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Formulation of Improved Grey Wolf Optimization Methodology for ELD Problem

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Abstract-In this paper, a new meta-heuristic technique IGWO(Improved Grey Wolf Optimization) is being formulated to solve Economic Load Dispatch Problem. And the results have been compared with single objective GWO for three unit system with 9 bus-system and for six unit system with 30 bus-system. Furthermore the proposed algorithm obtains competitive performance compared to other proposed techniques.

Index Terms- IGWO (Improved Grey Wolf Optimizer);ELD (Economic Load Dispatch); GWO(Grey Wolf Optimizer)

1. INTRODUCTION

In power system, the economic load dispatch problem arose when two or more generating units mutually produced the electrical power which goes beyond the required generation. Engineers resolve this problem by executing that how to divide the load among the committed generating units. Two third of the electrical power generated in India is from coal based power stations. The electricity generated from fossil fuel release several pollutants, such as Nitrogen Oxides (NO_x), Sulphur Oxides (SO_x) and Carbon Dioxide (CO_2) into atmosphere. These cause harmful effects to human healthiness and the class of life.. But this load allocation may boost the cost of operation of the generating units. So, it is necessary to find out solutions which give an impartial result among cost and emission. This possibly will be accomplished by Combined Economic Emission Dispatch problem.

Many traditional methods including linear programming method, gradient method, Newton Raphson method and lambda iteration method have been applied to solve ELD problem. The ELD problem has been also solved by the technique of dynamic programming but it suffers from the problem of dimensionality. Some of the meta-heuristic techniques such as differential evolution, particle swarm optimization, tabu search, harmony search, cuckoo search, GWO (Grey Wolf Optimization) have been applied to solve ELD problem. In this paper, a new meta-heuristic technique Improved GWO has been formulated to solve the ELD problem.

2. OBJECTIVE OF ELD

The main objective of the problem of ELD is to minimize the total cost that is generated while satisfying the different constraints, when the required power load is being supplied. The objective function that has to be minimized is given by the following equations:

$$F(P_g) = \sum_{i=1}^{n} (a_iP_{gi}^2 + b_iP_{gi} + c_i)$$

Where a_i, b_i, c_i are the coefficient of fuel cost of ithgenerator,Rs/MW^2 h, Rs/MW h, Rs/h

and $F(P_g)$ is the total fuel cost in Rs/h

The overall fuel cost has to be reduced with the following constraints:

- Power balance constraint: The total generation must be equal to the total power demand and the system's power losses.
  $$\sum_{i=1}^{n} P_{gi}– P_d- P_l$$

Where P_l and P_d are the transmission losses and the power demand in MW

- Generator limit constraint: The power generation of each generator has to be controlled within its particular upper and lower operating limits.
  $$\sum_{i=1}^{n} P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} ;i= 1,2,….ng$$

Where $P_{gi}^{min}$is the minimum limit of generator for ith generator in MW and$P_{gi}^{max}$is the maximum limit of generation for ith generator in MW

3. GWO (GREY WOLF OPTIMIZATION)

GWO algorithm was primarily proposed by Syed Mohammad Mirajili. A grey wolf is characterized by powerful teeth, bushy tail and grey wolves hunt in a pack which has an average group size of 5-12. Their natural habitats are found in the mountains, forests and plains of North America, Asia and Europe. GWO algorithm consists of four models which are as follows:

3.1 **Social Hierarchy**- The hierarchy of the grey wolves exist in a pack in which 'α' is the leader and the most dominant one & takes the important decisions, 'β' and 'δ' are subordinates & assists 'α' in decision making and the rest are the omega which have to follow the directions given by 'α', 'β', and 'δ'.

3.2 **Encircling Prey-** The mathematical modelling involved in encircling prey is represented by following equations :

$$D = | CX_p - AX(t) \quad ....(1)$$

$$X(t+1) = X_p(t) – AD \quad ......(2)$$

Where A and C are coefficients vectors given by :

$$A = 2 a*r_1*a \; ..... (3)$$

$$C = 2*r_2 \; .... (4)$$

t is the current iteration

X is the position vector of a wolf

r_1 and r_2 are random vectors € [0,1] and 'a' linearly decreases from 2 to 0

3.3 **Hunting-**The hunting mechanism of the grey wolves involves the following steps:

- ✓ Tracking, chasing and approaching the prey.
- ✓ Pursuing, encircling and harassing the prey until the time it stops moving.
- ✓ Finally, attacking the prey.

