Imperialist Competitive Algorithm for Economic Dispatch with Valve Point Loading Effect

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ABSTRACT:
The present study investigated economic load dispatch problem, taking into consideration valve point loading effect using an imperialist competitive algorithm. To portray the efficiency of the proposed method, the algorithm was applied to two popular test systems in the area including 13 and 40 thermal units. The obtained results from the algorithm were compared to those of other algorithms which indicated the efficiency and response of the proposed algorithm in solving economic load dispatch problem.

KEYWORDS: Economic Load Dispatch; Optimization Algorithm; Imperialist Competitive Algorithm; Valve Point Effect.

1. INTRODUCTION
Due to its significance in power system operation, economic load dispatch (ELD) problem has been studied extensively [1]. The objective of ELD is to determine the share of each unit in providing the demanded load, such that the load demands are met at the lowest possible cost considering the available power plant and system constraints. There are numerous studies in the literature on this issue [2]. ELD problem can be most simply defined as having quadratic continuous smooth cost functions and equality constraint of generation and consumption. The problem is solved using classical methods including Lagrangian method and Lagrangian-based methods, such as Lambda iteration method [3]. Having considered ramp rate constraints, prohibited zones, valve point loading effect, and plurality of fuels, ELD problem is turned into a non-smooth or non-convex optimization problem. Therefore, it cannot be solved employing traditional mathematical methods. Application of intelligent algorithms is a solution to this problem. Recent decades witnessed considerable advancements in innovative algorithms inspired by natural, biological, and synthetic phenomena. Studies show that these methods are perfectly capable of replacing traditional mathematical methods in solving complex computational problems. Some examples include Genetic Algorithm (GA) [4], Particle Swarm Optimization (PSO) [5], differential evolution (DE) [6], Artificial Bee Colony (ABC) [7], Ant Colony Optimisation (ACO) [8] and Biogeography-Based Optimization (BBO) [9]. Further methods have also been proposed in the form of combinations of the above algorithms[10].

The present study attempted to solve the ELD problem utilizing the Imperialist Competitive Algorithm (ICA), while considering constraints of valve point loading effect and equality of generation and consumption as well as generation limits. As for efficiency and reliability assessment of the proposed algorithm in solving ELD problem, two different testing systems were employed and the results were compared to those of other algorithms, which indicated efficiency and response of the proposed algorithm in solving ELD problem.

2. PROBLEM FORMULATION
ELD, a method with maximized efficiency, lowest possible costs, and reliable exploitation, designates a power system for system’s load supply through appropriate distribution of energy generation resources. Its main objective is to minimize the total cost of generation while honoring exploitation constraints of generation resources. ELD problem determines loads for power generation facilities with an aim to lower costs. Its formulation is similarly proposed as an
optimization problem to minimize the sum total fuel cost of all the power plants supplying the load and loss. ELD problem can therefore be expressed by the following objective function:

\[
\text{Min}(F_T) = \sum_{i=1}^{N_g} F_i(P_{gi}) = \sum_{i=1}^{N_g} \left( a_i + b_i P_{gi} + c_i P_{gi}^2 \right)
\]

(1)

Where \( F_T \) is the total generation cost in $/h, \( F_i(P_{gi}) \) is the fuel cost function of unit \( i \) in $/h, \( a_i, b_i \) and \( c_i \) are the fuel cost coefficients of unit \( i \), \( P_{gi} \) is the real power output of unit \( i \) in MW, \( N_g \) is the number of generating units in the system.

### 2.1. Generator limits constraint

The real power output \( P_{gi} \) of unit \( i \) should be limited between its upper and lower bounds for safety operation expressed by:

\[
P_{gi, \text{min}} \leq P_{gi} \leq P_{gi, \text{max}}
\]

(2)

Where \( P_{gi, \text{min}} \) and \( P_{gi, \text{max}} \) are the minimum and maximum generation limits of the real power output of unit \( i \), respectively.

