A New Approach To Economic Load Dispatch Of Power System Using Imperialist Competitive Algorithm

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Abstract: Electrical power industry restructuring has introduced a highly vibrant and competitive market which altered revolutionized many aspects of the power industry. In this changed scenario, the scarcity of energy resources, the ever increasing power generation cost, environmental concerns, ever growing demand for electrical energy necessitate optimal economic dispatch. Practical economic dispatch (ED) problems have nonlinear, non-convex type objective function with intense equality and inequality constraints. The conventional optimization methods are not able to solve such problems due to local optimum solution convergence. In the past decade, Meta heuristic optimization techniques especially Imperialist Competitive Algorithm (ICA) has gained an incredible recognition as the solution algorithm for such type of ED problems. The application of ICA in ED problem which is considered as the most complex optimization problem has been summarized in present paper.

Key words: Economic Load Dispatch, Imperialist Competitive Algorithm, Power System.

INTRODUCTION

Economic dispatch problem has become a crucial task in the operation and planning of power system. The primary objective of ED is to schedule the committed generating units output so as to meet the required load demand at minimum cost satisfying all unit and system operational constraints. Improvement in scheduling the unit outputs can lead to significant cost saving. Initially, ED problem was formulated as economic cost dispatch (ECD), but further due to the amendment of clean air act in 1990s, existence of emission dispatch (EMD) leads to the formulation of combined emission economic dispatch (CEED) and emission controlled economic dispatch (ECED) problem formulation, as individual optimization of these two contradictory objective will not serve the purpose. Various conventional methods like Bundle method (Mezger Alfredo J, et al., 2007), nonlinear programming (Martinez Luis Jose, et al., 2001), mixed integer linear programming (Gar CW, et al., 2001), dynamic programming (Shi CC, et al., 1990), quadratic programming (Erion Finardi C, et al., 2005), Lagrange relaxation method (Tkayuki S., & Kamu W. 2004), network flow method (Franco PEC, et al., 1994), direct search method (Wood AJ., & Wollenberg BF. 1984) reported in the literature are used to solve such problems. Practically, ED problem is nonlinear, nonconvex type with multiple local optimal point due to the inclusion of valve point loading effect, multiple fuel options with diverse equality and inequality constraints. Conventional methods have failed to solve such problems as they are sensitive to initial estimates and converge into local optimal solution and computational complexity. Modern heuristic optimization techniques proposed by researchers based on operational research and artificial intelligence concepts, such as evolutionary programming (Sinha N, et al., 2003), genetic algorithm (Xiaohui Y, et al., 2003), simulated annealing (Basu M., 2005), ant colony optimization (Huang JS., 2001), Tabu search (Mantawy AH, et al., 2002), neural network (Liang RH, & Hsu YY. 1995), particle swarm optimization (Cohelo SL, & Mariani VC. 1999) provide the better solution. This paper is a response note on previous work of application of population based ICA algorithm to solve the various ED problems.

Formulation of the ELD Problem:

The objective of the ELD problem is finding the optimal combination of power generations that minimizes the total generation cost while satisfying an equality constraint and inequality constraints. The most simplified cost function of each generator can be represented as a quadratic function as given in (2) whose solution can be obtained by the conventional mathematical methods (Wood AJ., & Wollenberg BF. 1984):

\[
C = \sum_{j=1}^{J} F(P_j) \tag{1}
\]

\[
F_j(P_j) = a_j + b_j P_j + c_j P_j^2
\]

Where,

C: Total generation cost

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$F_j$: Cost function of generator $j$
$\alpha_j, \beta_j, \gamma_j$: Cost coefficients of generator $j$
$P_j$: Electrical output of generator $j$
$J$: Set for all generators.