However in abstract search space, we have no idea about the location of the optimum (prey).In order to mathematically simulate the hunting behaviour, we assume that the alpha, beta and delta have better knowledge about the potential location of the prey as follows:

$D_\alpha = C_1.X_\alpha−X$

$D_\beta= C_2.X_\beta−X,$

$D_\delta= C_3.X_\delta−X$ …. (8)

$X_1=X_\alpha−A_1.(D_\alpha)$

$X_2=X_\beta−A_2.D_\beta$

$X_3=X_\delta−A_3.(D_\delta)$ ….(9)

$$X (t+1) = \frac{(X_1+X_2+X_3)}{3} …(10)$$

Where t is the current iterationandX_α, X_β and $X_\delta$are the position vector of the grey wolves α , β and δ.

3.4 **Attacking prey and search for prey (exploitation and exploration) -** The ability of the grey wolves may result in the global optima; which is the exploitation ability. Since the value of *a* decreases from 2 to 0, *A* is also simultaneously decreased. *A* is a random value in the interval [-2*a*, 2*a*]. When **|A|** < **1**, the grey wolves are forced to attack the prey. The random values of *A* are used to indulge the search agent to diverge from the prey. When **|A|** > **1**, the grey wolves are forced to diverge from the prey.

4. AN IMPROVED GREY WOLF OPTIMIZATION(IGWO) ALGORITHM

The agent's movement in GWO depends significantly on the circumstances of the alpha, beta and delta. Fig. (1) below shows how a search agent is updating its position. In this paper, we added a new approach to calculate the vectors D'_α, D'_β, D'_δ which willbe helpful for a search agent to have more exploration ability and it will not get trapped in the local optima. The update position can be calculated as follows:

$D'_{\alpha} = | C_1 . Xr_1 - Xr_3 |$

$D'_{\beta} = | C_2 . Xr_2 - Xr_1 |$

$D'_{\delta} = | C_3 . Xr_3 - Xr_1 |$ …..(11)

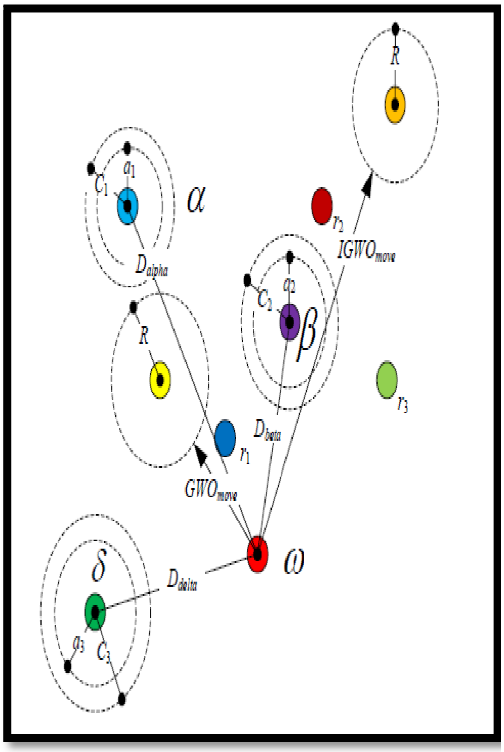
$X'_{1} = X_{\alpha} - A_1 . (D'_{\alpha})$

$X'_{2} = X_{\beta} - A_2 . (D'_{\beta})$

$X'_{3} = X_{\delta} - A_3 . (D'_{\delta})$…. (12)

$X'(t+1) = \frac{X'_{1} + X'_{2} + X'_{3}}{3}$….(13)

The pseudo code of IGWO algorithm has been shown in figure (2), the differences between the standard GWO and the IGWO have been highlighted by " » ".



