

# Multi-area economic dispatch using Improved Bat Algorithm

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## Abstract

This paper presents application of Improved Bat algorithm for solving multi-area economic load dispatch problem (MAED) considering tie line constraint, transmission loss, multiple fuel options, valve point loading effect and prohibited operating zones. Improved bat algorithm is an optimization algorithm motivated by the echolocation behavior of natural bats in finding their foods. Potency of the algorithm is tested on three different test cases consist of varying degree of complexity and it is compared with artificial bee colony optimization, differential evolution, evolutionary programming and real coded genetic algorithm. The promising results show the quick convergence and effectiveness of the projected technique.

**Keywords:-**Multi-area economic dispatch, prohibited operating zones, valve point loading effect, multi fuel, tie line constraint, Improved Bat Algorithm.

## 1. Introduction:-

Economic dispatch [1] problem is one of the vital optimization problems in the industrial operation of power systems. The primary objective of the ED problem is to resolve the excellent schedule of online generating units so as to meet the power demand at least possible operating cost under various systems and operating constraints. Generally, in power system the generators are divided into many generation areas and they interconnected by using tie-lines. Multi-area economic dispatch (MAED) is an expansion of economic dispatch. MAED determines the generation level and trade of power between areas such that total fuel cost in all areas is curtailed while satisfying power balance constraints, generating limits constraints and tie-line capacity constraints. Shoults et al [2] included power transfer limits between areas for solving the economic dispatch problem. This study gives a complete formulation of multi-area generation scheduling, and an idea for multi-area studies. Romano et al. [3] Solved constrained economic dispatch of multi-area systems using the Danzig-Wolfe decomposition principle which reduces the complexity of the problem by separating it into several sub-problems. A. L. Desell et al. [4] Applied a linear programming to transmission constrained generation production cost analysis in power system planning for a large electrical network. Ouyang and Shahidehpour [5] proposed heuristic multi-area unit commitment with economic dispatch

with an inclusion of simple and effective tie-line constraint checking. Wang et al. [6] Proposed a decomposition approach for the multi-area generation scheduling with tie-line constraints having non-linear characteristics using expert systems.

Dan Streiffert et al. [7] proposed an Incremental Network Flow Programming algorithm for solving the multi-area economic dispatch problem with transmission constraints. Jayabarathi et al. [8] solved multi-area economic dispatch problems with tie line constraints using evolutionary programming technique. Manoharan et al. [9] explored the efficiency and effectiveness of the various evolutionary algorithms such as the Real-coded Genetic Algorithm, Particle Swarm Optimization, Differential Evolution and Covariance Matrix Adapted Evolution Strategy on multi-area economic dispatch problems. Prasanna et al. [10] solved the Security Constrained Economic Dispatch in interconnected power system by using Fuzzy logic strategy incorporated with Evolutionary Programming and with Tabu-Search algorithms. Manisha Sharma et al. [11] compared the search capability and convergence behavior of algorithms such as Classical differential evolution (DE) and its various strategies, Classical particle swarm optimization (PSO), An improved PSO with a parameter automation strategy having time varying acceleration coefficients (PSO-TVAC) for solving MAED problems. P. S. Manoharan et al. [12] proposed an Evolutionary Programming with Levenberg-Marquardt Optimization technique to solve multi-area economic dispatch problems with multiple fuel options. M. Zarei et al. [13] proposed a direct search method (DSM) to solve the two-area economic dispatch of the generating units with some equality and inequality constraints with different kind of complex fuel cost function.

Arthur K. Kordon [14] gives realistic guidelines on how to handle the numerous technical, nontechnical issues and for typical real-world applications. James Kennedy and Russell C. Eberhart [15] explained the dynamic behavior of the swarms and their performance under different optimization problem. Sumathi and surekha [16] gives an idea of applying the optimization problem in the environment of Matlab programming. Andries P. Engelbrecht [17] gives a brief introduction about the evolutionary algorithms and swarm intelligence based algorithms and their effect of parameter on applications. BijayaKetanPanigrahi and YuhuiShi [18] gives a collection of swarm intelligence applications on various practical real world problem. Bat algorithm (BA) [19-21] is an

optimization algorithm based on echolocation characteristics of bats and developed by mimics of ‘bats’ foraging behavior. The exploration and exploitation mechanism of BA was well suitable for the real world optimization problems.

In this paper, MAED problem with three different cases with inclusion of operating zones, transmission loss, valve point effect and multiple fuel sources has been solved by using the IBA. The proposed IBA approach has been verified by applying it to three different test systems. The performance of the proposed IBA has been compared with differential evolution (DE), evolutionary programming (EP), real coded genetic algorithm (RCGA), and artificial bee colony optimization (ABCO) as per the literature.

**2. Problem formulation**

The main objective of MAED in electrical power system is to reduce the overall production cost of supplying loads to all areas while satisfying power balance constraints, generating limits constraints and tie-line capacity constraints as much as possible [24].

**2. 1. Multi-area economic dispatch with quadratic cost function prohibited operating zones and transmission losses**

The objective of the MAED problem is:-

$$F_t = \sum_{i=1}^N \sum_{j=1}^{M_i} F_{ij}(P_{ij}) = \sum_{i=1}^N \sum_{j=1}^{M_i} a_{ij} + b_{ij}P_{ij} + c_{ij}P_{ij}^2 \quad (1)$$

where  $F_{ij}(P_{ij})$  is the cost function of  $j$ th generator in area  $i$  and is usually expressed as a quadratic polynomial;  $a_{ij}$ ,  $b_{ij}$  and  $c_{ij}$  are the fuel cost coefficients of  $j$ th generator in area  $i$ ;  $N$  is the number of areas,  $M_i$  is the number of committed generators in area  $i$ ;  $P_{ij}$  is the real power output of  $j$ th generator in area  $i$ . The MAED problem minimizes  $F_t$  subject to the following constraints.

