



## GREY WOLF OPTIMIZER FOR SOLVING ECONOMIC DISPATCH PROBLEM WITH VALVE-LOADING EFFECTS

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### ABSTRACT

This paper presents the application of recent swarm intelligence (SI) techniques in solving the Economic Dispatch (ED) problem. ED is known as one of the fundamental problems in power system operation which aimed to obtain the combination of the fuel based power generation so that the minimum cost can be achieved. In this paper, the effect of valve-loading will be considered in order to solve the complex optimization problem. The recent SI algorithm namely Grey Wolf Optimizer (GWO) will be utilized in this paper. To show the effectiveness of GWO in solving ED problem, 13-units and TAIPOWER 40-units systems are used and then the performance of GWO will be compared to the other recent techniques.

**Keywords:** economic dispatch, swarm intelligence technique.

### INTRODUCTION

Economic Dispatch (ED) is one of the complex problems faced by power engineers in the world. This is due to the difficulty of determining the combination of the power generation in order to meet with the demand with the minimum cost. Small improvement can bring a massive cost saving to the power providers. That is why the ED problem still becoming the major interest by the researchers around the world.

Since ED problem is treated as an optimization problem, various techniques have been proposed in order to obtain the minimum cost of total generation from hard computing techniques until the recent techniques called Swarm Intelligence (SI). SI is the recent technique for solving optimization problem that mimics the nature inspired behavior such as birds, fish, ants, and many more. From the literature, it has been proven that the researches tend to use SI techniques to solve ED problem compared to using hard computing techniques.

One of the well-known SI techniques is Particle Swarm Optimization (PSO). It has been proposed in solving ED problem with non-linear characteristics [1]. It is a population based technique motivated by the biological concepts like swarming and flocking. The generator constraints such as ramp rate limits and prohibited operating zones are considered with network loss.

Song *et al.* [2] applied an Artificial Ant Colony Search Algorithm (ACSA) to an ED problem. This is a new cooperative agent search approach obtained from the food foraging behavior of ants. The ACSA converges to the optimum solution through an autocatalytic process. The massive parallel agent cooperation makes the ants able to jump over the local optimum and to identify the right cluster easily; hence, a good solution can be found. Although the results of this paper are very encouraging, there is a common problem always faced by bio-inspired

algorithm which is particularly in the areas of improvement of its computation efficiency.

A Hopfield Model based approach for solving the ED problem with the power balance constraint including transmission loss and the generation capacity constraint has been proposed in [3]. Lin *et al.* [4] suggested a new optimization technique in which EP, Tabu Search (TS) and Quadratic Programming (QP) was integrated and is applied to a non-convex ED problem. Hybrid EP and TS was used for quality control and the QP for performance enhancement. This technique is better than GA in aspect of quality and performance due to its active repairing strategy to probe for the new solution, while GA uses penalty function to passively test feasible and infeasible solutions.

Hybrid of EP and Sequential Quadratic Programming (SQP) has been proposed in [5]. It has been used to solve the Dynamic Economic Dispatch (DED) with non-smooth cost function. The EP is used to perform a base level search and leads to global search region and the SQP is used to conduct a local search in that region to find the optimal solution.

Wang *et al.* [6] applied an Ant Direction Hybrid Differential Evolution (ADHDE) to solve the ED problem in a power system, where the Ant Colony search technique is employed to determine the correct mutation operation for hybrid DE to generate a global optimum solution. ADHDE is quite fast for finding the global solution compared to GA and SA.

The combination of chaotic differential evolution and Quadratic Programming (QP) has been discussed in [7]. Differential Evolution (DE) with chaos sequences is the global optimizer and the QP is the local optimizer. This method which combining DE, chaos sequences, and SQP seem can be very effective in solving ED problems with the valve-point effect.

In this paper, the recent SI technique namely Grey Wolf Optimizer (GWO) [8] has been applied in



solving ED problem with valve-loading effects. Next sub chapter will discuss about the ED formulation in brief followed by GWO and GWO application to solve ED problem. It is followed by results and discussion and finally conclusion is stated at the end of the paper.