### 2.2. Valve point loading effect constraint

The valve point loading effect is considered in power plant facilities, their generation cost function assumes a non-smooth nature due to mechanical effects [11]. The discussed effect is usually mathematically modeled as follows through fitting a sinusoidal term to the power plant cost function:

\[
\text{Min}(F_T) = \sum_{i=1}^{N_g} \left( a_i + b_i P_{gi} + c_i P_{gi}^2 + e_i \sin(f_i(P_{gi, \text{min}} - R_i)) \right)
\]

(3)

Where \( e_i \) and \( f_i \) are the fuel cost coefficients of unit \( i \) with valve point loading effect. Fig.1 portrays cost function changes for power plant with valve point loading effect.

![Fig. 1. Cost Curve for power plant with valve-point loading effect](image)

### 3. IMPERIALIST COMPETITIVE ALGORITHM

Imperialist Competitive Algorithm (ICA) is a new evolutionary algorithm in the Evolutionary Computation field based on the human’s socio-political evolution. It starts with an initial population called colonies. Each individual of the population is called a country. Some of the best countries in the population are selected to be the imperialist and the rest form the colonies of these imperialists. The colonies are then shared among the imperialist according to each imperialist’s power. An imperialist with his colonies forms an empire. The flowchart of this algorithm is shown in Fig.2 [12].

![Fig. 2. Flowchart of the Imperialist Competitive Algorithm](image)

#### 3.1. Creation of initial empires

The goal of optimisation is to find an optimal solution in terms of the variables of the problem. We form an
array of variable values to be optimized. In an $N_{var}$-dimensional optimisation problem, a country is a $1 \times N_{var}$ array. The cost of a country is found by evaluation of the cost function $f$ at variables $(p_1,p_2,p_3,...,p_{Nvar})$. So we have

$$\text{cost} = f(\text{country}) = f(p_1,p_2,p_3,...,p_{Nvar})$$

To start the optimisation algorithm, initial countries of size $N_{Country}$ is produced. We select $N_{imp}$ of the most powerful countries to form the empires. The remaining $N_{col}$ of the initial countries will be the colonies each of which belongs to an empire.

To form the initial empires, the colonies are divided among imperialists based on their power. That is, the initial number of colonies of an empire should be directly proportionate to its power. To proportionally divide the colonies among imperialists, the normalized cost of an imperialist is defined by

$$C_n = c_n = \max_{i} \{c_i\}$$

(5)

Where $c_n$ is the cost of the $n^{th}$ imperialist and $C_n$ is its normalized cost. Having the normalized cost of all imperialists, the normalized power of each imperialist is defined by

$$P_n = \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i}$$

(6)

The initial colonies are divided among empires based on their power. Then the initial number of colonies of the $n^{th}$ empire will be

$$N_{C_n} = \text{round}(p_n \times N_{col})$$

(7)

Where $N_{C_n}$ is the initial number of colonies of the $n^{th}$ empire and $N_{col}$ is the total number of initial colonies. To divide the colonies, $N_{C_n}$ of the colonies are randomly chosen and given to the $n^{th}$ imperialist. These colonies along with the $n^{th}$ imperialist form the $n^{th}$ empire.

### 3.2. Assimilation: Movement of Colonies toward the Imperialist

Pursuing assimilation policy, the imperialist states tried to absorb their colonies and make them a part of themselves. More precisely, the imperialist states made their colonies to move toward themselves along different socio-political axis such as culture, language and religion. In the ICA, this process is modelled by moving all of the colonies toward the imperialist along different optimization axis.

The direction of movement is not necessarily the vector from colony to the imperialist. To model this fact and to increase the ability of searching more area around the imperialist, a random amount of deviation is added to the direction of movement. Fig. 3. shows the new direction. In this figure $\theta$ is a parameter with uniform distribution. Then

$$\theta \sim U(-\gamma,\gamma)$$

(8)

Where $\gamma$ is a parameter that adjusts the deviation from the original direction. Nevertheless the values of $\beta$ and $\gamma$ are arbitrary, in most of implementations a value of about 2 for $\beta$ and about $\pi/4$ (Rad) for $\gamma$ results in good convergence of countries to the global minimum.