While minimizing the total generation cost, the total generation should be equal to the total system demand plus the transmission network losses. However, the network losses is not considered in this paper for simplicity. Thus, the equality constraint is given by:

$$\sum_{j \in J} P_j = P_D$$

(2)

Where, $P_D$ is the total system demand. The generation output of each unit should be between its minimum and maximum limits i.e.: the following inequality constraint for each generator should be satisfied:

$$P_{j,\min} \leq P_j \leq P_{j,\max}$$

(3)

Where, $P_{j,\min}$, $P_{j,\max}$ is the minimum, maximum active power of generator $j$.

**ICA Algorithm Introduction:**

Fig 1 shows ICA algorithm flowchart. This algorithm, such as other evolutionary algorithms begins with some accidental primary crowds that each of them has been called a "country". Some of best elements of crowds are selected as imperialist (equal with elites in genetic algorithms) .the remaining crowds have been considered as colony. Imperialist, with their power, absorb these colonies to themselves with special trend that will be discussed at future. Power of each empire depends on its two constitutive part namely imperialist country (as central nucleus) and its colonies. In mathematics this dependence models with empire power definition in the form of power sum of imperialist country plus percents of average power of its colonies. The imperialist competition between them begins with forming early empires. Each empire that cannot be successful in imperialist competition and increases its power, will be removed from imperialist competition scene .therefore the survival of each empire depends on its power in absorption of revival empire's colonies and ruling over them. As a result, in imperialist competition streams, the power of greater empires will be increased and weak empires will be removed. Empire will be obliged improve their colonies for increasing their power. Colonies gradually near the empires and we can observe some sort of convergence. Final extent of imperial extent is when we have had unit empire in the world, with colonies which are close to the imperialist country accordance with their position.For starting the algorithm , we create N numbers of early countries .we select N imp of the best members of this crowd as imperialist ( the countries including minimum amount of cost function) , the remains forms N col of colonies countries in which each of them belongs to one empire. We give some of these colonies to each imperialist for dividing the early colonies among the imperialist accordance with their power. consider their normalized cost as follow:

$$P_n = \frac{C_n}{\Sigma_{i=1}^{N_{impr}} C_i}$$

(4)

Where $C_n$ imperialist cost max ($C_i$) is highest cost among imperialist and $C_n$ is normalized cost of this imperialist.

Each imperialist which have had more cost (be weaker imperialist), includes less normalized costs. Normalized respective power of each imperialist, with having normalized costs, has been calculated as follow and accordance with it, colonies countries have been divided between imperialist.

$$N.C.n = \text{round} \{P_n \cdot (N_{col})\}$$

(6)

Where $N.C.n$ is early number of empire 's colonies and $N_{col}$ is the total number of existing colonies countries in the early countries crowds . Round is also function that give closest integer t a decimal number. We select accidentally some of these primary colonies countries, with considering $N.C.$ for each empire an give it to N imperialist, the imperialist competitive algorithm begins with having primary status of all empires. Evolutionary trend which located in a segment that continues till the stop condition fulfillment. Fig 2 shows the manner of early empires forming . Bigger empires have more colonies. In this Fig, imperialist number 1 creates the strongest empire and have most number of colonies.
Absorption Policy Modeling:
Colonies movement toward the assimilation policy of imperialist has done with the purpose of analyzing the culture and social structure of colonies in central government culture. Imperialist countries began to creating development (building transportation substructure, university establishing, …).

Fig. 1: Flowchart of the Imperialist Competitive Algorithm

In fact this central government tries to close colony country to its self by applying attraction policy, in different political and social dimensions, with considering showing manner of country in solving optimization problem. This section of imperialistic process in optimization algorithm has been modeled in the form of colonies movement toward the imperialist country. The Fig 3 shows total image of this movement. According with this Fig, imperialist country attract to itself parallel with culture and language axis. As shown in this Fig, colony country moves in x unit size toward the attachment line of colony to the imperialist and drawn to new situation. In this Fig, distance between imperialist and colony is shown by D, and x is accidental number with steady distribution.