### ED PROBLEM

The primary concern of ED problem is to minimize of its objective function. The objective function is formulated as below, where  $F$  is total fuel cost,  $N$  is number of generating unit and  $F_i(P_{Gi})$  is operating fuel cost of generating unit  $i$ .

$$\min(F_T) = \min \sum_{i=1}^N F_i(P_{Gi}) \quad (1)$$

The generator cost curve is represented by quadratic functions and the total fuel cost  $F(P_G)$  in (RM/h) can be expressed as:

$$F(P_{Gi}) = \sum_{i=1}^N a_i + b_i P_{Gi} + c_i P_{Gi}^2 \quad (2)$$

where  $N$  is the number of generators;  $a_i$ ,  $b_i$ ,  $c_i$  are the cost coefficients of the  $i$ -th generator and  $P_G$  is the vector of real power outputs of generators.

To control every generators output power, the power plant employs several valves. The valve point loading effect occurs when each steam admission valve in a turbine starts to open, thus producing a rippling effect on the cost curve as depicted in the Figure-1. To account this effect in the economic load dispatch problem, a sinusoidal function is added to the quadratic cost function as follows:

$$F_T = \left( \sum_{j=1}^n F_j(P_{Gi}) \right) \quad (3)$$

$$= \left( \sum_{j=1}^n a_j P_{Gi}^2 + b_j P_{Gi} + c_j + e_j \sin(f_j (P_{Gi}^{\min} - P_{Gi})) \right)$$

where  $e_j$  and  $f_j$  are the coefficients of  $i$ -th generator with valve point loading.

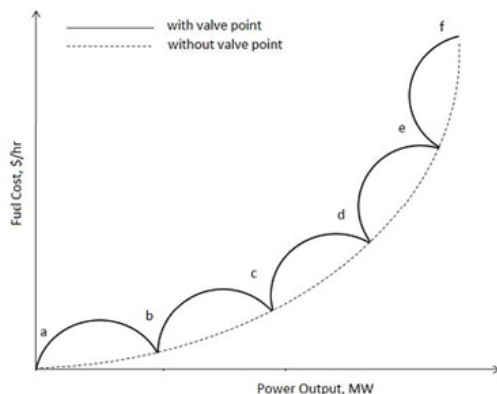


Figure-1. Fuel cost curve under valve point loading.

The cost function in (3) is subject to the following constraints:

### Generation limits

For stable operation, the real power output of each generator is restricted by lower and upper limits as follows:

$$P_{Gi}^{\min} \leq P_{Gi} \leq P_{Gi}^{\max} \quad i = 1, 2, \dots, N \quad (4)$$

where  $P_{Gi}$  is the output power of generator  $i$ ,  $P_{Gi}^{\min}$  and  $P_{Gi}^{\max}$  are the minimum and maximum power output limit of generator  $i$  respectively.

### Power balanced

The total output power generation is the sum of the total power demand,  $P_D$  and total power losses,  $P_{loss}$ . Hence the total output power is shown in Equation 2.9 below:

$$\sum_{i=1}^N P_{Gi} - P_D - P_{loss} = 0 \quad (5)$$

where  $P_D$  is load demand and  $P_{loss}$  is transmission loss in the system.

### GREY WOLF OPTIMIZER

Grey Wolf Optimizer (GWO) was first introduced by [8]. It is considered as a top level of predators and residing at the top in the food chain. They live in a pack which consists of 5-12 wolves on average. In the group, strict dominant hierarchy is practised where the pack is leads by the alphas, followed by the beta which is the subordinate wolves that responsible to assist the alpha in decision making.

The beta reinforces the alpha's commands throughout the pack and gives feedback to the alpha. Meanwhile, the lowest ranking of grey wolves is called omega which commonly plays the role of scapegoat. They also are the last wolves that allowed eating the prey. If a wolf is not alpha, beta and omega, he or she is called a delta. The role of delta wolves are as scouts, sentinels, elders, hunters and caretakers. The hierarchy of grey wolves is depicted in Figure-2. The steps of GWO which is social hierarchy, tracking, encircling and attacking prey can be obtained in [8].

