# Solving The Environmental Economic Dispatch Problem using Whale Optimization Algorithm

***Haider J.Touma,***

*Master Degree in Electrical Power Engineering from University of Technology ,Iraq.*

*Email : haidertomah@yahoo.com*

***Abstract :***

***In this work, the Whale Optimization Algorithm method used to solve the Environmental Economic Dispatch Problem. The performance of the used algorithm is substantiated using standard test system of three thermal generating units. The proposed algorithm produced optimum or near optimum solutions. The obtained results in this study using the Whale Optimization Algorithm are compared with the obtained results using other intelligent methods such as Particle Swarm Optimization, Simple Genetic Algorithm and Genetic Algorithm. The comparison demonstrated the obtained results in this research are close to these obtained using the above revealed approaches.***

***Key words:***

***Particle Swarm Optimization (PSO), Simple Genetic Algorithm (SGA) ,Genetic Algorithm(GA), Whale Optimization Algorithm (WOA), Environmental Economic Dispatch (EED).***

## I. Introduction

The economic dispatch represents important concern in the controlling of power system operation. The main target for economic dispatch is how to schedule the generating units to ensure minimum generation cost for the electricity utilities to achieve highest profits and to be more competitive in the electricity market [1,2,3,4]. This aim has faced the environmental challenges. Because the electric power generation often depends on thermal units which are operating with fossil fuel (oil, coal, natural gas). Using such fuels leads to emission of dangerous diverse gases such as carbon dioxides and sulfur dioxide. The emission of mentioned gases has represented main cause of the global warming problem and thus main cause in different environmental problems such as temperature increase, rain acid as well as healthy problems such as cancer diseases. The Environmental Economic Dispatch (EED) signifies one of the important necessities of the power system operation as a measure to deal with the emission problem. The chief role of (EED) is attaining minimum cost and minimum emission. Since the minimum cost implies the emissions will be secondary, then again, minimum emission implies increasingly extra cost and taxes for emissions treatment in this manner, the two destinations are clashing [5, 6, 7, 8] . This study attempts to solve EED by using one of latest meta heuristic algorithms which has sufficient aspects such as precision and fast convergence.

## II. Mathematical Formulation [ 3, 9, 14]

### *2.1 Electrical Constraints*

The fuel-cost function in the most studies is a second order equation as described in equation (1) .

$FC_i=a_i P_i^2 + b_i P_i + c_i$ (\$/h) ………… (1)

The generator limits describe the electrical inequality constraints in the economic dispatch formulation [10, 11].

$P_{i\,min} \leq P_i \leq P_{i\,max}$ i= 1,…..,n

For proper reliable operating conditions, the total generation is more than the total load demand and transmission losses. Transmission losses has two significant impacts on the optimal economic scheduling of the generators .First, the total real power loss in the system increases the total generation demand, and second the generation schedule may have to be adjusted by shifting generation to diminish flows on transmission circuits because they would otherwise become overloaded [1].

the losses of power system [12,13] can be represented in the form given by equation (2).

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{j=1}^{n} B_{0j} P_j + B_{00} \quad \ldots\ldots\ldots\ldots \quad (2)$$

The coefficients $B_{ij}$ are called loss coefficients or $B-$ coefficients. The impact of losses on the scheduling of the generators has been described by equation (3) which represents the electrical equality constraints in the problem .

$$P_D = \sum_{i=1}^{n} P_i - P_L \quad \ldots\ldots\ldots..(3).$$

*2.2 Environmental Constraints*

The environmental constraint makes utilities and consumers partners in facing this challenge , thus as it was explained, the regulated taxes on the pollutants emissions represent a part of solution for the environmental problem to reduce or control the emission quantities. Practically, the emission function of each thermal generating unit is characterized as quadratic smooth function similar to the fuel cost function with measuring unit kilogram of a certain emission per hour (Kg/h) as shown below.

$$EC_i = d_i P_i^2 + e_i P_i + f_i \quad \ldots\ldots\ldots\ \ldots\ldots\ (4)$$

In order to transform the emission function (kg/h) to emission cost function needing to multiplying the emission function by control or penalty factor(hi) measured by ($/kg) which is obtained by dividing the maximum fuel cost of generating unit($FC_{imax}$) by maximum emission of it ($EC_{imax}$) ,thus the produced function measured by ($/h) such as fuel cost function then by adding the produced function(emission cost function ) to the fuel cost function getting the total cost function [6,14,11] .