'Figure (1) showing position of omega (**ω**) or any other hunters in GWO & IGWO'

Initialize the grey wolf population X_i(i = 1,2,…..n)

Initialize a, A and C

Calculate the fitness of each search agent

X_{α} = the best search agent

X_{β} = the second best search agent

X_{δ}= the third best search agent

While(t< Max number of iterations)

for each search agent

» **if** |A| < 1

» Calculate vectors D_{α}, D_{β} and D_{δ} by equation (8)

» **else**

» Calculate vectors D'_{α}, D'_{β} and D'_{δ} by equation (11)

» **end if**

Update the position of the current search agents by equation (10) or (13) depending upon the selected strategy.

end for

Update a and C by (4) and
A is updated by using (3)
Calculate the fitness of all search agents
Update X_{α}, X_{β}, X_{δ}
T = t + 1

end while

Return Xα

'Figure (2) showing Pseudo- Code of IGWO'

Formulation of Improved GWO methodology for ELD problem involves the following steps:

Step I: Implementation

The main task of ELD is to allocate the load demand among participating generators at minimum possible cost without violating any system constraints. The ED problem is formulated by Eq. (i) and transmission losses are formulated by Eq. (ii)

$$F_t = \sum_{i=1}^{n} A_i P_{gi}^2 + B_i P_{gi} + C_i \text{ (i)}$$

$$P_L = \sum_{i=1}^{n} P_{gi} B_{ij} P_{gj} + \sum_{i=1}^{n} B_{0i} P_{gi} + B_{00} \text{ (ii)}$$

Step II: Improved Grey Wolf Pack Representation

Real power generations are the decision variable for ELD problem. Let if there are NG generators in the system, the representation of the wolf position would be described in the form of vector length NG. Let NP wolves are taken in the pack, the representation of complete pack in the matrix form as noted below:

$$\text{Pack} = \begin{bmatrix} P_{11} & P_{12} & \dots & P_{1NG} \\ P_{21} & P_{22} & \dots & P_{2NG} \\ \dots & \dots & P_{ij} & \dots \\ P_{NP1} & P_{NP2} & \dots & P_{NPNG} \end{bmatrix} \dots\text{(iii)}$$

Step III: Pack Initialization

The initialization of each element of above described pack matrix is occurred randomly within capacity constraints depend upon Eq. (iv). The initialization of the wolf positions is done through this inequality:

$$P_j^{min} < P_{ij} < P_j^{max}$$

(i=1,2..NP;j=1,2...NG)……..(iv)

$$P_i = P_i^{min} + rand(\quad)(P_i^{max} - P_i^{min}) \text{..(v)}$$

Step IV: Evaluation of Objective function

To satisfy energy constraints, one of the committed generators is chosen as a dependent/slack generator d and this is obtained by:

$$P_d^j = Z^j \text{(i=1, 2...NP; j= 1, 2...NG)} \quad \text{(vi)}$$

Where

$$Z = P_d - \sum_{i=1, i\neq d}^{NG} P_i \dots \text{ (vii)}$$

If there is the violation of the operating limits by the production of the dependent/slack generator then it is set by equation :

$$P_i^j = \begin{cases} P_i^{min}; & P_i^j < P_i^{min} \\ P_i^{max}; & P_i^j > P_i^{max} \\ P_i^j; P_i^{min} < P_i^j < P_i^{max} & \end{cases}$$

(i=1,2...NG ; i≠ d; j= 1,2..L)..(viii)

After restraining the value of dependent generator, a penalty term is set up in objective function. Therefore the function is defined by:

$$f^j = F(P_i^j) + \emptyset \quad \dots \text{ (ix)}$$

Step V: Encircling the prey

The encircling behaviour can be mathematically modelled as follows:

$$\vec{D} = \left|\vec{C}.\vec{P}_p(t) - \vec{P}(t)\right| \dots \text{ (x)}$$

$$\vec{P}(t+1) = \vec{P}_p(t) - \vec{A}.\vec{D} \dots \text{ (xi)}$$

Where $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{P}_p$ is the prey's position vector, $\vec{P}$denotes the grey wolf's position vector and t is the current iteration.

The calculation of vectors A and C is done as follows:

$$\vec{A} = 2.\vec{a}.\vec{r}_1.\vec{a} \dots \text{ (xii)}$$

$$\vec{C} = 2.\vec{r}_2 \dots \text{ (xiii)}$$

Where values of '$\vec{a}$'are linearly reduced from 2 to 0 during the course of iterations and r_1, r_2 are arbitrary vectors in [0, 1].

