ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 7, Issue 3, March 2018

Design and Development of Grey Wolf Optimization Algorithm to Solve Economic Dispatch Problem

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ABSTRACT*:* With a specific ultimate objective to take care of economic dispatch issue in a helpful way, GWO algorithm is actualized in this paper. The conservative dispatch intends to locate the aggregate power generation of different units in a plant at least cost. This paper, for the most part, intends to limit the aggregate cost of power generation by utilizing GWO algorithm. In the meantime, this algorithm is focused on enhancing the effectiveness of power generation and it is focused on taking care of the power demand. The monetary dispatch issue is a vital streamlining issue in scheduling the generation of thermal generators in power system. The proposed procedure is executed on IEEE standard six unit and fifteen unit test frameworks. The acquired outcome by utilizing this algorithm is contrasted with PSO-ANFIS technique has been finished. The outcomes inform the highness of GWO algorithm among different strategies to take care of economic dispatch issue.

KEYWORDS: Economic dispatch problem; quadratic cost function; prohibited operating zones; ramp rate limit; valve point effect; grey wolf optimization

I. INTRODUCTION

The economic load dispatch is used to distribute the power demand among the generating units in the most sparing way while satisfying all the equality and inequality constraints of electric power generation. The power generation of existing units is properly allocated to save the cost. In the past few decades, number of approaches such as gradient method, Newton's method, lambda iteration method [1] etc., were developed to solve this problem. These methods are fast and trustworthy but it is difficult to find an optimal solution for practical economic load dispatch problems. In mathematically, the global optimal solutions are not achieved at so easy. So that, more intelligent methods such as Evolutionary Programming (EP), Differential Evolution (DE), Genetic Algorithm (GA) etc., [2] are developed by the researchers. These intelligent methods which have iterative procedure avoid the local optimal solutions and find global optimal solutions. In EP approach, it does not need the large computer memory but it needs appropriate preferment of control parameters to obtain an optimal solution. The stochastic search algorithms such as Hopfield Neural Network (HNN), Adaptive Hopfield Neural Network (AHNN) and Simulate Annealing (SA) are used to solve the non-convex economic dispatch problem but these algorithms require more time for execution. In DE algorithm [3], it has become robust and efficient but it adopts mutation, crossover and selection operators. It may take some time to achieve the global optimal solutions. Likewise, GA also depends on crossover, mutation and selection operators. The proper selection of input parameter in GA should be considered. If the selection is improper, the performance will degrade. To improve the performance of conventional GA, other GAs such as hybrid GA, improved GA and self-adaptive real-coded GA are proposed. Particle Swarm Optimization (PSO) technique is a robust technique in the last two decades. PSO [4] is inspired by the social analogy of swarm behavior in the population of natural organisms such as a flock of birds or a school of fish. The conventional PSO after attaining the few iterations, the most particles concentrate towards the specific position and it is very difficult to separate the particles from its local optimal point. In order to improve the

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PSO technique, the conventional PSO is modified such as Hybrid PSO (HPSO), PSO-ANFIS [5] and Gaussian and Chaotic PSO [6]. Nowadays, number of various optimization techniques is proposed to solve the economic load dispatch problem. They are named as Chaotic Ant Swarm Optimization (CASO), Bacteria Foraging Optimization (BFO), Ant Colony Optimization (ACO), Gravitational Search Algorithm (GSA) and Biogeography Based Optimization (BBO). These techniques are able to provide an efficient solution but it does not obtain fast convergence rate and it has several parameter tunings.

In this paper, GWO [7] algorithm has been used which is a powerful and newly emerged technique. This technique is inspired by the grey wolves. It mimics the leadership hierarchy and hunting mechanism of grey wolves. This technique has successfully applied in various power systems optimization problems, recently. It can highly improve the converging speed and obtain an optimal solution easily. The GWO algorithm is the best conveying mechanism and it considers three candidate solutions randomly to get better results. It converges quickly by jumping from local optimal solution towards a global optimal solution. The proposed GWO approach is applied to solve IEEE six unit and 15 unit test systems to justify the effectiveness of this method. The performance of this solution results is compared with PSO-ANFIS technique.