### 3.3. Revolution: A sudden change in socio-political characteristics of a country

Revolution is a fundamental change in power or organizational structures that takes place in a relatively short period of time. In the terminology of ICA, revolution causes a country to suddenly change its socio-political characteristics. That is, instead of being assimilated by an imperialist, the colony randomly changes its position in the socio-political axis. A very high value of revolution decreases the exploitation power of algorithm and can reduce its convergence rate. In our simulations the revolution rate is 0.1. That is 10 percent of colonies in the empires change their positions randomly.

### 4. NUMERICAL RESULTS

The proposed algorithm was tested to the power systems 13 of a power plant with a total load demand of 1800 megawatts as well as 40 of a power plant with a total load demand of 10500 megawatts. To run a simulation of the algorithm, MATLAB®R2011a was used, and the simulation was performed on a COREi5 Intel, 2.3 GHz, with 4 GB of RAM. The parameters that were used in the ICA, are shown in Table 1.

![Fig. 3. Movement of colonies toward their relevant imperialist in a randomly deviated direction](image)

**Table 1. Parameters of ICA**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Number of Decades</td>
<td>500</td>
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<td>Number of Countries</td>
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<tr>
<td>Number of Empires</td>
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<tr>
<td>Assimilation Percentage</td>
<td>0.60</td>
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<td>Revolution Probability</td>
<td>0.10</td>
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<tr>
<td>Revolution Strength</td>
<td>0.03</td>
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</table>
4.1. 13-unit system
The test system consists of 13 generating units from [13] supplying to load demands of 1800MW. The obtained results for the 13-generator system using the ICA are given in Table 2. The results are compared with the other methods.

4.2. 40-unit system
The test system from [13] comprises 40 generating units supplying to a load demand of 10500 MW. The solution obtained by the proposed ICA method for this case is given in Table 3 and Table 4 shows the comparison of best total cost obtained by the proposed ICA to that from other methods in the literature.

Table 2. Solution for 13-unit system for load demands of 1800 MW and comparison of best total costs ($/h)

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<tr>
<td>ABC[7]</td>
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Table 3. Solution for 40-unit system by ICA

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<tr>
<td>P1(MW)</td>
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<td>94.4803</td>
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<td>87.1718</td>
<td>140.0000</td>
<td>259.5699</td>
<td>284.6954</td>
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<td>130.3279</td>
<td>94.0000</td>
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<td>140.0000</td>
<td>512.8363</td>
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<td>P2(MW)</td>
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<td>10.0263</td>
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<td>199.1394</td>
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<td>P3(MW)</td>
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<td>100.0000</td>
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Table 4. Comparison of best total costs for 40-unit system

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<th>BestCost($/h)</th>
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<tbody>
<tr>
<td>DE[6]</td>
<td>121416.29</td>
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<td>ABC[7]</td>
<td>121441.03</td>
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<td>ACO[8]</td>
<td>121532.41</td>
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<td>BBO[9]</td>
<td>121426.59</td>
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<td>DE/BBO[10]</td>
<td>121420.90</td>
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<td>FAPSO-NM[14]</td>
<td>121418.30</td>
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<td>NIPSO[15]</td>
<td>121412.54</td>
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<td>ICA-PSO[18]</td>
<td>121413.20</td>
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<td>UHGA[19]</td>
<td>121424.48</td>
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<tr>
<td>ICA</td>
<td>121401.32</td>
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</tbody>
</table>

5. CONCLUSION
The present study proposed a method based on ICA for solving ELG problem, taking into account power plants’ constraint of valve point loading effect. Two sample systems were adopted for the efficiency assessment of the proposed methods and the numerical results were presented. Comparison of the simulation results of the proposed method to other existing methods indicated the superiority of the ICA algorithm over the other methods, it can thus be considered as a proper instrument for solving economic dispatch problems in power systems.

REFERENCES
Majlesi Journal of Energy Management


