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Multi-Area Economic Dispatch with Valve Point Effect 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 and valve point loading effect. 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 four area system with forty 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 , 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.

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

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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 inclusion of valve point effect 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 [24].

A. *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 jth 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, Mi 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.

1) *Active power balance constraint*

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

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) *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.

$$-T_{ik}^{max} \leq T_{ik} \leq T_{ik}^{max} \quad (3)$$

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.

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

$$P_{ij}^{min} \leq P_{ij} \leq P_{ij}^{max} \quad i \in N \quad j \in M_j \quad (4)$$

B. *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. Wire 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

$$F_t = \sum_{i=1}^{N}\sum_{j=1}^{M_i} F_{ij}(P_{ij}) = \sum_{i=1}^{N}\sum_{j=1}^{M_i} a_{ij} + b_{ij}P_{ij} + c_{ij}P_{ij}^2 + \left|d_{ij} \times \sin\{e_{ij} \times (P_{ij}^{min} - P_{ij})\}\right| \quad (5)$$

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III. 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.

Each bats identify the distance between the prey and background barriers using echolocation.

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_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.

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.

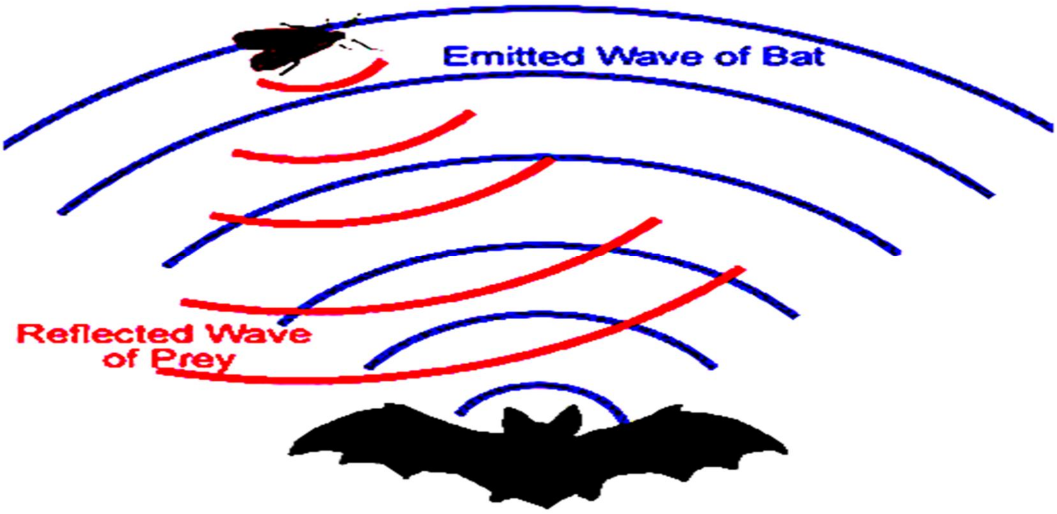

Fig.1.Ecolocation behaviour of bats

A. Initialization of Bat Population

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

$$x_{ij} = x_{min\,j} + rand(0,1) * (x_{max\,j} - x_{min\,j}) \tag{6}$$

Where *i*=1, 2…*n, j*=1, 2….*d*, $x_{min\,j}$ and x_{maxj} 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.

$$f_i = f_{min} + (f_{max} - f_{min})\beta \tag{7}$$

$$v_i^t = v_i^{t-1} + (x_i^t - x^*)f_i \tag{8}$$

$$x_i^t = x_i^{t-1} + v_i^t \tag{9}$$

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.

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$$x_{new} = x_{old} + \varepsilon A^t \quad (10)$$

Where A^t, is average loudness of all bats, $\varepsilon \in [0, 1]$ 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

$$A_i^{t+1} = \alpha A_i^t \quad (11)$$

$$r_i^{t+1} = r_i^0\left[1 - e^{(-\gamma t)}\right] \quad (12)$$

Where α and γ are constants. ri^0 and A_i are factors which consist of random values and Ai^0 can typically be [1, 2], while ri^0 can typically be[0,1].

