

Multi-Area Economic Dispatch with Multi Fuel Option 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 ,valve point loading effect and Multi fuel option. Improved bat algorithm is an optimization algorithm motivated by the echolocation behaviour of natural bats in finding their foods. Potency of the algorithm is tested on three area system with ten generating units 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, valve point loading effect, multi fuel, tie line constraint, Improved Bat Algorithm.

I. 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.

Shoultis 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

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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.

Bat algorithm (BA) [14-16] 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 inclusion of 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 test system. 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.

II. 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 [19].

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.

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

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

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 .

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.

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

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

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

$$P_{ij}^{\min} \leq P_{ij} \leq P_{ij}^{\max} \quad i \in N \quad j \in M_j \quad (5)$$

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

$$F_t = \sum_{i=1}^N \sum_{j=1}^{M_i} F_{ij}(P_{ij}) = \sum_{i=1}^N \sum_{j=1}^{M_i} a_{ij} + b_{ij}P_{ij} + c_{ij}P_{ij}^2 + |d_{ij} \times \sin \{e_{ij} \times (P_{ij}^{\min} - P_{ij})\}| \quad (6)$$

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

$$F_{ij}(P_{ij}) = a_{ijm} + b_{ijm}P_{ij} + c_{ijm}P_{ij}^2 + |d_{ijm} \times \sin \{e_{ijm} \times (P_{ijm}^{\min} - P_{ij})\}| \quad (7)$$

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

$$F_t = \sum_{i=1}^N \sum_{j=1}^{M_i} F_{ij}(P_{ij}) \quad (8)$$

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.

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III. 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

$$P_{iM_i} = P_{Di} + P_{Li} + \sum_{k, k \neq i} T_{ik} - \sum_{j=1}^{M_i-1} P_{ij} \quad (9)$$

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

$$P_{Li} = \sum_{l=1}^{M_i-1} \sum_{j=1}^{M_i-1} P_{lj} B_{ilj} P_{il} + 2P_{iM_i} \left(\sum_{j=1}^{M_i-1} B_{iM_i j} P_{ij} \right) + B_{iM_i M_i} P_{iM_i}^2 + \sum_{j=1}^{M_i-1} B_{0ij} P_{ij} + B_{0iM_i} P_{iM_i} + B_{00i} \quad (10)$$

Expanding and rearranging, equation (10) becomes

$$B_{iM_i M_i} P_{iM_i}^2 + \left(2 \sum_{j=1}^{M_i-1} B_{iM_i j} P_{ij} + B_{0iM_i} - 1 \right) P_{iM_i} + \left(\begin{array}{l} P_{Di} + \sum_{k, k \neq i} T_{ik} + \sum_{l=1}^{M_i-1} \sum_{j=1}^{M_i-1} P_{lj} B_{ilj} P_{il} \\ + \sum_{j=1}^{M_i-1} B_{0ij} P_{ij} - \sum_{j=1}^{M_i-1} P_{ij} + B_{00i} \end{array} \right) = 0 \quad (11)$$

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

IV. 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 1. Some guidelines are studied to enhance the structure of BAT algorithm and use the echolocation nature of bats.

- 1). Each bats identify the distance between the prey and background barriers using echolocation.
- 2). Bats fly randomly with velocity v_i at position x_i with a fixed frequency f_{min} (or Wavelength λ), varying wavelength λ (or frequency f) and loudness A_0 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.
- 3). Although the loudness of the bats can be modified in many ways, we consider that the loudness varies from a large (positive) A_0 to a minimum value A_{min} according to the problem taken.