It means for x, we have:

\[ x \sim \mathcal{U}(0, \beta \times d) \]  

(7)

Where \( \beta \) is a number bigger than 1 and nears to 2. A good selection can be \( \beta = 2 \). The existence of coefficient \( \beta > 1 \) causes the colony country closes to the imperialist country from different aspects while moving. With historical survey of assimilation phenomena, one clear fact in this field is in spite that imperialist countries followed seriously the attraction policy but facts did not follow totally accordance with applied policy and there were deviances in the work results. In introduced algorithm, this probable deviation has done with adding an accidental angle to the attraction path of colonies. For this purpose, in the colonies movement toward the imperialist, we add an accidental angle toward the colony movement. Fig 4 shows this state. this time we continue our path in stead of x movement toward the imperialist and in toward the vector and colony maxim to the imperialist in the same extent, but with \( \theta \) deviation in the path, and consider \( \theta \) accidentally and with constant distribution (but any ideal and proper distribution can be used), then \( \theta \sim \mathcal{U}(-\gamma, \gamma) \).

Fig. 3: Total image of colony movement toward imperialist.

Fig. 2: Manner of forming primary empire, imperialist number 1 creates strongest empire and has maximum number of colonies.
In this relation $y$ is ideal parameter that its increasing causes increasing searching around imperialist and its decreasing causes colonies close possibly to the vector of connecting colony to the imperialist. With considering the radian unit for $\theta$, a number close to $\pi/4$ was proper selection in the most depletion.

**Position Displacement of Colony and Imperialist:**

In some cases attraction policy has had positive result for them, in spite of destroying political-economical structures of colony countries. Some of countries with applying this policy accessed to general self-confidence and after awhile it was the educated people who combat with the nation leadership for escaping from imperialist. We can find various cases of these in enland and france’s colonies. From other perspective, looking at up and downs of power circulation in the countries shows truly that the countries in which were at the peak of politic military power, after awhile declined and contrary the countries reached to the power that before were not into the power. This historical movement in the modelling in the algorithm has been applied in the way of colony movement toward the imperialist country, some of these colonies may reach to a better condition than imperialist (reaching to the points in cost function that generate less costs than cost function extent). In this state, the imperialist country and colony change their position and algorithm continues with imperialist country in new situation and this time it is the new imperialist country in which begin to applying assimilation policy for its colonies. The colony and imperialist displacement is shown in the Fig 5. In this Fig the best empire's colony in which has less costs than imperialist, is shown with dark colour. Fig 6 shows the whole empire after position changing.

**Total Power of an Empire:**

The power of an empire equals with the power of imperialist country in addition to some percentage of total power of whole colonies, in this case the total cost of an empire calculate as follow:

$$T.C. = \text{Cost(Imperialist,)} + \zeta \text{mean(Cost(colonies of empire,))}$$

Where $T.C.n$ is the empire's total cost and $\zeta$ is positive number that is usually between zero and one and near to zero. This low considering of $\zeta$ cause total cost of empire be nearly equal with its central government and increasing $\zeta$ causes increasing the colonies' costs measure influence of an empire in determining the its total costs. In generic state $\zeta = 0.05$ in the most cases resulted to proper answers.

**Imperial Competition:**

Each empire which cannot increase its power and looses its competition power, will be removed from imperialistic competitions. This removing forms gradually. It means that with passing the time, weak empire
give up their colonies and the strong empire take possession of these colonies and increase their power. For modeling this fact, we assume the empire at the time of deleting is the weakest existing empire. So in the algorithm repetition, we take some of weakest colonies of the empire and create a competition between the whole empires. Mentioned colonies will not necessarily be possessed the strongest empire. But this is the stronger empire which has more chance for its ownership. Fig 9 shows total image of this part of algorithm.