D. Pseudo Code of Bat Algorithm

1) Objective function: f(x), $x=(x_1\ldots.x_d)^t$.
2) Initialize bat population x_i and velocity v_i i=1, 2...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** (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** (rand< Ai and f(xi)< f(x*)).
12) Accept new solutions.
13) Increase r_i, reduce Ai.
14) **End if.**
15) Ranks the bats and find current best x*.
16) **End while.**
17) Display results.

IV. 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.

$$diff_j = \sqrt{(x_{ij} - x_j^*)^2} \quad (13)$$

$$range = \max(diff) - \min(diff) \quad (14)$$

$$f_j = f_{min} + \frac{\sqrt{(\min(diff) - (diff_j))^2}}{range} * (f_{max} - f_{min}) \quad (15)$$

The distances between i_{th} solution and global best solution are calculated first then the frequency updating are assigned

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according to Eq. (16), so the frequency variation is depend on difference in distances as per the Eq. (14).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. (16) must be updated as follows.

$$v_{ij}^{t} = v_{ij}^{t-1} + \left(x_{ij}^{t} - x_{ij}^{*}\right)f_j \qquad (16)$$

A. 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. (14-16).
4).Define loudness A_i and the initial velocities v_i (i= 1, 2, . . . , N); Set pulse rate r_i.
5).While (t<maximum number of iterations)
6).Evaluate objective function for generating new solutions by varying the frequency and update velocity Eq.(14-16).
7).**If** (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** (rand< A_i and $f(x_i)$< $f(x^*)$)
12).Accept new solutions
13).Increase r_i, reduce A_i
14).**End if**

V. SIMULATION RESULTS AND DISCUSSION

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, 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 RGCA obtained from Table 3 shows that improved bat algorithm gives better result.

Table 3 Simulation result

Power(MW)	IBA	ABCO[24]	DE[24]	EP[24]	RCGA[24]
$P_{1,1}$	112.6745	111.102	93.0826	114	94.0855
$P_{1,2}$	111.3751	109.9774	109.0592	114	47.7313
$P_{1,3}$	101.6238	100.9238	89.7493	63.7726	85.4353
$P_{1,4}$	190.7	190	116.9489	138.8847	131.2807
$P_{1,5}$	97.639	96.939	97	75.3245	79.1771
$P_{1,6}$	97.6675	96.9675	140	106.4216	131.4026
$P_{1,7}$	260.395	259.695	283.7266	300	176.5484
$P_{1,8}$	276.7	276.8725	286.2646	300	232.6707
$P_{1,9}$	300.7	300	284.9088	284.9513	292.1746
$P_{1,10}$	130.7	130.6977	131.6349	136.7335	130.1531
$P_{2,1}$	244.4007	245.1007	169.8738	175.3639	340.9307
$P_{2,2}$	93.3	94	110.9708	94	185.7976
$P_{2,3}$	124.3	125	229.8845	263.8126	462.1471
$P_{2,4}$	434.1062	434.8062	387.4742	331.0545	391.6765
$P_{2,5}$	389.9743	390.6743	427.7543	394.2191	376.9261
$P_{2,6}$	394.3043	395.0043	478.278	413.0955	484.3564
$P_{2,7}$	499.3	500	490.1819	499.6763	481.2045