**2. 1. 1. Active power balance constraint**

$$\sum_{j=1}^{M_i-1} P_{ij} = P_{Di} + P_{Li} + \sum_{k,k \neq i} T_{ik} \quad i \in N \quad (2)$$

The transmission loss  $P_{Li}$  of area  $i$  may be expressed by using B-coefficients as

$$\sum_i P_{Li} = \sum_i \left( \sum_{l=1}^N \sum_{j=1}^{M_l} P_{ij} B_{ilj} P_{il} + \sum_{j=1}^{M_i} B_{0ij} P_{ij} + B_{00i} \right) \quad (3)$$

where  $P_{Di}$  real power demand of area  $i$ ;  $T_{ik}$  is the tie line real power transfer from area  $i$  to area  $k$ .  $T_{ik}$  is positive when power flows from area  $i$  to area  $k$  and  $T_{ik}$  is negative when power flows from area  $k$  to area  $i$ .

**2. 1. 2. Tie line capacity constraints**

The tie line real power transfer  $T_{ik}$  from area  $i$  to area  $k$  should not exceed the tie line transfer capacity for security consideration.

$$-T_{ik}^{max} \leq T_{ik} \leq T_{ik}^{max} \quad (4)$$

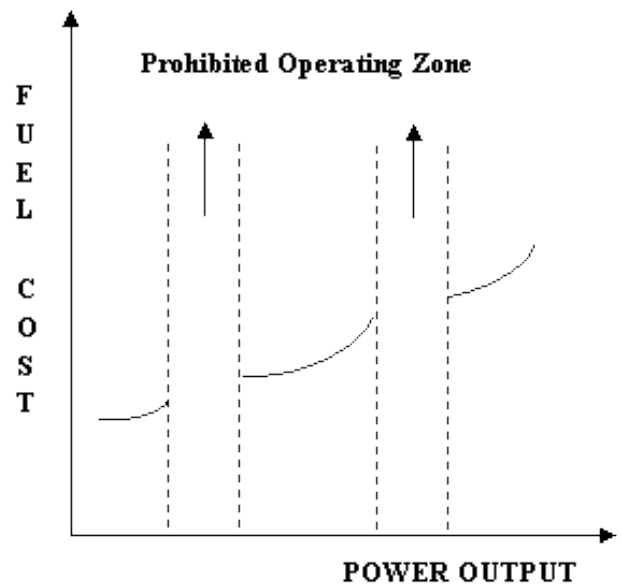
Where  $T_{ik}$  the power flow is limit from area  $i$  to area  $k$  and is the power flow limit from area  $k$  to area  $i$ .

**2. 1. 3. Real power generation capacity constraints**

The real power generated by each generator should be within its lower limit  $P_{ij}^{min}$  and upper limit  $P_{ij}^{max}$ , so that  $P_{ij}^{min} \leq P_{ij} \leq P_{ij}^{max} \quad i \in N \quad j \in M_j \quad (5)$

**2. 1. 4. Prohibited operating zone**

The prohibited operating zones are the range of power output of a generator where the operation causes undue vibration of the turbine shaft bearing caused by opening or closing of the steam valve. This undue vibration might cause damage to the shaft and bearings. Normally operation is avoided in such regions. The feasible operating zones of unit can be described and represented as Fig1:-



**Fig. 1. prohibited operating zone**

The feasible operating zones of unit can be described as follows:-

$$P_{ij}^{min} \leq P_{ij} \leq P_{ij,1}^l$$

$$P_{ij,m-1}^u \leq P_{ij} \leq P_{ij,m}^l; \quad m = 2, 3, \dots, n_{ij} \quad (6)$$

$$P_{ij,n_{ij}}^u \leq P_{ij} \leq P_{ij}^{max}$$

Where  $m$  represents the number of prohibited operating zones of  $j$  the generator in area  $i$ .  $P_{ij,m-1}^u$  is the upper limit of  $(m-1)$ th prohibited operating zone of  $j$ th generator in area  $i$ .  $P_{ij,m}^l$  is the lower of  $m$ th prohibited operating zone of  $j$  the generator in area  $i$ . Total number of prohibited operating zone of  $j$ th generator in area  $i$  is  $n_{ij}$ .

**2. 2. Multi area economic dispatch with valve point loading**

The generator cost function is obtained from a data point taken during ‘‘heat run’’ tests when input and output data are measured as the unit slowly varies through its operating region. Valve drawing effects, which occur as each steam admission valve in a turbine starts to open, produce a rippling effect on the unit curve. To consider the accurate cost curve of each generating unit, the valve point results in as each steam valve starts to open, the ripples like in Fig. 2 the cost function

addressing valve-point loadings of generating units is accurately represented as

$$F_t = \sum_{i=1}^N \sum_{j=1}^{M_i} F_{ij}(P_{ij}) = \sum_{i=1}^N \sum_{j=1}^{M_i} a_{ij} + b_{ij}P_{ij} + c_{ij}P_{ij}^2 + |d_{ij} \times \sin \{e_{ij} \times (P_{ij}^{\min} - P_{ij})\}| \quad (7)$$