II. ECONOMIC DISPATCH PROBLEM FORMULATION

In power system, the economic load dispatch is one of the most important optimization problems. The following objective and constraints are taken into consideration in the formulation of economic load dispatch problem.

A. *The Objective Function*

The objective of economic load dispatch is to minimize the total fuel cost in power generation while satisfying all the equality and inequality constraints. The following equation represents a simple formulation of economic load dispatch problem.

$$Min\, F_t = \sum_{i=1}^{n} F_i\,(P_{gi}) \tag{1}$$

Subject to,

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \tag{2}$$

$$\sum_{i=1}^{n} P_{gi} = P_D + P_L \tag{3}$$

where $F_i\,(P_{gi})$ is the fuel cost function of generating unit i, P_{gi} is the power output of generating unit i, P_D is the power demand, P_{gi}^{min} and P_{gi}^{max} are the lower and upper limits of generating unit i and P_L is the total system loss.

B. *Quadratic Cost Function*

The total fuel cost function is expressed as the sum of a quadratic function. The function is represented as

$$\sum_{i=1}^{n} F_i(P_{gi}) = \sum_{i=1}^{n} a_i(P_{gi})^2 + b_i(P_{gi}) + C_i \tag{4}$$

where a_i , b_i and c_i are the total fuel cost coefficients for generating unit i

C. *Cost Function with Valve-Point Effect*

In the generating units, the real input-output cost curves are non-convex due to valve point effect. A half tide resultant is generated in the steam entrance through the valve in a turbine, so it is more practical for considering the valve point effect with fuel cost function to affix flexible operational facilities. The fuel cost function in terms of real output power can be represented as the sum of a quadratic function and sinusoidal function in the following equation.

$$F_t = \sum_{i=1}^{n} F_i P_{gi} + [e_i \times |\sin\,(f_i \times (P_{gi}^{min} - P_{gi}))|] \tag{5}$$

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D. Constraints

Constraints in generator are considered as following.

1) Generator Capacity Constraints: The output power of each generating unit should be less than or equal to the maximum power permitted and also be greater than or equal to the minimum power permitted on specified unit. It can be written as

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max}$$

2) Power Balance Constraints: The total output power is generated by the generating units should be equal to the sum of power demand and transmission loss. It is mathematically expressed as

$$\sum_{i=1}^{n} P_{gi} = P_D + P_L$$

$P_L$is the transmissionloss and it is calculated by using Kron's loss formula or the B coefficient formula, as follows:

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_{gi} B_{ij} P_{gj} + \sum_{i=1}^{n} B_{i0} P_{gi} + B_{00} \quad (6)$$

where B , B_0 and B_{00} are the loss coefficients.

3) Prohibited Operating Zones: Due to the presence of physical operations such as vibration in shift bearing, some faults in generating units or their accessories like boiler and feed pumps, the generating units might have prohibited operating zones in an input-output curve of the generator. The generating units should avoid the operation in prohibited zones. It can be formulated as follows.

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi,1} \quad (i=1,2,...,n)$$
$$P_{gi,j-1} \leq P_{gi} \leq P_{gi,j} \quad (j=2,3,..ni-1)(i=1,2,..,n)$$
$$P_{gi,nj} \leq P_{gi} \leq P_{gi}^{max} \quad (i=1,2,...,n) \quad (7)$$

where $P_{gi,1}$ is the lower bound of a j^{th} prohibited operating zone of generating unit i, $P_{gi,j}$ is the upper bound of a j^{th} prohibited operating zone of generating unit i, *nj* is the total number of prohibited operating zones of generating unit i.