Step VI: Improved Grey Wolf Movement & Updating the position

Grey wolves have the capability to identify the position of prey and encircle them. The other wolves must update their positions according to best wolf position. The update of their agent position can be formulated as follows:

$$\vec{D}_\alpha = |\vec{C}_1.\vec{P}_\alpha - \vec{P}|\ ,\vec{D}_\beta = |\vec{C}_2.\vec{P}_\beta - \vec{P}|\ ,\vec{D}_\delta = |\vec{C}_3.\vec{P}_\delta - \vec{P}|$$

$$\vec{P}_1 = \vec{P}_\alpha - \vec{A}_1.(\vec{D}_\alpha),\vec{P}_2 = \vec{P}_\beta - \vec{A}_2.(\vec{D}_\beta)\ ,\vec{P}_3 = \vec{P}_\delta - \vec{A}_3.(\vec{D}_\delta)$$

$$\vec{P}(t+1) = \frac{\vec{P}_1 + \vec{P}_2 + \vec{P}_3}{3}$$

Position updating of the search agent according to beta, alpha and delta in a two dimensional search space is shown in fig.1 shown above.

IGWO agent position updating:

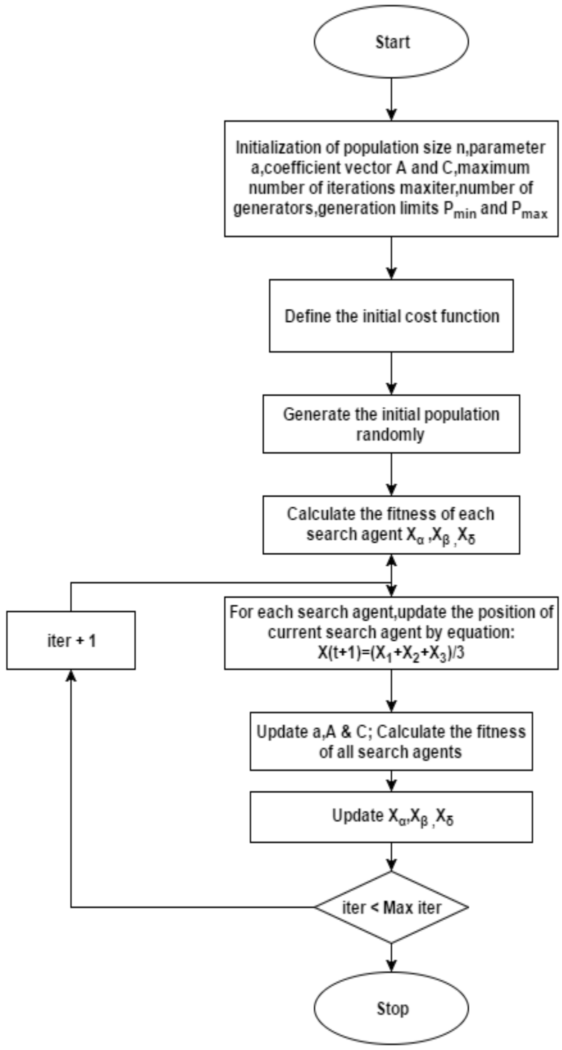
$$\vec{D'}_\alpha = |\vec{C}_1.\vec{P}_{r1} - \overrightarrow{P_{r3}}|\ ,\vec{D'}_\beta = |\vec{C}_2.\vec{P}_{r2} - \overrightarrow{P_{r1}}|\ ,\vec{D'}_\delta = |\vec{C}_3.\vec{P}_{r3} - \overrightarrow{P_{r1}}|$$

$$\vec{P'}_1 = \vec{P}_\alpha - \vec{A}_1.(\vec{D'}_\alpha),\vec{P'}_2 = \vec{P}_\beta - \vec{A}_2.(\vec{D'}_\beta)\ ,\vec{P'}_3 = \vec{P}_\delta - \vec{A}_3.(\vec{D'}_\delta)$$

$$\vec{P}'(t+1) = \frac{\vec{P'}_1 + \vec{P'}_2 + \vec{P'}_3}{3}$$

Step VII: Stopping Criterion

A stochastic optimization approach can be terminated by many criterions at hand. Some of them are maximum no. of iterations, no. of functions evaluations and tolerance. In the present case, maximum no. of iteration is taken for this task.