$P_{2,8}$	499.3	500	490.9476	500	421.9451
$P_{2,9}$	530.0889	530.7889	511.9152	533.8328	469.0019
$P_{2,10}$	513.709	514.409	511.8241	508.9305	511.2801
$P_{3,1}$	527.1275	527.1989	547.6323	520.6865	513.063
$P_{3,2}$	502.0081	502.0795	523.4937	531.7618	513.8375
$P_{3,3}$	530.2943	530.3657	522.6286	550	524.4524
$P_{3,4}$	542.271	542.3424	545.9437	531.7377	524.9246
$P_{3,5}$	520.1734	520.2448	523.6608	526.753	495.4096
$P_{3,6}$	533.5675	533.6389	527.3677	550	442.885
$P_{3,7}$	10	10	10	10	51.706
$P_{3,8}$	10	10	15.7851	10	42.4448
$P_{3,9}$	10	10	10	10	47.9812
$P_{3,10}$	96.6985	96.7699	93.0253	89.7589	95.5812
$P_{4,1}$	190	190	190	173.5365	149.1883
$P_{4,2}$	168.7555	168.6841	157.8968	190	159.4065
$P_{4,3}$	173.6879	173.6165	190	116.431	161.6999
$P_{4,4}$	186.4454	186.374	200	180.6554	167.5135
$P_{4,5}$	200	200	90	162.0916	172.422
$P_{4,6}$	165.0284	164.957	149.454	173.092	179.221
$P_{4,7}$	92.6341	92.5627	110	109.4254	91.9333
$P_{4,8}$	97.0625	96.9911	88.163	74.3342	92.5453
$P_{4,9}$	109.8153	109.8153	25	99.6914	89.0354
$P_{4,10}$	431.4725	431.4011	538.4695	541.9711	458.8239
T_{12}	198.6246	191.7078	200	200	-118.736
T_{13}	6.424	6.674	91.5412	94.6831	-25.9549
T_{32}	182.9355	183.1852	147.8992	186.0147	174.0405
T_{41}	87.1918	86.859	51.0838	46.2286	81.5599
T_{42}	95.4904	95.3237	42.9964	100	19.429
T_{43}	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

