Optimal Placement and Sizing of DGs in Distribution System for Improving Voltage Profile and Reducing the Power Loss using Moth Flame Optimization Technique

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Abstract

Owing to the fast growth of electricity consumption, Distributed Generation (DGs) plays an important role in distribution network due to their advantages. This paper presents a novel multi-objective optimization technique called Moth Flame (MFO) for determining the optimal location and size of Distribution Generation units (DGs) in distribution systems. Due to the best size and placement of DGs installation the voltage profile is improved, minimize the system loss and reduce the investment cost of distributed generation units is also achieved. In this paper the proposed technique will be implemented on two benchmark systems, the IEEE 14-bus and IEEE 39 using MATLAB simulation program. The simulated results prove the effectiveness and accuracy of the proposed technique compared to other optimization technique Harmony Search (HS).

Keywords *– multi-objective optimization, Moth Flame Optimization (MFO), Harmony Search (HS), Voltage Drop (VD), distribution generators (DGs)*

I. INTRODUCTION

The evolution of electricity consumed is growing rapidly. DG is one of the improved substitutions to satisfy this ever rising energy demand. DGs play an important role in distribution system due to their merits, reduce losses and improved voltage profile and decrease the investment system cost. Distributed generation technologies are renewable and nonrenewable types [1]. Renewable technologies are solar photovoltaic,geothermal and wind.Nonrenewable technologies such as fuel cell, micro turbines, internal combustion engine [2], and combined cycle.So optimal location and size of DGs will decrease the costs associated to transmission of electricity to distant places.

Due to the difficulties of the problem of DGs size and placement, several optimization techniques have beensuggested and implemented to reach the best size and allocation of DGs, There are many optimization techniques have been applied before forDG placement such as genetic algorithm [3], PSO [4], ant colony and gravitational earth algorithm [5].This paper will study the minimization of multi-objective function with MFO technique using four DG s technologies within the range 10Mw-50Mw,to improve the voltage profile, reduce the total system loss, and increase the annual cost saving of the distribution system.

II. THE POWER SYSTEM MODELED

The IEEE-14bussystem [6],the system consists of 14 buses, 5 generation, three transformers, 20 branches and 2 shunt capacitors. The system also consists of 11 loads with total real load of 244.1 MW and reactive load of 72.4 MVAR. Also, The IEEE-39 bus system [7],the system consists of 39bus, 10 (generator), 46 branches, 29loads.

III. MOTH FLAME MULTI-OBJECTIVE OPTIMIZATION TECHNIQUE (MFO)

Moth-Flame Optimization (MFO) algorithm is a novel nature-inspired optimization; this technique depend on the behaviour of the Moths (fancy insects) , they are very like to the family of butterflies, the main stage is the inspiration of this optimizer is the navigation method of moths in nature which called transverse orientation. Moths fly in night by maintaining a fixed angle with respect to the moon, a very effective mechanism for travelling in a straight line for long distances as shown in fig .1, Later the moon is far away from the moth, this mechanism assurances flying in straight line. However the efficiency of transverse orientation, usually observed that moths fly spirally round the lights [8]. Also moths are deceived by artificial lights and show same behaviours, Due to the disorganization of the transverse orientation which it is only accommodating for moving in straight line when the light source is very far. When moths see an artificial light, moths attempt to maintain a similar angle with the light to fly in straight line. Then if a light is very close associated to the moon these fancy insects are trapped in a useless/deadly spiral path around artificial lights, a theoretical model of this behaviour is illustrated in Fig(2). It may be experiential that the moth finally joins towards the light. This procedure is modelled mathematically to suggest an optimization algorithm which called Moth-Flame Optimization (MFO)

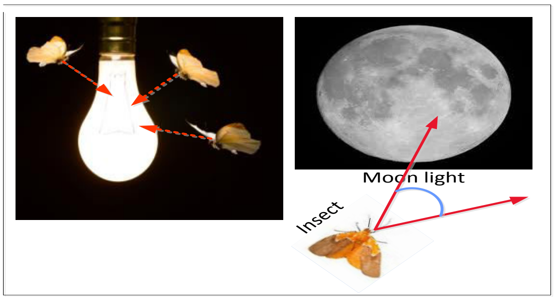
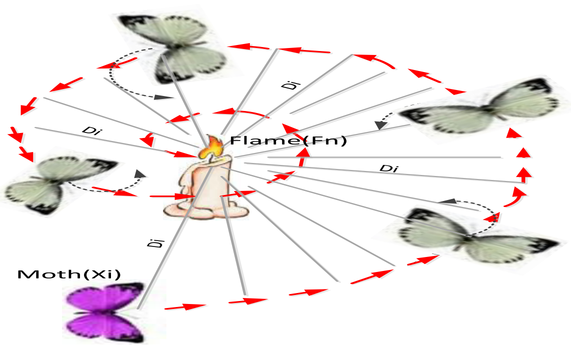


Fig (1) Transverse Orientation of Moths Fly



Fig(2) Moth Direction to the Flame

This algorithm assumed that the candidate solutions are moths and the problem's variables are the position of moths in the space. So, the moths can fly in 1-D, 2-D, 3-D, or overexcited dimensional space and changing their location vectors. Subsequently the MFO algorithm was a population-based algorithm; the set of moths is signified in a matrix as below [8]:

$$X=\begin{bmatrix} x_{1.1} & x_{1.2} & x_{1.3} & \cdots & x_{1.n} \\ x_{2.1} & x_{22} & \cdots & \cdots & x_{2.n} \\ \vdots & \ddots & \vdots & \vdots & \cdots \\ x_{n.1} & \cdots & \cdots & \cdots & x_{n.d} \end{bmatrix} \quad (1)$$

n : the number of moths
d : the number of variables (dimension)
For all the moths, assume that there is an array for storing the corresponding objective values as follows:

$$OX = \begin{bmatrix} ox_1 \\ ox_2 \\ ox_3 \\ \vdots \\ ox_n \end{bmatrix} (2)$$

n : the number of moths.