4) Ramp Rate Constraints: The successful operation of generating unit's range is prohibited by its ramp rate limit. In actual systems, the output power of generating units cannot change suddenly. The changes in output power occur from one specific interval to the next cannot exceed a specified limit. It can be expressed by following equations. As the output power increases,

$$P_{gi} - P_{gi0} \leq U\,R_i \quad (8)$$

As the output power increases,

$$P_{gi} - P_{gi0} \leq D\,R_i \quad (9)$$

Combining (8) and (9) with (2) can be written as,

$$max\left(P_{gi}^{min}, P_{gi0} - DR_i\right) \leq P_{gi} \leq min\left(P_{gi}^{max}, P_{gi0} - UR_i\right) \quad (10)$$

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where P_{gi0} is the unit output power at a previous interval, $U\ R_i$ and $R\ R_i$ are the up-ramp and down-ramp limits of generating unit i.

III. GREY WOLF OPTIMIZATION ALGORITHM

A. GWO Algorithm

GWO algorithm is an optimization method which is presented newly. It is inspired by the wolves of grey. It has the hierarchy of leadership and mechanism of hunting in grey wolves. The grey wolves are divided into four types and that wolves form a group. It is represented in a hierarchical system in the form of alpha (α), beta (β), delta (δ) and omega (ω). From the hierarchy of leadership system, the leader can be either a male or a female called alpha. It takes the power to make a verdict for hunting, place to sleep etc..,. The next to alpha, beta is the ancillary wolf that helps to alpha for taking a decision. The next to beta, delta is the third level of the hierarchical system which dominates the omega. The lowest order of grey wolves in the hierarchical system is omega. It should ever pursue the discipline of α, β and δ.

B. Model of GWO

Developing the model which is based on social hierarchy and hunting mechanism of GWO.

1) Social Hierarchy: The main three wolves (α, β & δ) are considered to find the fitness solution. The remaining wolves (ω) follow the instruction of main wolves.

2) Encircling Prey Wolves are going to hunt for prey. They surround the prey when they locate the prey where it is. Surrounding the prey by grey wolves is modeled by equations (11) and (12).

$$B = |C.V_p(t) - A.V(t)| \tag{11}$$

$$V(t+1) = V(t) - A.B \tag{12}$$

where the present iteration is denoted as t, the preys position vector is represented as V_p, the grey wolves position vector are represented as V and the coefficient vectors are named as A & C. The coefficient vectors are determined by the equations (13) and (14).

$$A = 2a.r_1.a \tag{13}$$

$$C = 2.r_2 \tag{14}$$

where the component of a is decreased gradually in each and every iteration from the value 2 to 0 and the random variables are denoted as $r_1$and r_2 which are in the interval [0,1]. The position of grey wolves is updated in each and every iteration to attain the best optimal solution by utilizing the equations (11) and (12).

3) Hunting for Prey: The ultimate job of grey wolves is hunting process. The wolves are involved in hunting for getting their prey. At first, they cannot locate the prey where itis but they have to find the location of prey. Among all wolves, alpha takes the lead role to guide all other wolves. Beta and delta helps to alpha for making decision. Finally, the grey wolves with the guidance of main wolves achieve the location of prey i.e., the best optimal solution. These all are modeled by using equations (15), (16) and (17). The three best solutions are carried out in entire process. For that, the position of grey wolves is updated over every iterations.

$$B_\alpha = |C_1.V_\alpha - V|$$

$$B_\beta = |C_2.V_\beta - V|$$

$$B_\delta = |C_3.V_\delta - V| \tag{15}$$

$$V_1 = V_\alpha - A_1.B_\alpha$$

$$V_2 = V_\beta - A_1.B_\beta$$

$$V_3 = V_\delta - A_1.B_\delta \tag{16}$$

$$V(t+1) = \frac{V_1+V_2+V_3}{3} \tag{17}$$

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Website: www.ijareeie.com

Vol. 7, Issue 3, March 2018

Here, the positions of grey wolves i.e., the three best solutions are represented as V_{α}, V_{β}& V_{δ}. The location of prey is examined by the main three wolves of α, β and δand the remaining wolves are surrounded the prey by the instruction of alpha.

4) Attacking Prey: The grey wolves attack the prey when they find the location of prey. The preys are stopped to move at one situation. At that time, the grey wolves easily attack the prey and they had it. This is the termination of hunting process of grey wolves. The situation to attack the prey is made by the value of coefficient vector A. It is in an interval [-2a, 2a]. The value of a is reduced linearly from 2 to 0. When $|A| < 1$, the wolves are moved over prey to attack. This is the condition of grey wolf to attack the prey. The position of grey wolves is updated to find the best three solutions.