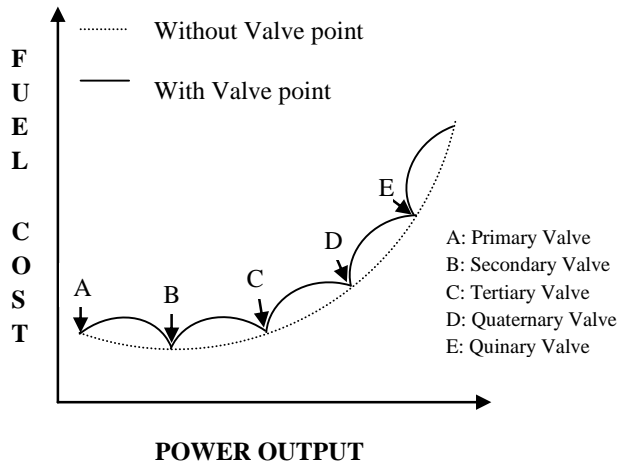


Fig. 2. Valve-point loading effect

### 2. 3. Multi-area economic dispatch with valve point loading multiple fuel sources and transmission losses

The main objective of “Economic Dispatch with multiple fuel option” is to find which fuel is most economical to burn. Say, for example, a plant consisting of many generating units which are supplied with numerous (coal, nature gas and oil) of fuel may be faced with the dilemma of determining which fuel is most economical to burn. the piecewise quadratic function is used to represent multiple fuel options and the cost and incremental cost functions are illustrated in Fig. 3. To obtain an accurate and practical economic dispatch, the realistic operation of the economic dispatch problem should be considered both valve-point effects and multiple fuel options. This paper proposed an incorporated cost model, which combines the valve point loadings and the fuel changes into one frame. Therefore, the cost function should combine both and it is expressed as

$$F_{ij}(P_{ij}) = a_{ijm} + b_{ijm}P_{ij} + c_{ijm}P_{ij}^2 + |d_{ijm} \times \sin \{e_{ijm} \times (P_{ijm}^{\min} - P_{ij})\}| \quad (8)$$

Where  $P_{ij}^{\min} \leq P_{ij} \leq P_{ij}^{\max}$  for fuel type m and  $m = 1, 2, \dots, N_F$   
 The objective function  $F_t$  is given by

$$F_t = \sum_{i=1}^N \sum_{j=1}^{M_i} F_{ij}(P_{ij}) \quad (9)$$

The objective function  $F_t$  is to be minimized subject to the constraints given in (2), (4) and (5). The valve-point loading, prohibited operating zones and other constraints turn the decision space into disjoint subsets, transforming the multi-area economic problem into a difficult non-smooth non-convex optimization problem.

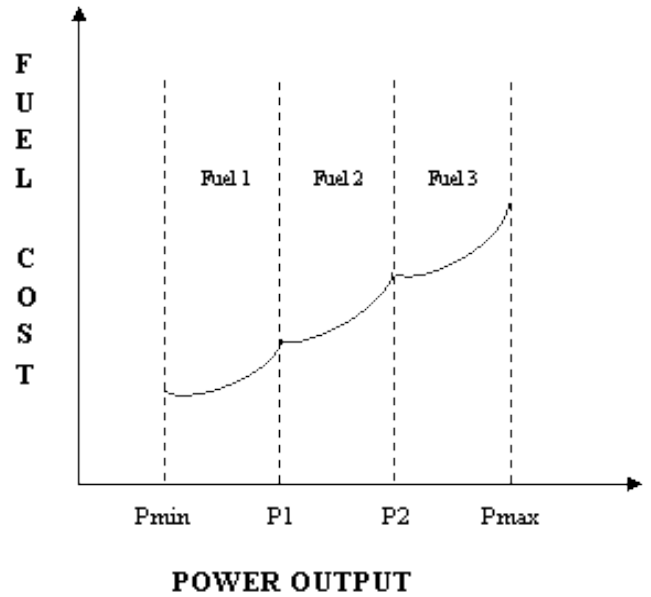


Fig. 3. Multi-fuel option.

### 3. Determination of generation level of slack generator

$M_i$  committed generators in area i deliver their power output subject to the power balance constraint (2), tie line capacity constraints (4) and the respective generation capacity constraints (5). Assuming the power loading of first ( $M_i-1$ ) generators is known, the power level of the  $M_i$ th generator (i. e. the slack generator) is given by

$$P_{iM_i} = P_{Di} + P_{Li} + \sum_{k,k \neq i} T_{ik} - \sum_{j=1}^{M_i-1} P_{ij} \quad (10)$$

The transmission loss  $P_{Li}$  is a function of all generator outputs including the slack generator and it is given by

$$P_{Li} = \sum_{l=1}^{M_i-1} \sum_{j=1}^{M_i-1} P_{ij} B_{ilj} P_{il} + 2P_{iM_i} \left( \sum_{j=1}^{M_i-1} B_{iM_i j} P_{ij} \right) + B_{iM_i M_i} P_{iM_i}^2 + \sum_{j=1}^{M_i-1} B_{oij} P_{ij} + B_{oiM_i} P_{iM_i} + B_{ooi} \quad (11)$$

Expanding and rearranging, equation (10) becomes

$$B_{iM_i M_i} P_{iM_i}^2 + \left( 2 \sum_{j=1}^{M_i-1} B_{iM_i j} P_{ij} + B_{oiM_i} - 1 \right) P_{iM_i} + \left( P_{Di} + \sum_{k,k \neq i} T_{ik} + \sum_{l=1}^{M_i-1} \sum_{j=1}^{M_i-1} P_{ij} B_{ilj} P_{il} + \sum_{j=1}^{M_i-1} B_{oij} P_{ij} - \sum_{j=1}^{M_i-1} P_{ij} + B_{ooi} \right) = 0 \quad (12)$$

The loading of the slack generator (i. e.  $M_i$ th) can then be found by solving equation (12) using standard algebraic method.