The mathematical formulation of EED can be explained as below:

The price penalty factor of each generating unit (hi) is obtained as follows:

$$h_i = \frac{EC\ imax}{FC\ imax} \quad \ldots\ldots\ldots(5)$$

Where,

$$EC_{imax} = d_i P_{imax}^2 + e_i P_{imax} + f_i \quad \ldots\ldots\ldots\ldots(6)$$

$$FC_{imax} = a_i P_{imax}^2 + b_i P_{imax} + c_i \quad \ldots\ldots\ldots\ldots(7)$$

The minimization problem for the EED will be :

minimize $f(FC,EC) = \min (FC + \sum h_i EC_i)$ ……….(8)

## III. The proposed algorithm Whale Optimization Algorithm (WOA) [ 15, 16, 17]:

### *3.1 Introduction*

The Whale Optimization Algorithm (WOA) has been built on the whale hunting technique. This is pursuing procedure is called bubble-net feeding strategy. Humpback whales want to chase little fishes near the surface by making bubble net around the prey rises along a circle path as shown in figure 1.

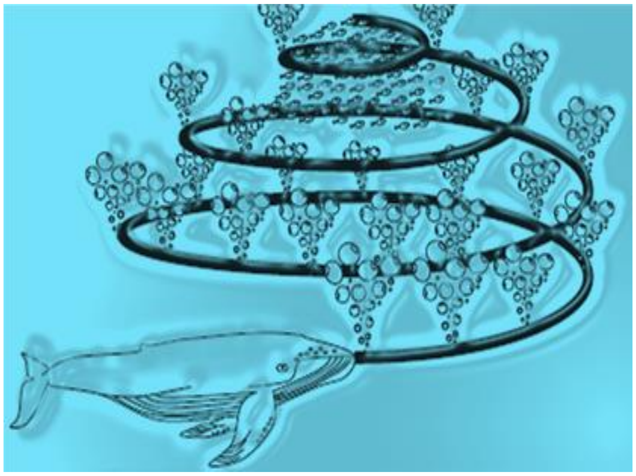


**Figure 1 . Bubble-net feeding technique of humpback whales**

### *3.2 Mathematical Formulation* [17]

$D = | C. X^*(t) - X(t) |$ ……… (9.1)

$X(t+1) = X^*(t) - A.D$ ………(9.2)

Where

t present iteration,

A and C coefficient vectors,

$X^*$ position vector of the best solution

X position vector,

| | absolute value

$A = 2a \cdot r - a$ …….. (9.3)

$C = 2 \cdot r$ …….. (9.4)

where

a is linearly diminished from 2 to 0 through the number of iteration (in both investigation and exploitation stages) and r is an arbitrary vector in [0,1].

*3.3.1. Bubble-net assaulting strategy (exploitation stage):*

Two approaches are utilized to figure the air bubble net conduct of humpback whales as below:

i. Shrinking circling system:

Eq.(9.3) has explained this approach . The fluctuation scope of A is additionally diminished by a . As such A will be random in the interval $[-a, a]$ ,where a is diminished from 2 to 0 throughout iterations . A is in $[-1,1]$, the new position of a search operator has been estimated between the first position of the agent and the position of the present best agent. Figure. 2 (a) shows this behavior.