![Fig. 7: Exchanging the positions of a colony and the imperialist](image1.png)

![Fig. 8: The entire empire after position exchange](image2.png)

For modeling the competition between the empires for possessing these colonies, first of all we calculate the ownership probability of each empire (that be fit with the power of that empire) with considering total cost of each empire, as follow: first we determine total costs of empire based on its normalized costs: $N \cdot T \cdot C_i = T \cdot C_i - \max_i \{T \cdot C_i\}$

$$N \cdot T \cdot C_i = T \cdot C_i - \max_i \{T \cdot C_i\} \quad (9)$$

Where T.C.N is total cost of empire and N.T.C.n is normalized cost of that empire. Each emire which have had less T.C.N has more n.t.cn. In fact T.C.n equals total cost of an empire and N.T.C.N equals its total power.

![Fig. 9: Total image of imperialistic competition: bigger empire take the possession of the other empire's colonies with more likelihood.](image3.png)

The probability of colony ownership in competition by each empire calculates as follow:

$$p_{_{i}} = \frac{N \cdot T \cdot C_i}{\sum_{i=1}^{n} N \cdot T \cdot C_i} \quad (10)$$

With ownership probability of each empire, we divide the mentioned colonies accidentally between the empires, but with related probability to ownership probability of each empire. Then we form vector $P$ based on above probability extents as follow:

$$P = \left[ p_{_{p_1}}, p_{_{p_2}}, p_{_{p_3}}, ..., p_{_{p_{_n}}} \right] \quad (11)$$

Vector $P$’s size is $1 \times nimp$ and is constituted based on probability amounts of empires ownership. Then we form the accidental vector $R$ as equal as vector $P$, the arrays of this vector are accidental number with the same distribution in $[0,1]$. 

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Then we form vector D as follow:

\[ D = \text{P} - \text{R} \]  \hspace{1cm} (13)

We give the mentioned colonies to the empires with having cector D so that related andis in vector D be bigger than others. The empire which has more ownership probability, has the highest extent, with more chances in related andis in vector D.

**Declining The Weak Impires:**

Weak empires gradually decline in imperialistic competition and strong empires take the possession of their colonies. There are different conditions for declining an empire. In suggested empire, when an empire lose its colonies, it assumed deleted.

**Convergency:**

The mentioned algorithm continues till fulfillment of one convergency condition or a finishing the number of whole repitition. After awhile all the empires will decline and we have only one empire and other countries are under the control of this united empire. In this new ideal world all the colonies are controled bye an united empire and the colonies’s cost and situations equals with the empirilaist ‘s cost and situation. in this new world, there are no difference not only between colonies but also between colonies and imperialist country. in other words, all the countries are both colony and imperialist at the same time. In such situation the imperialistic competition have been finished and stops as one stop codition of algorithm.

**ICA Algorithm:**

Assimilation : this function applies assimilation part or in other word attraction policy. Primary empires : it forms primary empires with proper dividing of colonies among them, with considering situation and cost of primary countries. Imperialistic competition: The imperialistic competition between the emipres in order to attract each other colonies is done by this function. Removing the weak empires is also in this function. Imperialist and colony displacement: Displacement of imperialist and colony is done in this function. If a colony reach to a better position than imperialist, it immediately take the control of emperor and continues the work with applying the attraction policy on them. The colonies revolution: Revolution, that is main counterweight of discovery balance and exploitation and is useful for discovery, applies in this function. Sudden changes happens in some countries and in some cases leads to discovery of minimum indiscernible point in function.

**ICA Algorithm's Similar_Code:**

1. Select some accidental point on the function and form the primirary empires. we mean the powerhouses power that are considered as primary guess.
2. Move the colonies toward the imperialist country (assimilation policy).
3. If there are an empire that has less costs than imperialist, change the position of colony and imperialist.
4. Calculate total costs of an empire (with pay attention to imperialist and its colonies's costs).
5. Select one colony from weakest empires and give it to the empire which has more chance for ownership.
6. Delete weak empires.
7. Stop if there are only one remained empire, otherwise go to 2.