'Flowchart of IGWO'

5. *RESULTS AND DISCUSSIONS:*

(ELD with transmission losses)

(5.1) <u>Case 1: Three unit system</u>

The IGWO algorithm has been implemented on a system consisting of three generator units with transmission loss. The population number is set to 30 and maximum number of iterations performed is 500. The ELD result is shown in table 2 in which various columns represent power demand, allocation of loads, power loss and fuel cost. Table 3 shows the comparison of IGWO method with other methods and the convergence curve of fuel cost is shown in the figure 3.

Table 1.Generating unit data for test case I

Unit	a_i	b_i	c_i	P_{gi}^{min}	P_{gi}^{max}
1	0.03546	38.30553	1243.5311	35	210
2	0.02111	36.32782	1658.5696	130	325
3	0.01799	38.27041	1356.6592	125	315

$$B_{mn} = \begin{bmatrix} 0.000071 & 0.000030 & 0.000025 \\ 0.000030 & 0.000069 & 0.000032 \\ 0.000025 & 0.000032 & 0.000080 \end{bmatrix}$$

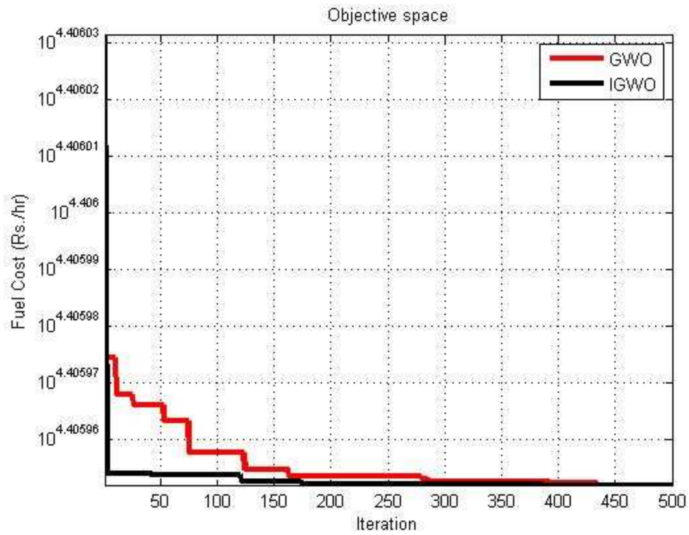
Where $B_{mn}$is loss coefficient matrix and is derived from reference [18] and also givenin the above table 1

Table 2.ELD using IGW0 for 3-unit system

Sr.no	**Method**	**Power demand (MW)**	P_1**(MW)**	P_2**(MW)**	P_3**(MW)**	P_L**(MW)**	**Fuel Cost (Rs/hr)**
1	GWO	350	70.2909156	156.273451	129.212702	5.77706865	18564.48400014865
	IGWO		70.3109238	156.262282	129.203690	5.77689684	18564.48399949439
2	GWO	450	93.9033202	193.782924	171.926898	9.61314331	23112.36364959517
	IGWO		93.9385261	193.767679	171.906550	9.61275586	23112.36358629148
3	GWO	500	105.940338	212.627333	193.346108	11.9137811	25465.46954033266
	IGWO		105.845787	212.760656	193.308321	11.9147654	25465.46920953829

Table 3.Comparison of fuel cost with other techniques for 3-unit system

Sr.no.	**Power demand (MW)**	**Fuel Cost (Rs/hr)**			
		Lambda Iteration Method [18]	**CSA [18]**	**GWO[29]**	**IGWO**
1	350	18570.7	18564.5	18564.4840	18564.4839
2	450	23146.8	23112.4	23112.3636	23112.3635
3	500	25495.2	25465.5	25465.4695	25465.4692



'Figure 3 showing convergence curve for three generators for 500 MW demand'

(5.2) <u>Case 2: Six unit system</u>

The IGWO algorithm has been implemented on a test system of six generator units. The ELD result is shown in table 5 in which various columns represent method used, power demand, allocation of loads, power loss and fuel cost. Table 6 shows the comparison of IGWO method with other methods and the convergence curve of fuel cost is shown in figure 4.