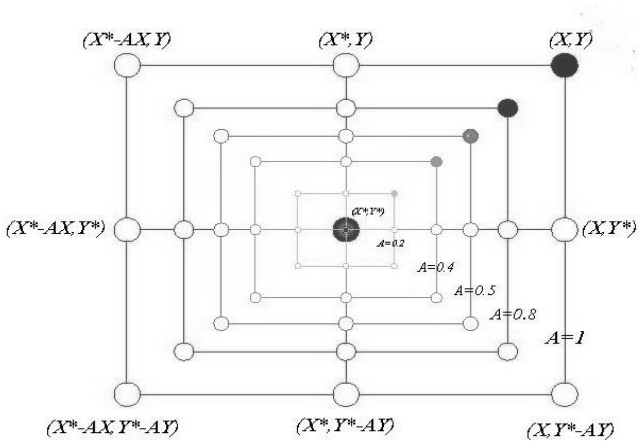
ii. Spiral updating position:

This approach shown in figure 2.(b) depends on determining the distance between the whale situated at $(X, Y)$ and prey situated at $(X^*, Y^*)$. Eq (9.5) represents the spiral path between the position of whale and prey .

$X(t+1) = D' . e^{bl} . \cos(2\pi l) + X^*(t)$ …………. (9.5)

where $D' = | X^*(t) - X(t) |$ and demonstrates the separation of the i th whale to the prey (best solution), b is a constant for characterizing the state of the logarithmic spiral , l is an random number in $[-1,1]$. Whales swim around the prey inside Shrinking circle and along a spiral form . There is a probability of half to select one of two approaches as shown :

$$X(t+1) = \begin{cases} X^*(t) - A . D & \text{if } p < 0.5 \quad \text{…………….(9.6)} \\ D' . e^{bl} . \cos(2\pi l) + X^*(t) & \text{if } p \geq 0.5 \quad \text{………………(9.7)} \end{cases}$$



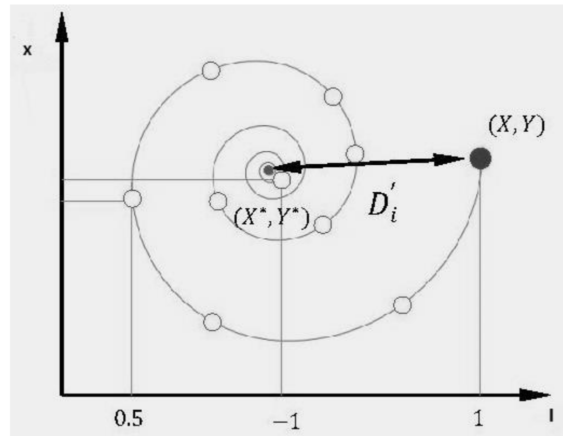




**Figure. 2 ( a) shrinking encircling mechanism** **Figure . 2 (b) spiral updating position.**

where p is an arbitrary number in [0,1].

*3.3.2 Scan for prey (investigation stage)*

whales pursue randomly as per the position of each other. Thus, A is utilized with the random values more than 1 or under −1 to make search agent to move far from a reference whale. The position of search agent has been updated in the investigation stage as per a randomly picked search agent rather than the best pursuit agent discovered in this way. This scheme and $|A| > 1$ highlight investigation and tolerate the WOA calculation to perform a global pursuit. The mathematical model is as per the following:

$D = | C . X_{rand} - X |$ ……….(9.8)

$X ( t + 1 ) = X_{rand} - A . D$ ……….(9.9)

The WOA can be summarized in the below:

Step-1 : Initialize the whales population $X_i$ (i = 1, 2, ..., n)

Step-2 : Calculate the fitness of each search agent
X*=the best search agent

Step-3: for each search agent
Update a, A, C, l, and p (while t < maximum number of iterations)

Step-4 : if1 (p<0.5)
if2 |A|< 1

Step-5 : Update the position of the current search agent by the Eq.(9.1)

Step-6 : if2 $| A | \geq 1$
Select a random search agent ($X_{rand}$)

Update the position of the current search agent by the Eq.(9.9)

Step-7 : if1 ($p \geq 0.5$)
Update the position of the current search by the Eq. (9.5)

Step-8 : if
Any search agent goes beyond the search space and amend it Calculate the fitness of each search update X*
if there is a better solution t=t+1

Step-9 : select new X*

## IV. CASE STDUIED AND RESULTS

In this study , the (WOA) method has been executed. The application is performed on standard test system of three thermal generating units . The Matlab 7.8 version is used throughout this work on a laptop of Intel processor , CPU M 350@ 2.27 GHZ,RAM 4 GB(2.99G B usable ,operating system 32 bit).