5) Searching Prey: Initially, the wolves cannot locate the place of prey in hunting process. So, they started to search for locating the prey. All wolves are not gone in same direction. They are separated from each other for finding the location of prey. When they locate the prey, the wolves are joined back together and start to attack it. The whole process is smoothly led by alpha, the best solution. The equation (13) can be given an instruction to wolves for diverging from each other. When $|A| > 1$, the prey is attacked by wolves and finally it brings the ending in process of hunting.

The following synopsis defines the Grey Wolf Optimization (GWO) algorithm.

1. Initialize the number of grey wolves is involved in whole process i.e., the size of population is initialized.
2. And also initialize the position of grey wolves and prey which is surrounded by wolves in the random location i.e., the iteration point is fine-tuned at maximum.
3. Among all the grey wolves, finding the fitness solution is the ultimate task in at individual wolf. The fitness solution is nothing but the distance between location of prey and an individual wolf.
4. By calculating the fitness value, the three best wolves are analyzed and it is said as alpha, beta and delta. Prey's location is identified in the hunting process by utilizing equation (15).
5. The updating positions of grey wolves are necessary to find the best solution utilizing equations (16) and (17).
6. Repeating the step 3 to step 5 until the grey wolves reach the location of prey for attacking it. The best solutions are the main three wolves.
7. The optimal solution is attained when the process reaches its terminating criterion i.e., the maximum iteration point.

IV. IMPLEMENTATION OF GWO ALGORITHM IN ECONOMIC LOAD DISPATCH PROBLEM

GWO algorithm is implemented to do the optimization in economic dispatch problem. The upcoming steps convene the implementation of GWO in economic dispatch problem.

Step 1: Read the input data of the test systems which are chosen in the process for computing the aggregate rate of fuel utilizing in the test systems.

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Vol. 7, Issue 3, March 2018

The flowchart of GWO algorithm is shown in Fig. 1

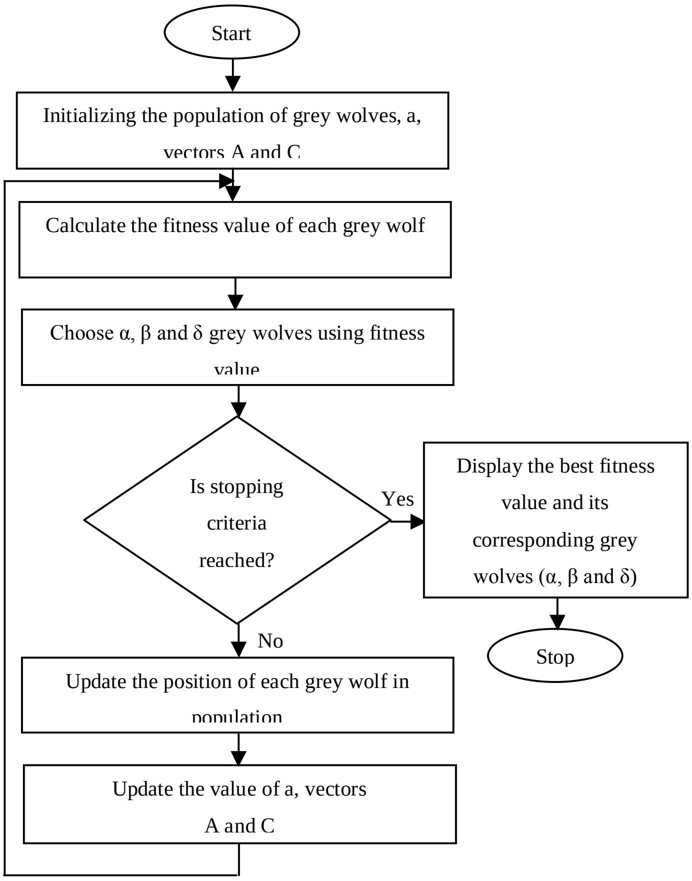

Fig. 1 Flowchart of GWO algorithm

Step 2: Initialize the parameters which are involved in GWO to solve economic dispatch problem i.e., the population size, maximum iteration point and stopping criterion.
Step 3: Initialize the design variable (B) and it is chosen by how many number is needed for the test systems. In consonance with population size, originated the design variable for test systems randomly by using equation (18).