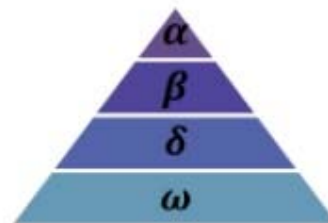


Figure-2. Hierarchy of grey wolves [8].

### SOLVING ED PROBLEM USING GWO

This section discusses the implementation GWO



into solving the ED problems. The implementation of the GWO is to find of the optimal power output for each generation aimed is to minimize the objective function (cost) while fulfilling all the constraints mentioned previously. Initially, the number of candidate of solution and the maximum iteration are set. The vector of population can be expressed as follows:

$$X = \begin{bmatrix} x_1^1 & \cdots & x_n^1 \\ \vdots & \ddots & \vdots \\ x_1^p & \cdots & x_n^p \end{bmatrix} \quad (6)$$

where  $n$  is the number of control variables and  $p$  is the number of population.

The step of GWO in solving the ED is depicted in Figure-3. From this figure, it can be seen that it is started by generating the random solution using the (6) and then the process of GWO is done following the rules of hierarchy that have been presented in [8].

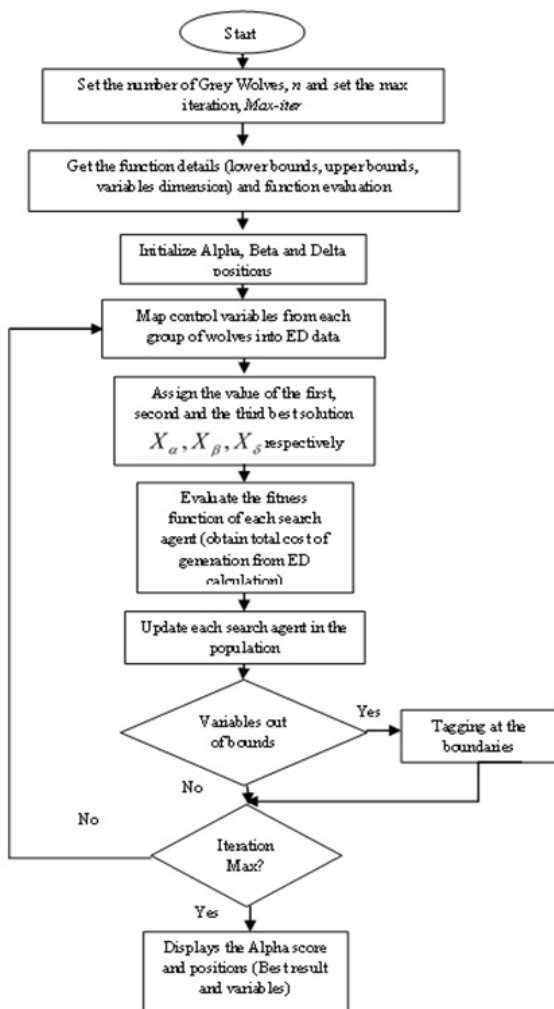


Figure-3. Flow for ED solution using GWO.

## RESULTS AND DISCUSSION

GWO technique to solve ED problem has been tested and implemented on two test systems: 13-units and TAIPOWER 40-units generator systems.

### 13-units system

This test case consists of thirteen thermal units of generation with effects of valve-point as given Table-1 [9]. This makes the systems more complex and nonlinear. The required load demands to be met by all the thirteen generating units is 1800 MW. Based on the convergence characteristic of GWO in Figure-4, the performance of 40 search agents is better than other quantity of search agent thus 40 search agents is fixed for every simulation. The results obtained for this case study are presented in Tables-2, 3 and Figure-5 respectively, which show that the simulation results obtained by GWO is slightly better compared among the reported methods in literature. Although the result is not the best, it still proves the feasibility of GWO in solving ED problem with valve point loading effects.

Table-1. Units data for 13-unit system with valve point loading.