*4.1 Three –Generating Units Test System* [7, 8, 18 ]

The necessary data required for this case are presented in tables 1 and 2. The B-coefficients for the power demands under study are shown in table 3

**Table 1 Fuel Cost Function Parameter**

| Unit No. | Fuel Cost Coefficients | | | Generation Limits | |
|---|---|---|---|---|---|
| | a($/MW²h) | b ($/MWh) | c($/h) | Pmin (MW) | Pmax (MW) |
| 1 | 0.03546 | 38.30553 | 1243.531 | 35 | 210 |
| 2 | 0.02111 | 36.32782 | 1658.5696 | 130 | 325 |
| 3 | 0.01799 | 38.27041 | 1356.6592 | 125 | 315 |

**Table 2 Emission Function Parameters**

| Unit No. | Emission Function Coefficients | | |
|---|---|---|---|
| | d(kg/MW²h) | e(kg/MWh) | f (kg/h) |
| 1 | 0.00683 | -0.54551 | 40.26690 |
| 2 | 0.00461 | -0.51160 | 42.89553 |
| 3 | 0.00461 | -0.51160 | 42.89553 |

**Table 3 B-coefficients**

| B = | | |
|---|---|---|
| 0.000071 | 0.000030 | 0.000025 |
| 0.000030 | 0.000069 | 0.000032 |
| 0.000025 | 0.000032 | 0.000080 |

Tables 4 and 5 illustrate a comparison results have been nominated from literature and those obtained by new strategy involving WOA. The results show emission and total cost. The results of WOA are very competitive and reliable .It`s mentionable the obtained results regard losses are competitive too, but the concentration in this study is on the cost and emission.

**Table 4 .Total Cost ( $/h) Results Comparison for The 3-Unit System**

| Load (MW) | WOA | GA[8] | SGA[18] | PSO [8] |
|---|---|---|---|---|
| 400 | 29856 | 29563.2 | 29820 | 29559.9 |
| 500 | 39489 | 39220.1 | 39441 | 39210.2 |
| 700 | 64733 | 64866.2 | 66659 | 64862 |

**Table 5 .Total Emission (kg/h) Results Comparison for The 3-Unit System**

| Load (MW) | WOA | GA[8] | SGA[18] | PSO [8] |
|---|---|---|---|---|
| 400 | 200.4654 | 200.256 | 201.35 | 200.221 |
| 500 | 311.7782 | 311.273 | 311.89 | 311.15 |
| 700 | 652.8810 | 651.631 | 652.04 | 651.569 |

## V. Conclusion

(WOA) has been utilized to determine the optimal solution for the EED problems. This algorithm has been tested on system of three thermal generating units. A general conclusion can be indicated here the proposed technique produced optimal or near optimal solutions. The obtained results for the certain test system explain and verify some facts such as the closeness in general between the (WOA) method and the mentioned techniques in the obtained results as it is proved in the case studied. The load variation reveals on the performance of used optimization technique as shown in Figures 3and 4.