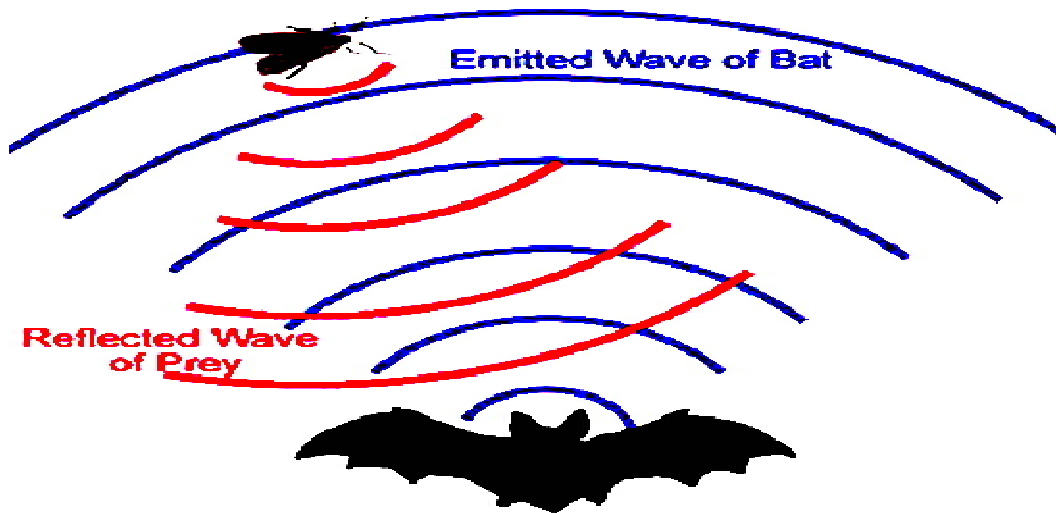


Fig.1.Ecolocation behaviour of bats

INITIALIZATION OF BAT POPULATION

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

$$x_{ij} = x_{minj} + \text{rand}(0,1) * (x_{maxj} - x_{minj}) \tag{12}$$

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

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.

$$f_i = f_{min} + (f_{max} - f_{min})\beta \tag{13}$$

$$v_i^t = v_i^{t-1} + (x_i^t - x^*)f_i \tag{14}$$

$$x_i^t = x_i^{t-1} + v_i^t \tag{15}$$

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.

$$x_{new} = x_{old} + \epsilon A^t \tag{16}$$

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

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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

$$A_i^{t+1} = \alpha A_i^t \quad (17)$$

$$r_i^{t+1} = r_i^0 [1 - e^{(-\gamma t)}] \quad (18)$$

Where α and γ 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 ($t <$ 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.

V. IMPROVED BAT ALGORITHM

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 [16].

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 (IBA).

$$\text{diff}_j = \sqrt{(x_{ij} - x_j^*)^2} \quad (19)$$

$$\text{range} = \max(\text{diff}) - \min(\text{diff}) \quad (20)$$

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$$f_j = f_{\min} + \frac{\sqrt{(\min(\text{diff}) - (\text{diff}_j))^2}}{\text{range}} * (f_{\max} - f_{\min}) \quad (21)$$

The distances between i_{th} solution and global best solution are calculated first then the frequency updating are assigned according to Eq. (21), so the frequency variation is depend on difference in distances as per the Eq. (19). 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. (22) must be updated as follows.

$$v_{ij}^t = v_{ij}^{t-1} + (x_{ij}^t - x_{ij}^*)f_j \quad (22)$$

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.

VI. SIMULATION RESULTS AND DISCUSSION

In this work an IBA algorithm is applied to solve the multi-area economic dispatch for three area system 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). This test system has ten generating units with valve point loading, multi fuel options and transmission losses are also considered.

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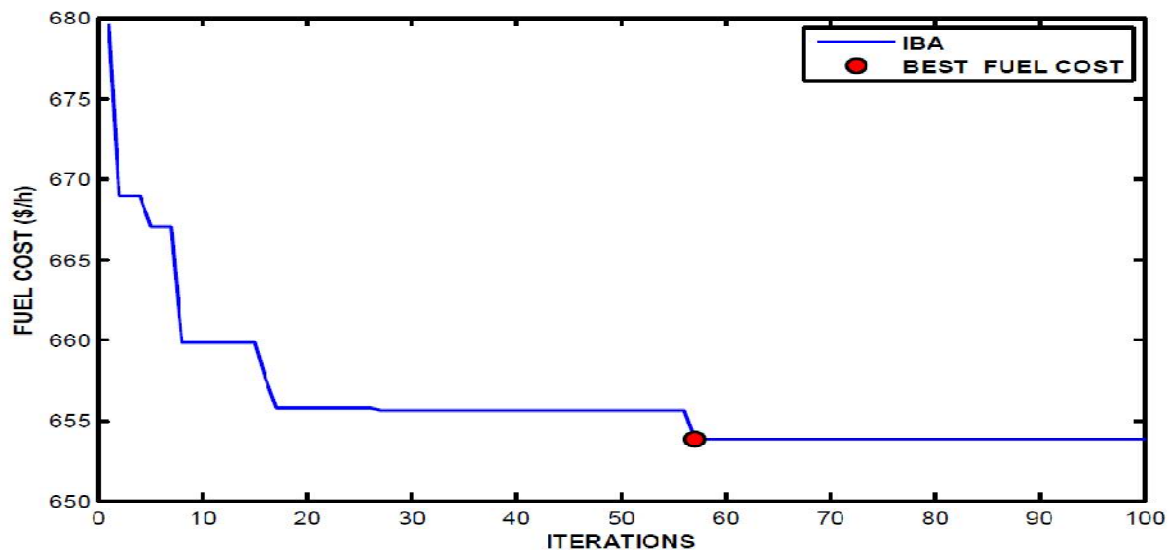