#### 4. Overview of bat algorithm

BAT algorithm is an optimization algorithm motivated by the echolocation behaviour of natural bats in finding their foods. It is introduced by Yang and is used for solving many real world optimization problems. Each virtual bat in the initial population employs a homologous manner by doing echolocation for updating its position. Bat echolocation is a perceptual system in which a series of loud ultrasound waves are released to produce echoes. These waves are returned with delays and various sound levels which make bats to discover a specific prey as shown in Fig 4. Some guidelines are studied to enhance the structure of BAT algorithm and use the echolocation nature of bats.

- i). Each bats identify the distance between the prey and background barriers using echolocation.
- ii). Bats fly randomly with velocity  $v_i$  at position  $x_i$  with a fixed frequency  $f_{\min}$  (or Wavelength  $\lambda$ ), varying wavelength  $\lambda$  (or frequency  $f$ ) and loudness  $A_o$  to search for prey. They can naturally adopt the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission  $r \in [0, 1]$ , depending on the closeness of their prey.
- iii). Although the loudness of the bats can be modified in many ways, we consider that the loudness varies from a large (positive)  $A_o$  to a minimum value  $A_{\min}$  according to the problem taken.

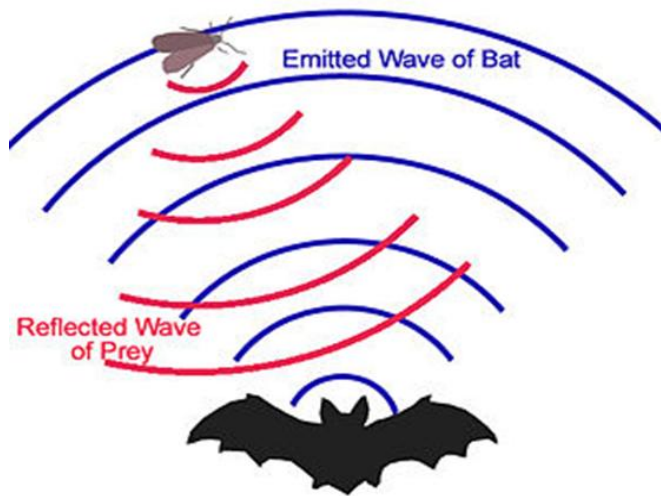


Fig. 4. Ecolocation behaviour of bats

##### A. Initialization of Bat Population

Population initialization of bats randomly in between the lower and the upper boundary can be achieved by the equation.

$$x_{ij} = x_{\min j} + \text{rand}(0,1) * (x_{\max j} - x_{\min j}) \quad (13)$$

Where  $i=1, 2 \dots n, j=1, 2 \dots d, x_{\min j}$  and  $x_{\max j}$  are lower and upper boundaries for dimension  $j$  respectively.

##### B. Update Process of Frequency, Velocity and Solution

The step size of the solution is controlled with the frequency factor in BA. This frequency factor is generated randomly in between the minimum and maximum frequency  $[f_{\min}, f_{\max}]$ . Velocity of a solution is proportional to frequency and

new solution depends on its new velocity and it is represented as.

$$f_i = f_{\min} + (f_{\max} - f_{\min})\beta \quad (14)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x^*)f_i \quad (15)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (16)$$

Where  $\beta \in [0, 1]$  indicates randomly generated number,  $x^*$  represents current global best solutions. For local search part of algorithm (exploitation) one solution is selected among the selected best solutions and random walk is applied.

$$x_{new} = x_{old} + A^t \quad (17)$$

Where  $A^t$  is average loudness of all bats,  $\square \in [0, 1]$  is random number and represents direction and intensity of random-walk.

##### C. Update Process of Loudness and Pulse Emission Rate

As iteration increases, the loudness and pulse emission must be updated because when the bat gets closer to its prey then their loudness  $A$  usually decreases and pulse emission rate also increases, the updating equation for loudness and pulse emission is given by

$$A_i^{t+1} = \alpha A_i^t \quad (18)$$

$$r_i^{t+1} = r_i^0 [1 - e^{(-\gamma t)}] \quad (19)$$

Where  $\alpha$  and  $\gamma$  are constants.  $r_i^0$  and  $A_i$  are factors which consist of random values and  $A_i^0$  can typically be  $[1, 2]$ , while  $r_i^0$  can typically be  $[0, 1]$ .

##### Pseudo Code of Bat Algorithm

- 1) Objective function:  $f(x), x=(x_1 \dots x_d)^t$ .
- 2) Initialize bat population  $x_i$  and velocity  $v_i$   $i=1, 2 \dots n$ .
- 3) Define pulse frequency  $f_i$  at  $x_i$ .
- 4) Initialize pulse rate  $r_i$  and loudness  $A_i$ .
- 5) While ( $t < \text{maximum number of iterations}$ ).
- 6) Generate new solutions by adjusting frequency, and updating velocities and location/solutions.
- 7) **IF** ( $\text{rand} > r_i$ ).
- 8) Select a solution among the best solutions.
- 9) Generate a local solution around the selected best solution.
- 10) **End if**.
- 11) **If** ( $\text{rand} < A_i$  and  $f(x_i) < f(x^*)$ ).
- 12) Accept new solutions.
- 13) Increase  $r_i$ , reduce  $A_i$ .
- 14) **End if**.
- 15) Ranks the bats and find current best  $x^*$ .
- 16) **End while**.
- 17) Display results.

##### 5. Improved bat algorithm (IBA)

Bat Algorithm is an efficient algorithm at exploitation but has some insufficiency at exploration, thus it can easily get trapped in local minimum on most of the multimodal test functions. In order to overcome this problem of standard BA, some modifications are made in the update process of frequency to improve exploration and exploitation capability of BA [21].