$$P_{ij} = P_{i,min} + rand(1) \times (P_{i,max} - P_{i,min}) \quad (18)$$

where $j=1,2,..,N$ and $i=1,2,..,B$. Then the formation of matrix B × N is done by utilizing equation (13).
Step 4: The best solution of fitness value is calculate in each and every individual population by using *Fp*. The best solution values are determined i.e., α, β and δ. The best solutions are arranged in higher order by using equation (19).

$$F_{P\alpha} = F_P(N), \quad F_{P\beta} = F_P(N-1) \ and \quad F_{P\delta} = F_P(N-2) \quad (19)$$

Step 5: The design variables are identical to fitness values $F_{p\alpha}$, $F_{p\beta}$and $F_{p\delta}$ are kept as $P_\alpha(t)$,$P_\beta(t)$ and $P_\delta(t)$ respectively.
Step 6: The fuel cost coefficients are evaluated by using equations (13) and (14).
Step 7: The position of individual grey wolves and prey are updated using equations (15) to (17).
Step 8: The process can be stopped when it reaches the termination criterion unless repeating the steps 4 to 7 until it reaches the terminating criterion of the GWO algorithm.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

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V. RESULTS AND DISCUSSION

A. Results

In order to show how to solve the economic load dispatch problem by using grey wolf optimization algorithm and to verify the feasibility of GWO, two practical power systems are engaged to test the algorithm. In practical power systems, the ramp rate limit and prohibited operating zones are included. The proposed GWO algorithm results are compared with PSO-ANFIS technique by two power systems of six unit and fifteen unit test systems.

System 1: The system 1 is IEEE standard six unit systems. It consists of 6 thermal units, 26 buses and 46 transmission lines. The load demand of the system is 1263 MW. The generating unit capacity and fuel cost coefficients of the six unit system are given in Table I. In the conventional operation of the system, the transmission loss coefficients B is given in Table II. The best solutions are obtained by the evolutionary process of the proposed method are shown in Table III.

System 2: The system 2 contains 15 thermal unit systems. The load demand for this system is 2630 MW. The generating unit capacity and fuel cost coefficients of 15 unit system are given in Table IV. In this system, the loss coefficient matrix is not mentioned due to space limitation. The best solutions are obtained by the evolutionary process of the proposed method are shown in Table V.

TABLE I
Generating Unit Capacity and Fuel Cost Coefficients of 6 Unit Systems

Unit	P_i^{min}(MW)	P_i^{max}(MW)	a_i	b_i	c_i
1	100	500	240	7.0	0.0070
2	50	200	200	10.0	0.0095
3	80	300	220	8.5	0.0090
4	50	150	200	11.0	0.0090
5	50	220	220	10.5	0.0080
6	50	120	190	12.0	0.0075

Table II
Loss Coefficients B of 6 Unit Systems

B_{ij}	1	2	3	4	5	6
1	0.0017	0.0012	0.0007	-0.0001	-0.0005	-0.0002
2	0.0012	0.0014	0.0009	0.0001	-0.0006	-0.0001
3	0.0007	0.0009	0.0031	0	-0.001	-0.0006
4	-0.0001	0.0001	0	0.0024	-0.0006	-0.0008
5	-0.0005	-0.0006	-0.001	-0.0006	0.0129	-0.0002
6	-0.0002	-0.0001	-0.0006	-0.0008	-0.0002	0.0150
B_{0i}	-0.0004	-0.0001	0.0007	0.0001	0.0002	-0.0007
B_{00}	0.056					