Fig.2.Convergence characteristics of IBA

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 three area generators [19] is given in Appendix . Result obtained from IBA is compared with other algorithms as per Table1,and the convergence characteristics of IBA is shown in Fig 2.and the parameter variation of bat algorithm is shown in fig.3 The result of comparison between IBA, ABCO, DE, EP and RCGA obtained shows that improved bat algorithm gives better result.

Table.1
Simulation result

	IBA		ABCO[19]		DE[19]		EP[19]		RCGA[19]	
	Fuel		Fuel		Fuel		Fuel		Fuel	
P _{1,1} (MW)	225.0009	2	225.9431	2	225.4448	2	223.8491	2	239.0958	2
P _{1,2} (MW)	211.1592	1	211.1594	1	210.1667	1	209.5759	1	216.1166	1
P _{1,3} (MW)	490.7469	2	489.9216	2	491.2844	2	496.068	2	484.1506	2
P _{1,4} (MW)	240.6234	3	240.6232	3	240.8956	3	237.9954	3	240.6228	3
P _{2,1} (MW)	254.1567	1	254.0397	1	251.0049	1	259.4299	1	259.6639	1
P _{2,2} (MW)	235.4925	3	235.4927	3	238.8603	3	228.9422	3	219.9107	3
P _{2,3} (MW)	263.8839	1	263.8837	1	264.0906	1	264.1133	1	254.514	1
P _{3,1} (MW)	237.0527	3	237.0006	3	236.9982	3	238.228	3	231.3565	3
P _{3,2} (MW)	328.737	1	328.7373	1	326.5394	1	331.2982	1	341.9624	1
P _{3,3} (MW)	248.8615	1	248.8607	1	250.3339	1	246.6025	1	248.2782	1
T ₂₁ (MW)	99.9931		99.8288		99.468		100		93.17	
T ₃₁ (MW)	99.7337		99.7334		100		100		93.8739	
T ₃₂ (MW)	31.3138		31.2615		30.281		32.5231		43.7824	
P _{L1} (MW)	17.2572		17.2095		17.268		17.4884		17.0297	

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P_{L2} (MW)	9.8538	9.8488	9.7688	10.0085	9.701
P_{L3} (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

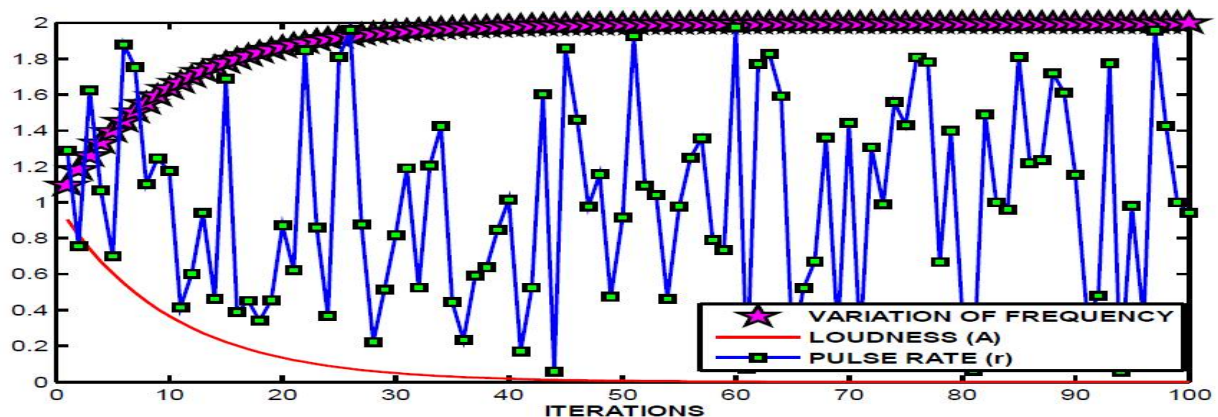


Fig.3.Parameter variation of IBA

VII. CONCLUSION

In this paper, IBA is applied to Multi-area economic load dispatch problem with three area system. 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.

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