Normally, in bat algorithm the frequency is randomly generated in between the minimum and maximum value, this frequency will have same effect to all dimensions of solution. In order to adopt the effect of change in dimensions on

solutions a dynamic frequency varying concept is assigned in this improved bat algorithm.

$$\text{diff}_j = \sqrt{(x_{ij} - x_j^*)^2} \quad (20)$$

$$\text{range} = \max(\text{diff}) - \min(\text{diff}) \quad (21)$$

$$f_j = f_{\min} + \frac{(\min(\text{diff}) - (\text{diff}_j))^2}{\text{range}} * (f_{\max} - f_{\min}) \quad (22)$$

The distances between  $i_{th}$  solution and global best solution are calculated first then the frequency updating are assigned according to Eq. (22), so the frequency variation is depend on difference in distances as per the Eq. (20). By varying the Frequency the step size of the solutions also varied. Thus, dimensions which are closer to global optimum point do not steer for irrelevant regions. Instead, they locally search around global optimum point. Velocity formulation Eq. (23) must be updated as follows.

$$v_{ij}^t = v_{ij}^{t-1} + (x_{ij}^t - x_{ij}^*)f_j \quad (23)$$

### Pseudo Code for Improved Bat Algorithm

- 1). Initialize the population of  $n$  bats randomly and evaluate the objective function for all bats.
- 2). Initialize temporary best solution among the solutions.
- 3). Define frequency as per the Eq. (20-22).
- 4). Define loudness  $A_i$  and the initial velocities  $v_i$  ( $i= 1, 2, \dots, N$ ); Set pulse rate  $r_i$ .
- 5). While ( $t < \text{maximum number of iterations}$ )
- 6). Evaluate objective function for generating new solutions by varying the frequency and update velocity Eq. (20-22).
- 7). **If** ( $\text{rand} > r_i$ )
- 8). Select a solution among the best solutions.
- 9). Generate a local solution around the selected best solution.
- 10). **End if**
- 11). **If** ( $\text{rand} < A_i$  and  $f(x_i) < f(x^*)$ )
- 12). Accept new solutions
- 13). Increase  $r_i$ , reduce  $A_i$
- 14). **End if**
- 15). Ranks the bats and find current best  $x^*$
- 16). **End while**
- 17). Display results.

## 6. Simulation results and discussion

In this work an IBA algorithm is applied to solve the multi-area economic dispatch for three different cases and the potential of the algorithm is compared with the differential evolution (DE), evolutionary programming (EP), artificial bee colony optimization algorithm (ABCO), and real coded genetic algorithm (RGCA).

### Case-1

The IBA algorithm is employed to solve the economic dispatch of two area system consist of three generators on each area with considering prohibiting zones, transmission loss, generating capacity constraint and tie line limit constraint, the total demand for two area system is 1263MW and it is shared by two areas, area1 demand is 757. 8MW

(60%), area2 demand is 505. 2MW (40%) and the tie-line power flow limit between area 1 and 2 is 100MW. Result obtained from IBA is compared with other algorithms as per Table1, and the convergence characteristics of IBA is shown in Fig 5. The result of comparison between IBA, ABCO, DE, EP and RGCA obtained from Table 1 as shown in Fig 6 shows that improved bat algorithm gives better result. The data for two area system [25] is given in the Table A, and the loss coefficients for the two area generators is given in Appendix A.

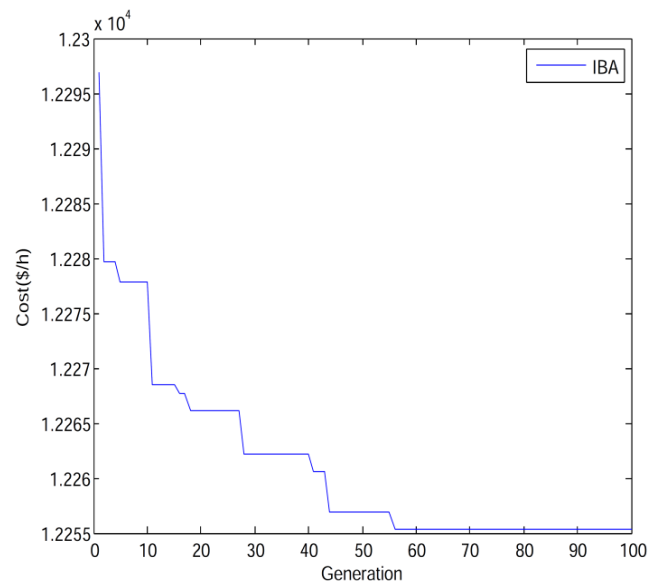


Fig. 5. Cost convergence for case-1

Table 1 Simulation result for case-1

	IBO	ABCO[24]	DE [24]	EP [24]	RCGA[24]
P <sub>1,1</sub> (MW)	500	500	500	500	500
P <sub>1,2</sub> (MW)	200	200	200	200	200
P <sub>1,3</sub> (MW)	149. 998	149. 9997	150	149. 9919	149. 6328
P <sub>2,1</sub> (MW)	204. 0006	204. 3358	204. 3341	206. 4493	205. 9398
P <sub>2,2</sub> (MW)	154. 9949	154. 9954	154. 7048	154. 8892	155. 8322
P <sub>2,3</sub> (MW)	67. 629	67. 2915	67. 577	65. 2717	65. 2209
T <sub>12</sub> (MW)	82. 7712	82. 7728	82. 7731	82. 7652	82. 4135
P <sub>L1</sub> (MW)	9. 4268	9. 4269	9. 4269	9. 4267	9. 4193
P <sub>L2</sub> (MW)	4. 1984	4. 1955	4. 189	4. 1754	4. 2064
Cost (\$/h)	12255. 36	12255. 39	12255. 42	12255. 43	12256. 23
CPU time (s)	7. 8641	10. 9844	11. 9219	16. 8906	19. 6094