Unit	$P_{Gi}^{\min}$ (MW)	$P_{Gi}^{\max}$ (MW)	$a_i$	$b_i$	$c_i$	$e_i$	$f_i$
1	0	680	0.00028	8.1	550	300	0.035
2	0	360	0.00056	8.1	309	200	0.042
3	0	360	0.00056	8.1	307	200	0.042
4	60	180	0.00324	7.74	240	150	0.063
5	60	180	0.00324	7.74	240	150	0.063
6	60	180	0.00324	7.74	240	150	0.063
7	60	180	0.00324	7.74	240	150	0.063
8	60	180	0.00324	7.74	240	150	0.063
9	60	180	0.00324	7.74	240	150	0.063
10	40	120	0.00284	8.6	126	100	0.084
11	40	120	0.00284	8.6	126	100	0.084
12	55	120	0.00284	8.6	126	100	0.084
13	55	120	0.00284	8.6	126	100	0.084

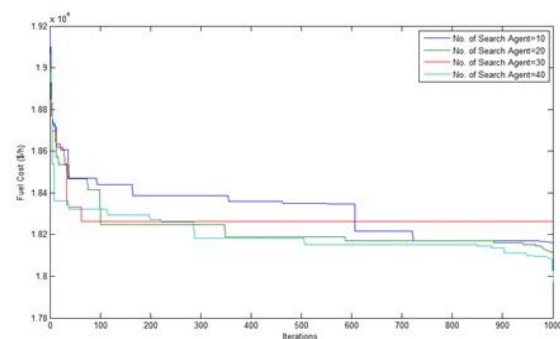


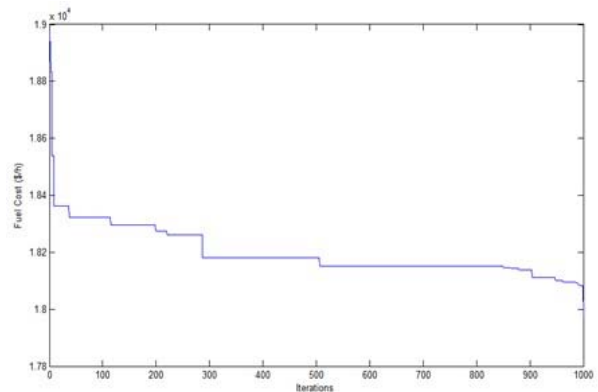
Figure-4. Convergence characteristic of proposed GWO with various numbers of search agents.

**Table-2.**Results obtained by the proposed method for test case 2 (1800MW).

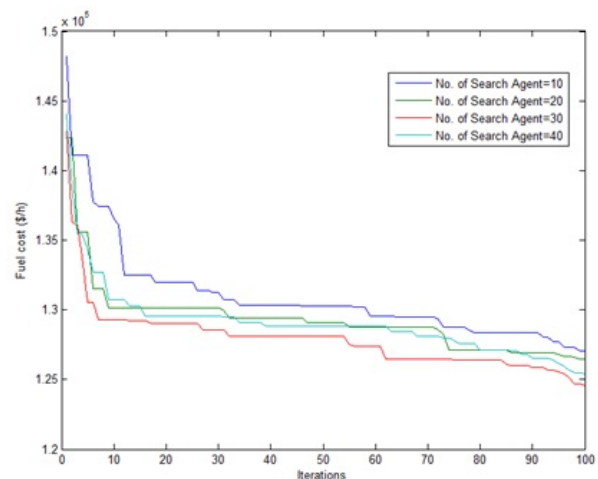
Unit (MW)	Proposed GWO
1	628.3184601
2	223.1052889
3	298.8585499
4	60
5	60
6	109.8592733
7	60
8	60
9	109.8584279
10	40
11	40
12	55
13	55
Total Power Output(MW)	1800
Total Cost(\$/h)	17972.94011