Table 4.Generating unit data for test case II

Unit	a_i	b_i	c_i	P_{gi}^{min}	P_{gi}^{max}
1	0.15240	38.53973	756.79886	10	125
2	0.10587	46.15916	451.32513	10	150
3	0.02803	40.39655	1049.9977	35	225
4	0.03546	38.30553	1243.5311	35	210
5	0.02111	36.32782	1658.5596	130	325
6	0.01799	38.27041	1356.6592	125	315

$$B_{mn}=\begin{bmatrix} 0.000014 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \\ 0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\ 0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\ 0.000019 & 0.000016 & 0.000017 & 0.000072 & 0.000030 & 0.000025 \\ 0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\ 0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000085 \end{bmatrix}$$

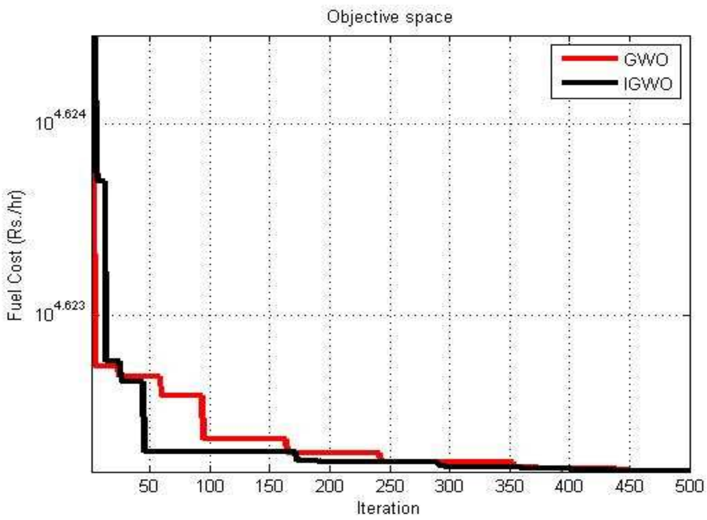
Where $B_{mn}$is the loss coefficient matrix and is derived from reference [18] and given in the table 4.

Table 5.ELD using IGWO for 6-unit system

Sr. No	Method	Power Demand (MW)	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (MW)	P_L (MW)	Fuel cost(Rs/h)
1	Conventional[17]	600	23.90	10.00	95.63	100.70	202.82	182.02	15.07	32069.58
	CS[18]		23.860	10	95.6389	100.708	202.832	181.198	14.2374	32094.7
	GWO[29]		23.826	10	95.835	100.727	202.597	181.248	14.2341	32094.6810
	IGWO		23.820	10	95.631	100.749	202.417	181.218	14.2378	32094.6787
2	Conventional[17]	700	28.33	10.00	118.95	118.67	230.763	212.80	19.50	36914.01
	CS[30]		28.351	10.00	118.887	118.675	230.763	212.745	19.4319	36912.2
	GWO[29]		28.312	10.003	118.950	119.190	230.252	212.714	19.424	36912.1620
	IGWO		28.235	10.002	118.952	118.628	230.784	212.830	19.434	36912.1465
3	Conventional[17]	800	32.63	14.48	141.54	136.04	257.65	243.00	25.34	4898.45
	CS[18]		32.586	14.484	141.548	136.045	257.664	243.009	25.3309	41896.7
	GWO[29]		32.756	13.684	141.925	136.278	257.808	242.893	25.34737	41896.7089
	IGWO		32.533	14.305	141.507	135.992	257.841	243.1620	25.3423	41896.6341

Table 6.Comparison of fuel cost with other techniques for six unit system

Sr.no.	Power demand (MW)	Fuel Cost (Rs/hr)					
		Lambda Iteration Method[18]	Conventional Method[17]	PSO[17]	CSA[18]	GWO[29]	IGWO
1	600	32129.8	32096.58	32094.69	32094.7	32094.6810	32094.6787
2	700	36946.4	36914.01	36912.16	36912.2	36912.162	36912.1465
3	800	41959.0	41898.45	41896.66	41896.9	41896.731	41896.6720



‘Figure.4 showing convergence curve for six generators for 800 MW demand’

6. CONCLUSION

In this paper, ELD problem has been solved by using IGWO. The results of IGWO are being compared for three and six generating unit system with the other techniques. The algorithm has been programmed in MATLAB(R2009b) software package. The results clearly show effectiveness of IGWO for solving the problem of economic load dispatch. The advantages of IGWO algorithm are simple structure, good reliability, fast convergence, better efficiency for practical applications and also the mechanism of balance between exploration and exploitation ability has been taken into account.

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