch problem formulation': gives the formulation of the ELD problem; Section 'Exchange market algorithm': explains the EMA; Section 'Implementation of exchange market algorithm for ELD problem': shows implementation pattern of EMA in solving ELD problem; Section 'Numerical results': shows implementation of the EMA to the test systems and obtained results; and Section ' Conclusions' gives our conclusions.

## Economic load dispatch problem formulation

### *Objective function*

The [14–18] have mentioned the formulation and ELD problem constraints in details. The aim of solving ELD problem is to minimize the outputs of the online generating units, while simultaneously satisfying all unit and system equality and inequality constraints. The simplified cost function of each generating unit can be approximated to be a quadratic function of the active power outputs from the generating units. The simplified cost function of each generation unit in ELD problem is as follows [5]:

$$F_t = \sum_{i=1}^{n} F_i(P_i) \tag{1}$$

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 \tag{2}$$

where $F_t$ is the system fuel cost, $F_i$ is the fuel cost of the $i$th unit, and $a_i$, $b_i$, and $c_i$ are the coefficients related to the $i$th unit fuel. Parameter $P_i$ represents the $i$th plant's generated power and $n$ is the number of the last power unit of the system.

### *Equality and inequality constraints*

*Active powers balance equation*

In order to balance the power, an equality constraint should be met. Total generated power of the plants should equal to total system demand power plus total transmission line power losses. In other words, the following should be valid:

$$\sum_{i=1}^{n} P_i = P_{\text{load}} + P_{\text{loss}} \tag{3}$$

where $P_{\text{load}}$ is the total system load. Parameter $P_{\text{loss}}$ is the power losses of transmission line and is a function of plants output power, which is defined as follows using $B$ factor:

$$P_{\text{loss}} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{0i} P_i + B_{00} \tag{4}$$

*Minimum and maximum power limits*

The output power of each power unit should fall between the maximum and the minimum values of the power plant proportionally with the following inequality:

$$P_{i,\min} \leqslant P_i \leqslant P_{i,\max} \tag{5}$$

where $P_{i,\min}$ and $P_{i,\max}$ are the minimum and the maximum powers of the $i$th unit, respectively.

*Ramp rate limits*

The actual operation interval of all power plants is limited by the ramp-up and ramp-down. In other words, the plant, which used to generate $P_i^0$ can just increase or decrease its generation to some extent. The constraints of ramp-up and ramp-down are defined as follows:

$$P_i - P_i^0 \leqslant UR_i \tag{6}$$

$$P_i^0 - P_i \leqslant DR_i \tag{7}$$

where $P_i^0$ is the previous output power of the $i$th generating unit, $UR_i$ and $DR_i$ are the ramp-up and ramp-down of the $i$th generating unit, respectively. In order to consider the ramp-up and ramp-down and power output limits constraints simultaneously, (5)–(7) can be redefined as the following inequality:

$$\max\{P_{i,\min}, P_i^0 - DR_i\} \leqslant P_i \leqslant \min\{P_{i,\max}, P_i^0 + UR_i\} \tag{8}$$

### *ELD problem considering prohibited operational zones*

In some cases, whole generation range of a generating unit is not available due to some executive physical limitations. Generating units may have some prohibited operation zones due to the existence of some deficiencies in machineries or in accessories. These defects might result in instability in some specific output power intervals. Therefore, some additional constraints should be added to the unit operation zones as follows for the plants with prohibited operational zones:

$$P_i \in \begin{cases} P_{i,\min} \leqslant P_i \leqslant P_{i,1}^l & i = 1,2,\ldots,npz \\ P_{i,k-1}^u \leqslant P_i \leqslant P_{i,k}^l & k = 2,3,\ldots,pz_i \\ P_{i,pzi}^u \leqslant P_i \leqslant P_{i,\max} & \end{cases} \tag{9}$$

where $P_{i,1}^l$ and $P_{i,k}^u$ are respectively the lower and the upper bands of the $i$th unit prohibited zone, $pz_i$ is the number of $i$th unit's prohibited zone and $npz$ is the number of units with prohibited zone [25].

### *ELD problem considering valve-point effects*

The generation units with multi steam valve create more variations in plant cost function. Since the existence of steam valves leads to ripple creation in plants characteristics, the cost function would have a more nonlinear formula. Therefore, the cost function (2) should be replaced by the following cost function:

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 + |e_i \times \sin(f_i \times (P_{i,\min} - P_i))| \tag{10}$$

where $e_i$ and $f_i$ are the coefficients of generator $i$ reflecting valve-point loading [27].

## Exchange market algorithm

Exchange market algorithm is an appropriate meta-heuristic algorithm for optimization problems solving. This algorithm has two searcher operators as well as two absorbent operators. This advantageous enables the algorithm to search around the optimum point and in a vast range simultaneously. In EMA, each member is one of the answers. In the proposed algorithm there exists specific