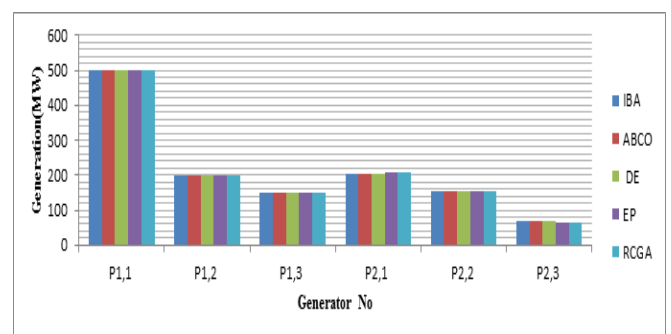
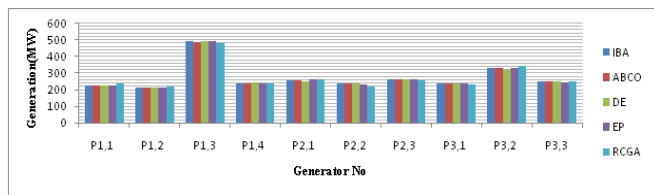


Fig. 6. Graph showing the result of comparison

**Table 2 Simulation result for case-2**

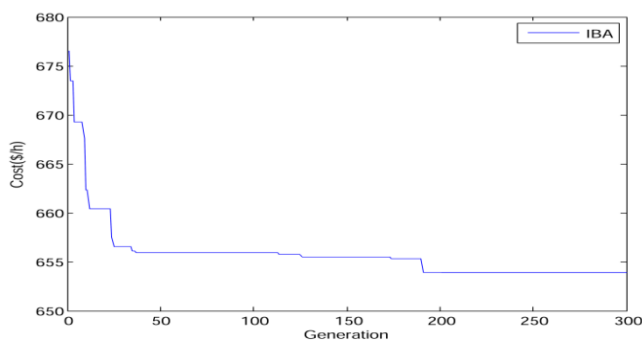
	IBA	ABCO[24]	DE[24]	EP[24]	RCGA[24]
	Fuel	Fuel	Fuel	Fuel	Fuel
P <sub>1,1</sub> (MW)	225.0009	225.9431	225.4448	223.8491	239.0958
P <sub>1,2</sub> (MW)	211.1592	211.1594	210.1667	209.5759	216.1166
P <sub>1,3</sub> (MW)	490.7469	489.9216	491.2844	496.068	484.1506
P <sub>1,4</sub> (MW)	240.6234	240.6232	240.8956	237.9954	240.6228
P <sub>2,1</sub> (MW)	254.1567	254.0397	251.0049	259.4299	259.6639
P <sub>2,2</sub> (MW)	235.4925	235.4927	238.8603	228.9422	219.9107
P <sub>2,3</sub> (MW)	263.8839	263.8837	264.0906	264.1133	254.514
P <sub>3,1</sub> (MW)	237.0527	237.0006	236.9982	238.228	231.3565
P <sub>3,2</sub> (MW)	328.737	328.7373	326.5394	331.2982	341.9624
P <sub>3,3</sub> (MW)	248.8615	248.8607	250.3339	246.6025	248.2782
T <sub>31</sub> (MW)	99.9931	99.8288	99.468	100	93.17
T <sub>32</sub> (MW)	99.7337	99.7334	100	100	93.8739
T <sub>41</sub> (MW)	31.3138	31.2615	30.281	32.5231	43.7824
T <sub>42</sub> (MW)	17.2572	17.2095	17.268	17.4884	17.0297
P <sub>1,1</sub> (MW)	9.8538	9.8488	9.7688	10.0085	9.701
P <sub>1,3</sub> (MW)	8.6038	8.6037	8.5905	8.6056	8.9408
Cost (\$/h)	653.8611	653.9995	654.0184	655.1716	657.3325
Time (s)	85.9608	90.4381	95.0351	108.0625	133.8438



**Fig. 7 Graph showing the result of comparison**

**Case-2**

This test system has ten generating units with valve point loading, multi fuel options and transmission losses are also considered. The total demand for three areas is 2700MW and it is shared by three areas, area1 demand is 1350MW (50%), area2 demand is 675MW (25%), area3 demand is 675MW (25%) and the tie-line power flow limit between area 1 and area 2 or from area 2 and area 1 is 100MW. the tie-line power flow limit between area 1 and area 3 or from area 3 and area 1 is 100MW. the tie-line power flow limit between area 3 and area 2 or from area 2 and area 3 is 100MW. so all the three tie line in area three having the same limit as 100MW, the loss coefficients for the two area generators [23] is given in Appendix B. Result obtained from IBA is compared with other algorithms as per Table2, and the convergence characteristics of IBA is shown in Fig 8. The result of comparison between IBA, ABCO, DE, EP and RCGA obtained from Table 2 as shown in Fig. 7 shows that improved bat algorithm gives better result.