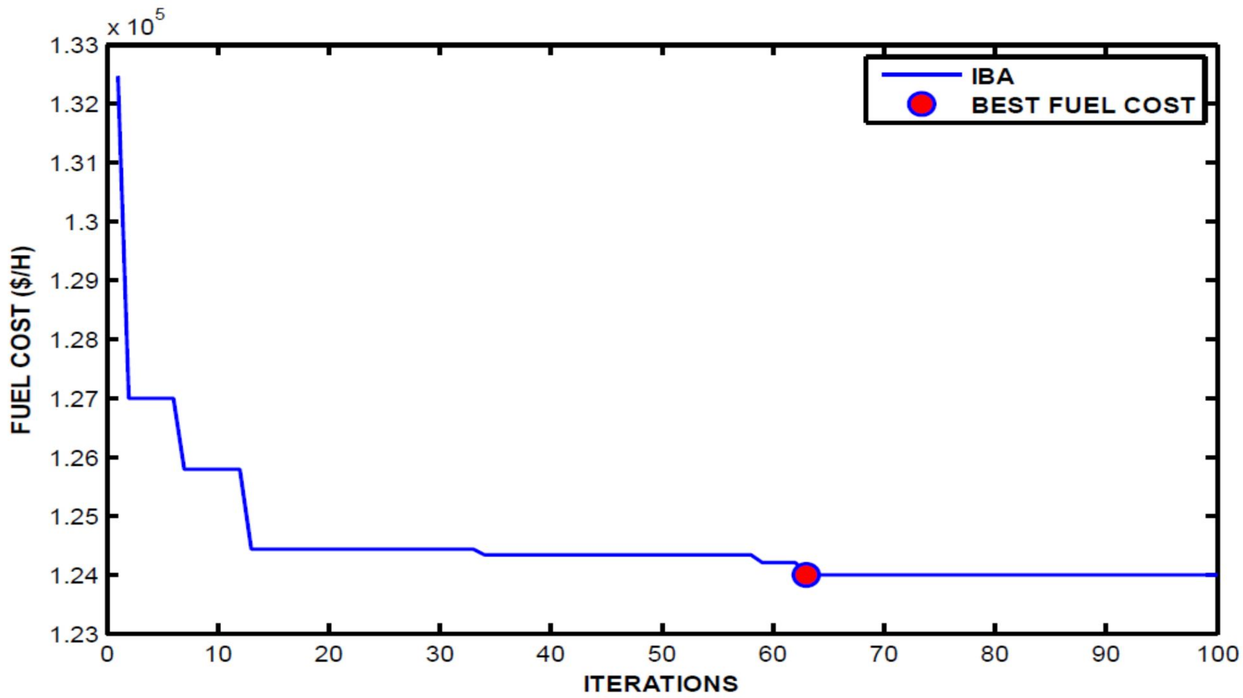

Fig.2. Convergence characteristics of IBA

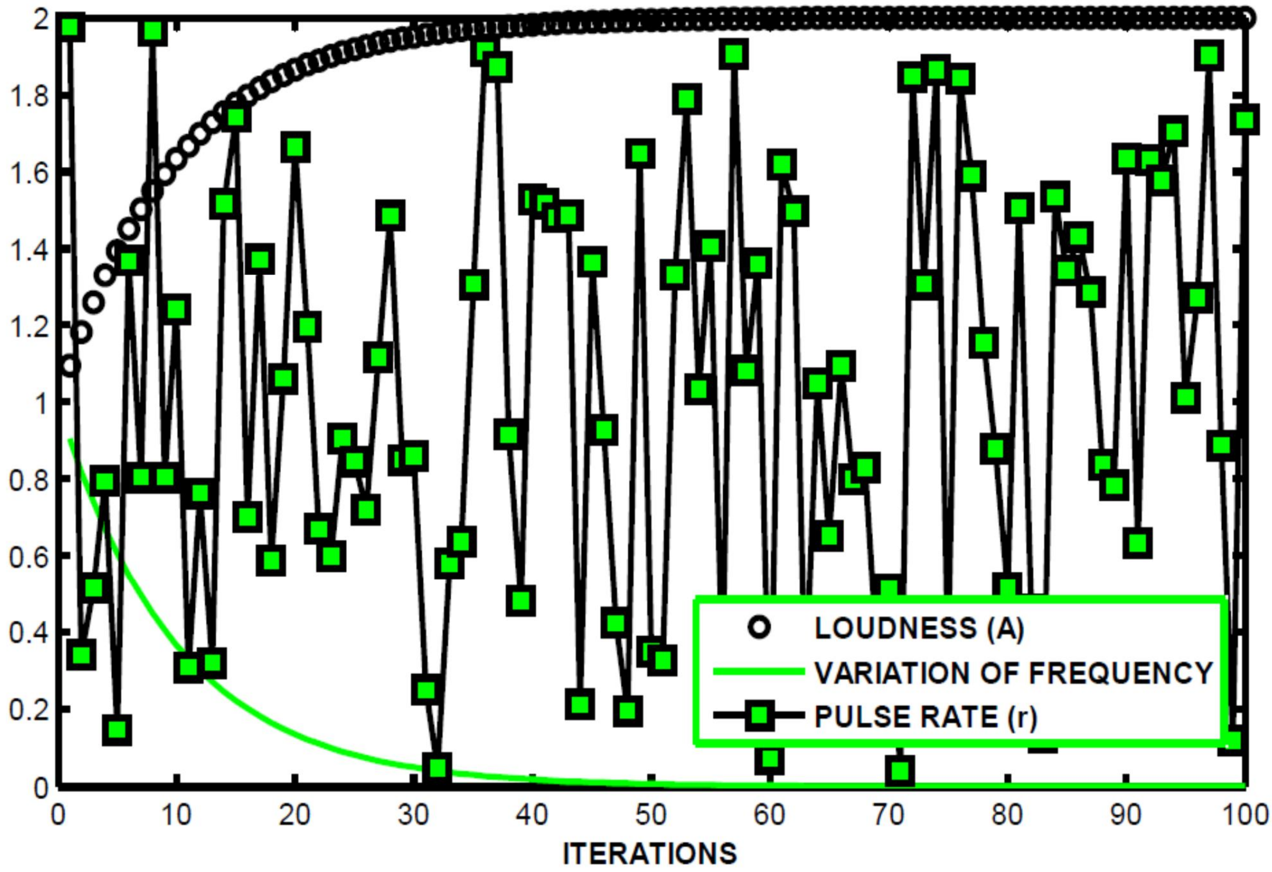

Fig.3.parameter variation of IBA