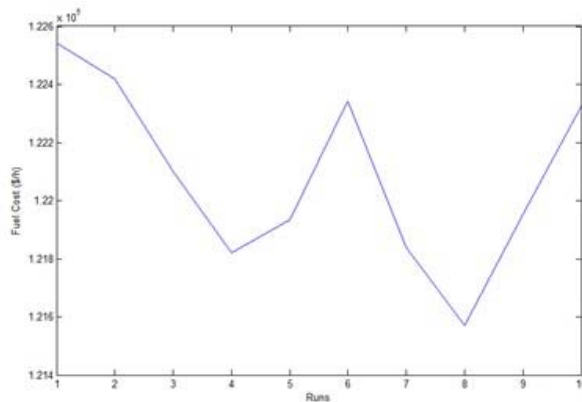
**Table-3.** Comparison of proposed method for 13-units system (1800MW).

Method	Total Cost (\$/h)
CEP[9]	18048.21
PSO[10]	18030.72
MFEP[9]	18028.09
FEP[9]	18018
IFEP[9]	17994.07
EP-SQP[10]	17991.03
HDE[11]	17975.73
CGA-MU[12]	17975.34
<b>GWO</b>	<b>17972.94</b>
PSO-SQP[13]	17969.93
PS[13]	17969.17
UHGA[9]	17964.81
QPSO[14]	17964
IGA_MU[15]	17963.98
ST-HDE[11]	17963.89
HGA[17]	17963.83
HQPSO(5) [18]	17963.957
DE[19]	17963.83
GSA[20]	17960.368

**Figure-5.** Convergence characteristic of proposed GWO for 13-units system (1800MW).**TAIPOWER 40-units system**

The 40-unit system consists of the fuel cost coefficient, minimum and maximum output of generator and power demand of 10500MW. The objective function of total fuel cost and fuel cost curve of the units are both presented in quadratic cost functions. The input data for the 40-unit system can be obtained in [9]. Based on the analysis of the numbers of search agents towards the performance of GWO in Figure-6, eventually, 30 number of search agents is set in every simulation due to its better convergence. Figure-7 shows the performance of 30 search agents of GWO with 10000 iterations in 10 runs. The detail results of power output of the optimal fuel cost and demand together with the SOH\_PSO are given in Table-4. It can be seen that GWO outperform SOH\_PSO [21] in total cost generation and can be said that GWO is promising technique in solving complex optimization problems.

**Figure-6.** Convergence characteristic of proposed GWO with various numbers of search agents.



**Figure-7.** Performance of 30 agents of GWO for 10 free running of simulations.

**Table-4.** Power output of generators in the best result of the proposed GWO for the 40-unit test system.

Unit	GWO (MW)	SOHPS O (MW)	Unit	GWO (MW)	SOHPSO (MW)
1	114.00	110.8	21	525.67	523.28
2	113.27	110.8	22	527.01	523.28
3	120.00	97.4	23	525.85	523.28
4	180.33	179.73	24	526.13	523.28
5	93.38	87.8	25	523.41	523.28
6	140.00	140	26	523.91	523.28
7	300.00	259.6	27	11.21	10
8	299.99	284.6	28	10.19	10
9	299.99	284.6	29	10.79	10
10	130.19	130	30	88.36	97
11	94.06	94	31	190.00	190
12	94.03	94	32	190.00	190
13	214.76	304.52	33	190.00	190
14	304.52	304.52	34	200.00	185.2
15	304.52	394.28	35	200.00	164.8
16	394.29	394.28	36	200.00	200
17	489.30	489.28	37	110.00	110
18	489.65	489.28	38	110.00	110
19	511.29	511.28	39	110.00	110
20	511.56	511.27	40	511.32	511.28
Total Generation (MW)				10500	10500
Total Generation cost (\$/h)				121488.4	121501.14

## CONCLUSIONS

This paper has presented a recent Swarm Intelligence (SI), GWO to solve ED problem with considering the valve-loading effects. The effectiveness of

GWO was demonstrated and tested on 13-units and TAIPOWER 40-units systems. From the simulations that have been conducted, it can be concluded that GWO offers promising and competitive results compared to other methods presented in this paper.

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