Table III
Best Solution of 6 Unit Systems

Unit Power Output	GWO Method	PSO-ANFIS Method
P1 (MW)	450.6635	447.0687
P2 (MW)	171.0152	173.1805
P3 (MW)	268.6272	263.9225
P4 (MW)	140.7383	139.0511
P5 (MW)	166.9556	165.5761
P6 (MW)	84.0125	86.6164
Total Power Output (MW)	1282.01	1275.4153
Power Loss (MW)	12.1472	12.9584
Total Generation Cost ($/h)	14,870	15,442

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Website: www.ijareeie.com

Vol. 7, Issue 3, March 2018

Table IV
Generating Unit Capacity and Fuel Cost Coefficients of 15 Unit Systems

Unit	P_i^{min}(MW)	P_i^{max}(MW)	a_i	b_i	c_i
1	150	455	671	10.1	0.000299
2	150	455	574	10.2	0.000183
3	20	130	374	8.8	0.001126
4	20	130	374	8.8	0.001126
5	150	470	461	10.4	0.000205
6	135	460	630	10.1	0.000301
7	135	465	548	9.8	0.000364
8	60	300	227	11.2	0.000338
9	25	162	173	11.2	0.000807
10	25	160	175	10.7	0.001203
11	20	80	186	10.2	0.003586
12	20	80	230	9.9	0.005513
13	25	85	225	13.1	0.000371
14	15	55	309	12.1	0.001929
15	15	55	323	12.4	0.004447

TABLE V
Best Solution of 15 Unit Systems

Unit Power Output	GWO Method	PSO-ANFIS Method
P1 (MW)	455	454.99
P2 (MW)	455	454.99
P3 (MW)	130	129.99
P4 (MW)	130	129.99
P5 (MW)	271.18	196.68
P6 (MW)	460	459.99
P7 (MW)	465	464.99
P8 (MW)	60	60
P9 (MW)	25	25
P10 (MW)	66.73	65.72
P11 (MW)	80	79.99
P12 (MW)	80	79.99
P13 (MW)	28	25
P14 (MW)	15	15
P15 (MW)	15	15
Total Power Output (MW)	2735.91	2657.32
Power Loss (MW)	24.51118	27.41125
Total Generation Cost ($/h)	32,256.754	32,346.285

B. Discussion

Table III and Table V show the best solution of 6 unit and 15 unit test systems. It gives the optimum solution of economic load dispatch problem. It generates the output power at minimum cost and it meets the load demand while power balance equation is to be maintained. The iterations are taken into account to get the best solution. The proposed method's solution of output power and power generation rate are compared with the PSO-ANFIS technique. The output power of GWO method is greater than PSO-ANFIS technique in both test systems. The loss of power is reduced in GWO when it is compared with the PSO-ANFIS technique. The total generation cost is calculated by adding each and every unit cost of power generation. By comparing the total generation cost of GWO is with PSO-ANFIS technique, the minimum cost of power generation is attained by GWO. Therefore, GWO gives the better optimum solution to solve the economic dispatch problem than PSO-ANFIS technique.

VI. CONCLUSION

In this paper, Grey Wolf Optimization (GWO) algorithm has proposed to solve the economic load dispatch problem with the generator constraints. GWO is inspired by grey wolves. The wolves have been involved in searching for prey and attacking it which are involved in hunting mechanism under the guidance of leader (α). Likewise, GWO algorithm has been used to solve economic load dispatch problem to get the best optimum solution of total generation cost in power generation. GWO algorithm has the special features when compare it with other optimization algorithms. The main difference between GWO and PSO-ANFIS technique is the leader. PSO-ANFIS technique does not have the leader for proper guidance to attain the best solution. In absence of that, the optimum solution may not be attained. So th60at, to solve optimization problem mostly prefer GWO to PSO-ANFIS technique. GWO has the advantages such as robustness, less computational efforts and avoids premature convergence. GWO algorithm has tested in 6 nit and 15 unit systems and it is concluded that GWO gives the promising results compared it with other optimization techniques. In future work, the proposed method may be implemented to solve other optimization problems in the field of power

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Website: www.ijareeie.com

Vol. 7, Issue 3, March 2018

system planning and operation. And also it can be tried in complex hydrothermal scheduling unit for getting good results.

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