VI. CONCLUSION

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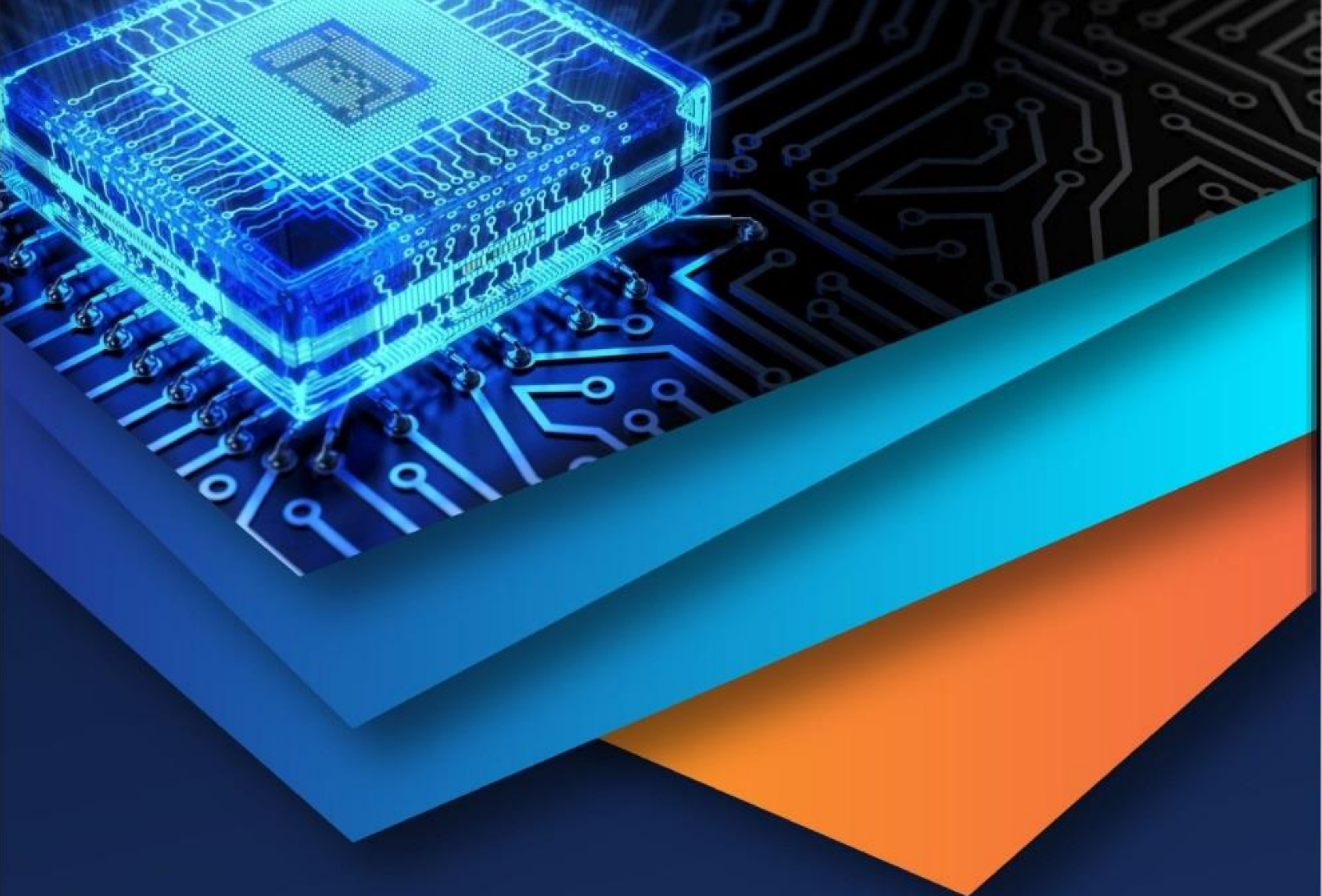

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