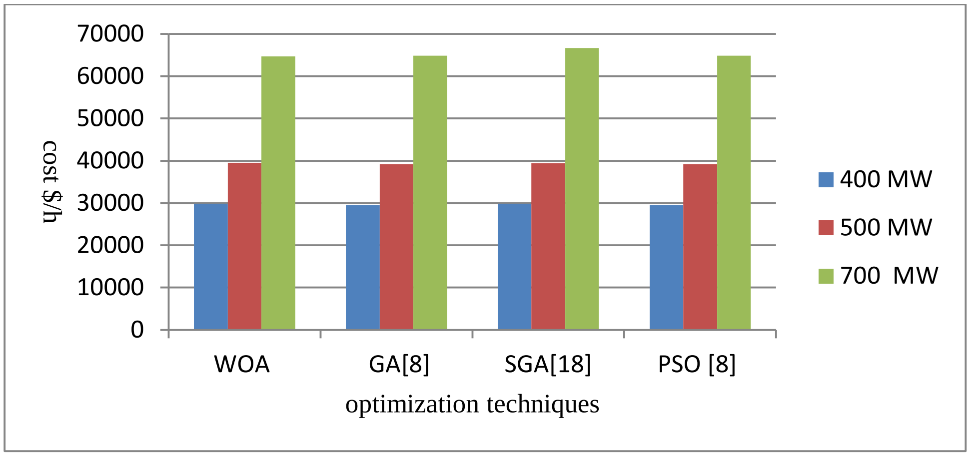



**Figure 3. Comparison in total cost( $/h) between the proposed algorithm and these selected from literature**

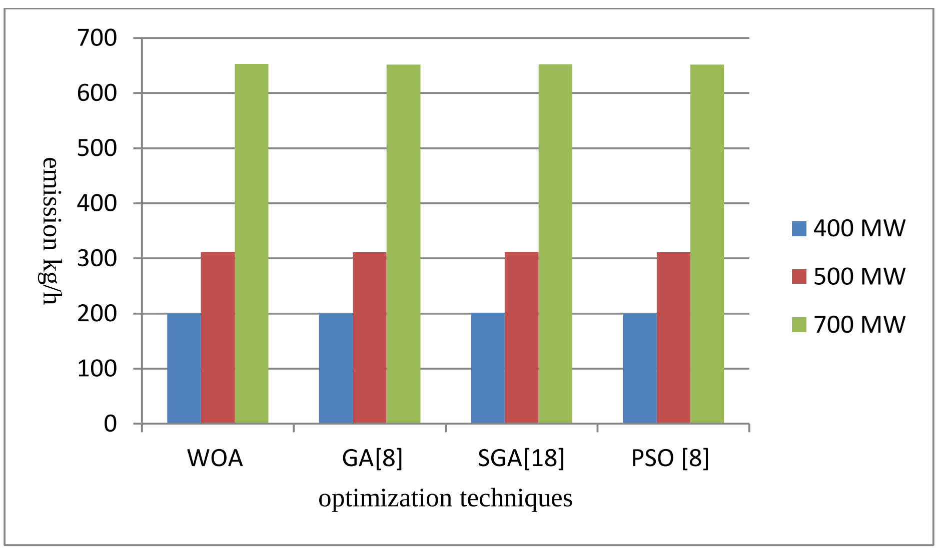



**Figure 4. Comparison in total emission (kg/h) between the proposed algorithm and these selected from literature**

*Nomenclature*

$FC_i$ fuel cost of unit (i) in $/h .
$P_i$ real power output of generator i.
a ($/MW$^2$ h) , b ($/MWh) and c ($/h) cost coefficients.
n number of units
$P_{i\ min}$ minimum limit for generating unit (i) in MW.

$P_{i\,max}$ maximum limit for generating unit (i) in MW.
$P_L$ total losses in MW .
$P_D$ total load demand in MW.
FC total fuel cost ($/h).

B loss coefficients

$h_i$ price penalty factor of the generating unit (i) in ($/kg).

$EC_{imax}$ maximum limit emission of generating unit (i) in kg/h .

$EC_i$ : emission of generating unit (i) in (kg/h) .

d (kg/ MW$^2$ h) , e (kg/ MWh) and f (kg/h) emission coefficients

$FC_{imax}$ maximum fuel cost of generating unit (i) in $/h

EC total emission in (kg/h)

FC total fuel cost ($/h)

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