**Fig. 8. Cost convergence for case-2**

**Table 3 Simulation result for case-3**

Power(MW)	IBA	ABCO[24]	DE[24]	EP[24]	RCGA[24]
P <sub>1,1</sub>	112.6745	111.102	93.0826	114	94.0855
P <sub>1,2</sub>	111.3751	109.9774	109.0592	114	47.7313
P <sub>1,3</sub>	101.6238	100.9238	89.7493	63.7726	85.4353
P <sub>1,4</sub>	190.7	190	116.9489	138.8847	131.2807
P <sub>1,5</sub>	97.639	96.939	97	75.3245	79.1771
P <sub>1,6</sub>	97.6675	96.9675	140	106.4216	131.4026
P <sub>1,7</sub>	260.395	259.695	283.7266	300	176.5484
P <sub>1,8</sub>	276.7	276.8725	286.2646	300	232.6707
P <sub>1,9</sub>	300.7	300	284.9088	284.9513	292.1746
P <sub>1,10</sub>	130.7	130.6977	131.6349	136.7335	130.1531
P <sub>2,1</sub>	244.4007	245.1007	169.8738	175.3639	340.9307
P <sub>2,2</sub>	93.3	94	110.9708	94	185.7976
P <sub>2,3</sub>	124.3	125	229.8845	263.8126	462.1471
P <sub>2,4</sub>	434.1062	434.8062	387.4742	331.0545	391.6765
P <sub>2,5</sub>	389.9743	390.6743	427.7543	394.2191	376.9261
P <sub>2,6</sub>	394.3043	395.0043	478.278	413.0955	484.3564
P <sub>2,7</sub>	499.3	500	490.1819	499.6763	481.2045
P <sub>2,8</sub>	499.3	500	490.9476	500	421.9451
P <sub>2,9</sub>	530.0889	530.7889	511.9152	533.8328	469.0019
P <sub>2,10</sub>	513.709	514.409	511.8241	508.9305	511.2801
P <sub>3,1</sub>	527.1275	527.1989	547.6323	520.6865	513.063
P <sub>3,2</sub>	502.0081	502.0795	523.4937	531.7618	513.8375
P <sub>3,3</sub>	530.2943	530.3657	522.6286	550	524.4524
P <sub>3,4</sub>	542.271	542.3424	545.9437	531.7377	524.9246
P <sub>3,5</sub>	520.1734	520.2448	523.6608	526.753	495.4096
P <sub>3,6</sub>	533.5675	533.6389	527.3677	550	442.885
P <sub>3,7</sub>	10	10	10	10	51.706
P <sub>3,8</sub>	10	10	15.7851	10	42.4448
P <sub>3,9</sub>	10	10	10	10	47.9812
P <sub>3,10</sub>	96.6985	96.7699	93.0253	89.7589	95.5812
P <sub>4,1</sub>	190	190	190	173.5365	149.1883
P <sub>4,2</sub>	168.7555	168.6841	157.8968	190	159.4065
P <sub>4,3</sub>	173.6879	173.6165	190	116.431	161.6999
P <sub>4,4</sub>	186.4454	186.374	200	180.6554	167.5135
P <sub>4,5</sub>	200	200	90	162.0916	172.422
P <sub>4,6</sub>	165.0284	164.957	149.454	173.092	179.221
P <sub>4,7</sub>	92.6341	92.5627	110	109.4254	91.9333
P <sub>4,8</sub>	97.0625	96.9911	88.163	74.3342	92.5453
P <sub>4,9</sub>	109.8153	109.8153	25	99.6914	89.0354
P <sub>4,10</sub>	431.4725	431.4011	538.4695	541.9711	458.8239
T <sub>12</sub>	198.6246	191.7078	200	200	-118.736
T <sub>13</sub>	6.424	6.674	91.5412	94.6831	-25.9549
T <sub>32</sub>	182.9355	183.1852	147.8992	186.0147	174.0405
T <sub>41</sub>	87.1918	86.859	51.0838	46.2286	81.5599
T <sub>42</sub>	95.4904	95.3237	42.9964	100	19.429
T <sub>43</sub>	57.219	57.2192	69.9032	100	45.8003
cost(\$/h)	123999.2	124009.4	124544.1	124574.5	129911.8
Time(s)	118.5886	126.9341	134.8125	144.5000	160.5313

**Case-3**

This test system has forty generating units with valve point loading effect without transmission loss. The total demand for three areas is 10500MW and it is shared by for areas, area1 demand is 1575MW (15%), area2 demand is 4200MW (40%), area3 demand is 3150MW (30%), area4 demand is 1575MW(15%) and the tie-line power flow limit between area 1 and area 2 or from area 2 and area 1 is 200MW. the tie-line power flow limit between area 1 and area 3 or from area 3 and area 1 is 200MW. the tie-line power flow limit between area 3

and area 2 or from area 2 and area 3 is 200MW. the tie-line power flow limit between area 4 and area 1 or from area 1 and area 4 is 100MW. the tie-line power flow limit between area 4 and area 2 or from area 2 and area 4 is 100MW. the tie-line power flow limit between area 3 and area 4 or from area 4 and area 3 is 100MW. The generator data are taken from[26]. Result obtained from IBA is compared with other algorithms as per Table1, and the convergence characteristics of IBA is shown in Fig 10. The result of comparison between IBA, ABCO, DE, EP and RGCA obtained from Table 3 as shown in Fig 10 shows that improved bat algorithm gives better result.