**Numerical Result:**

The proposed ICA algorithm was tested on two representative systems, i.e.: IEEE 30 bus and 57 bus power systems in comparison with the GA based method for the solution of the ELD problem. The system line and bus data for 30- and 57-buses test systems were adopted from (Y. Chumming., & D. Simon. 2005). The maximum generation was set to 2000 and 2500 for 30 and 57-buses power systems. These systems have 6 and 7 generators, respectively. The total demands for generators of these systems are set as 188.19 and 1250 MW, respectively. After several trials, the best obtained result is shown using the predetermined parameters. Tables 1 and 2 show the results for IEEE 30 bus and 57 bus test systems that obtained by the ICA and GA methods. The convergence characteristics for the two test cases using the Heuristic methods are shown in Figs. 5 and 6. From Table 3 it can be seen that the total cost obtained by the proposed technique is less than the GA based method.
Moreover, the proposed ICA method is faster than the GA based method, because unlike the GA method, which has to deal with two populations in the ICA method, there is only one population in each iteration that moves towards the global optimal point. Thus, the ICA method has good performance and can outperform compare to the GA technique.

**Fig. 3.** Topology of the IEEE 30-bus

**Fig. 4.** Topology of the IEEE 57-bus

**Conclusion:**

Many engineering problems such as ED problem in power system can be modelled as constrained nonlinear optimization. To solve the constrained optimization problems, penalty function based methods is the most popular approach. However, since the penalty function approach is generic and applicable to any type of constraint, their performance is not always satisfactory and consistent. During the present paper, to overcome this drawback, a ICA method is used for the solution of the ED problem. Regarding the memory characteristics of ICA, a new constraints handling strategy is developed. The strategies for handling constraints are developed with regard to the dynamic process of the ICA algorithm. The proposed method has been applied to two IEEE test systems (IEEE 30 buses and 57 buses) for the solution of the ED problem to demonstrate the effectiveness of its performance in comparison with GA based approach. The simulation results show that the proposed ICA method is superior to GA based technique and it is computationally faster. Besides, the obtained computational results for the solution of the ED problem confirms its good performance in terms of solution quality, computational cost as well as the convergence stability.

**Table 1.** Comparison of ICA and GA method for ED problem solution for the IEEE 30-bus power system (TP: Total Power [MW] and TC: Total Generation Cost)

<table>
<thead>
<tr>
<th>Unit</th>
<th>Genetic Algorithm</th>
<th>Imperialist Competitive Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost</td>
<td>MW</td>
</tr>
<tr>
<td>1</td>
<td>128.9859</td>
<td>44.80</td>
</tr>
<tr>
<td>2</td>
<td>162.166</td>
<td>57.41</td>
</tr>
<tr>
<td>3</td>
<td>60.8713</td>
<td>18.18</td>
</tr>
<tr>
<td>4</td>
<td>55.906</td>
<td>22.83</td>
</tr>
<tr>
<td>5</td>
<td>48.1510</td>
<td>14.79</td>
</tr>
<tr>
<td>6</td>
<td>105.545</td>
<td>30.120</td>
</tr>
<tr>
<td>TP</td>
<td>188.19</td>
<td></td>
</tr>
<tr>
<td>TC</td>
<td>561.6259</td>
<td></td>
</tr>
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</table>
Table II. Comparison of ICA and GA method for ED problem solution for the IEEE 57-bus power system (TP: Total Power [MW] and TC: Total Generation Cost)

<table>
<thead>
<tr>
<th>Unit</th>
<th>Genetic Algorithm</th>
<th>Imperialist Competitive Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost MW</td>
<td>Cost MW</td>
</tr>
<tr>
<td>1</td>
<td>4125 140.14</td>
<td>4219 141.583</td>
</tr>
<tr>
<td>2</td>
<td>3734 96.25</td>
<td>4109 98.32</td>
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<td>TP</td>
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<tr>
<td>TC</td>
<td>40972.26</td>
<td>40972.11</td>
</tr>
</tbody>
</table>

Fig. 5. Convergence characteristics of PSO for the 30-bus system

Fig. 6. Convergence characteristics of PSO for the 57-bus system
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