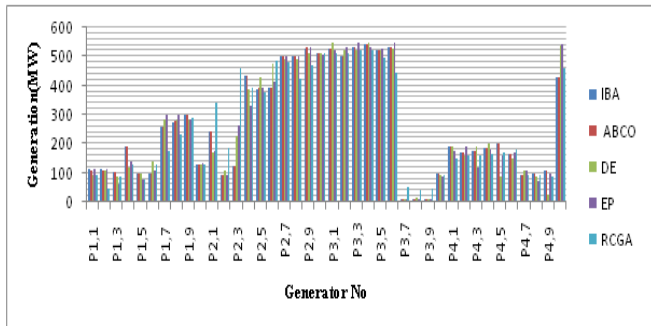


Fig. 9 Graph showing the result of comparison

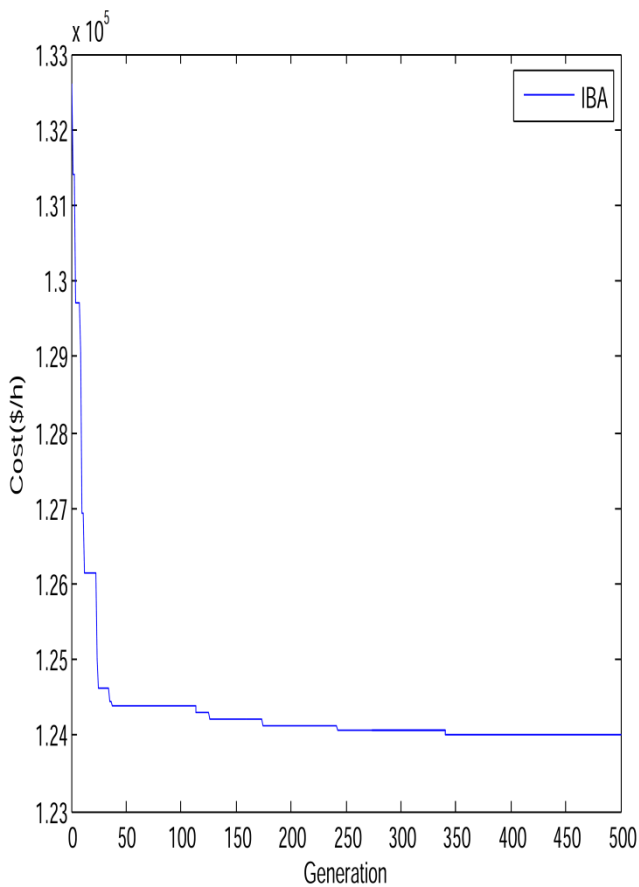


Fig. 10. Cost convergence for case-3

**7. Conclusion:-**

In this paper, IBA is applied to Multi-area economic load dispatch problems with three different cases. The results obtained by this method are compared with ABCO, DE, EP and RGCA. The comparison shows that IBA performs better than above mentioned methods. The IBA has superior features including quality of solution, stable convergence characteristics and good computational efficiency for large system. Therefore, this results shows that IBA is a promising technique for solving complicated problems in power system.

**Appendix A**

Transmission loss coefficients for two area system

$$B_1 = \begin{bmatrix} 17 & 12 & 7 \\ 12 & 14 & 9 \\ 7 & 9 & 31 \end{bmatrix} \times 10^{-6}$$

$$B_{01} = [-0.3908 \quad -0.1297 \quad 0.7047] \times 10^{-3}$$

$$B_{001} = 0.045$$

$$B_2 = \begin{bmatrix} 24 & -6 & -8 \\ -6 & 129 & -2 \\ -8 & -2 & 150 \end{bmatrix} \times 10^{-6}$$

$$B_{002} = [0.0591 \quad 0.2161 \quad -0.6635] \times 10^{-3}$$

$$B_{002} = 0.056$$

**Appendix B**

Transmission loss coefficients for three area system

$$B_1 = \begin{bmatrix} 8.70 & 0.43 & -4.61 & 0.36 \\ 0.43 & 8.30 & -0.97 & 0.22 \\ -4.61 & -0.97 & 9.00 & -2.00 \\ 0.36 & 0.22 & -2.00 & 5.30 \end{bmatrix} \times 10^{-5}$$

$$B_{01} = [-0.3908 \quad -0.1297 \quad 0.7047 \quad 0.0591] \times 10^{-3}$$

$$B_{001} = 0.056$$

$$B_2 = \begin{bmatrix} 8.60 & -0.80 & 0.37 \\ -0.80 & 9.80 & -4.90 \\ 0.37 & -4.90 & 8.24 \end{bmatrix} \times 10^{-5}$$

$$B_{02} = [0.2161 \quad -0.6635 \quad 0.5034] \times 10^{-3}$$

$$B_{002} = 0.045$$

$$B_3 = \begin{bmatrix} 1.20 & -0.96 & 0.56 \\ 0.96 & 4.93 & -0.30 \\ 0.56 & -0.30 & 5.99 \end{bmatrix} \times 10^{-5}$$

$$B_{03} = [-0.3216 \quad 0.4635 \quad 0.3503] \times 10^{-3}$$

$$B_{003} = 0.055$$

**Table A Generator data for two area system**

G <sub>ij</sub>	a <sub>ij</sub> (\$/h)	b <sub>ij</sub> (\$/MW h)	c <sub>ij</sub> (\$/(MW) <sup>2</sup> h)	P <sub>ij</sub> <sup>min</sup> (MW)	P <sub>ij</sub> <sup>max</sup> (MW)	Prohibited Zones(MW)
G <sub>1,1</sub>	550	8.1	0.00028	100	500	[210 240] [350 380]
G <sub>1,2</sub>	350	7.5	0.00056	50	200	[90 110] [140 160]
G <sub>1,3</sub>	310	8.1	0.00056	50	150	[80 90] [110 120]
G <sub>2,1</sub>	240	7.74	0.00324	80	300	[150 170] [210 240]
G <sub>2,2</sub>	200	8.00	0.00254	50	200	[90 110] [140 150]
G <sub>2,3</sub>	126	8.06	0.00284	50	120	[75 85] [100 105]

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