The fitness value is the return value of the objective function for each moth. The position vector (first row in the matrix X for instance) of each moth is passed to the objective function and the output of the fitness function is assigned to the consistent moth as its fitness value (OX_1)in the matrix OX for instance), other significant components in the proposed algorithm are flames.
A matrix similar to the moth matrix is considered as follows:

$$F = \begin{bmatrix} f_{1.1} & f_{1.2} & f_{1.3} & \cdots & f_{1.n} \\ f_{2.1} & f_{22} & \cdots & \cdots & f_{2.n} \\ \vdots & \ddots & \vdots & \vdots & \cdots \\ f_{n.1} & \cdots & \cdots & \cdots & f_{n.d} \end{bmatrix} \quad (3)$$

It be seen that the dimensions of X and F arrays are equal. For the flames, it is also expected that there is an array for storing the consistent objective values as follows[8]:

$$OF = \begin{bmatrix} of_1 \\ of_2 \\ of_3 \\ \vdots \\ of_n \end{bmatrix} (4)$$

It would be known that moths and flames are together solutions, and the variance between them is the way .The moths are definite search agents that move around the search space, whereas flames are the best position of moths that obtains so far. In additional words, flames can be measured as flags or pins that are released by moths when searching the search space. So, each moth searches around a flag (flame) and updates it in case of discovery a well solution, with this apparatus, a moth never drops its best solution.
The MFO algorithm is a three-tuple that approaches the global optimum of the optimization problems and defined as follows:

MFO= ((J, K, T) (5)

J is a function that produces a random population of moths and consistent objective values.
The systematic model of this function is as follows:

$J: \emptyset \rightarrow \{X, OX\}(6)$

The K function is the main function, moves the moths around the search space. This function conventional the matrix of X and revenues it's updated one finally.

$K: X \rightarrow X$ (7)

The T function proceeds true if the termination standard is satisfied and false if the termination criterion is not satisfied:

$T: X \{ \text{true}, \text{false}\}$(8)

There are two other arrays called ub andlb. These matrixes define the upper and lower bounds of the variables as follows:

$ub_i = [ub_1, ub_2, ub_3, \cdots . \cdots . ub_n]$(9)

ub_iIndicates the upper bound of the i-th variable.

$lb_i = [lb_1, lb_2, lb_3, \cdots . \cdots . lb_n]$(10)

lb_iindicates the lower bound of the i-th variable.

After the initialization, the J function is iteratively run until the T function revenues true. The J function is the key function that moves the moths round the search space, as stated before the inspiration of this algorithm is the transverse orientation.
In order to mathematically model this behaviour, the position of each moth is efficient with respect to a flame using the following equation:

$X_i = S\,(X_i\,, F_n)$ (11)
X_i : indicate the i-th moth
F_n: indicates the n-th flame
S: the logarithmic spiral function.
A logarithmic spiral is defined for the MFO algorithm as follows:
$S\,(X_i\,, F_n) = D_i \,.\, e^{bt} \,.\cos(2\pi t) + F_n$(12)
D_i : indicates the distance of the i-th moth for the n-th flame
b :a constant for defining the shape of the logarithmic spiral
t : a random number in [1, 1].
D is calculated as follows:
$D_i = |F_n - X_i|$ (13)

Consequently, a hyper ellipse can be expected around the flame in all directions and the next position of the moth would be within this space, the spiral movement is the key section of the suggested method because it dictates how the moths exchange their positions round the flames, so the spiral equation allows a moth to fly ‘‘around’’ a flame and not essentially in the space between them.
Then, the exploration and exploitation of the search space can be definite as the logarithmic spiral, space around the flame, and the position seeing different (t) on the curve, the flow chart illustrated in Fig3. Shows the procedure of the suggested algorithm

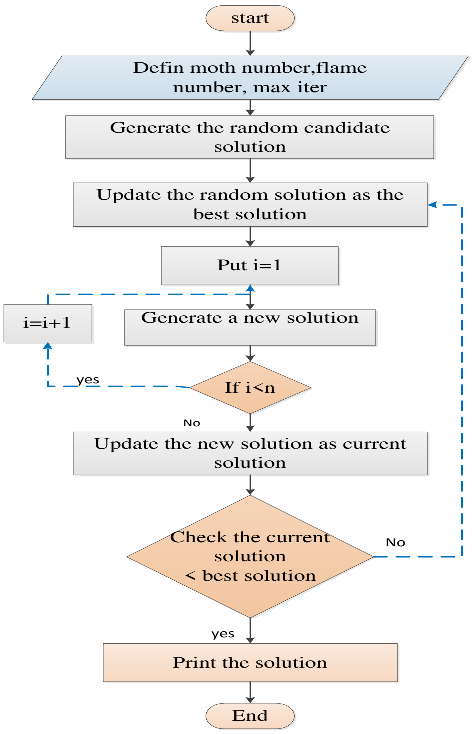


Fig (3) Flowchart of Moth Flame Optimization Technique

IV. MATHEMATICAL FORMULATION OF MULTI-OBJECTIVE FUNCTIONS

DGs allocation problem formulation:
The multi-objective optimization technique to determine the best locations and sizes of DGUs in distribution network system was as follows[9]:

$$\text{Min}\, f\,(P_l, Q_l, \Delta V, AC) = [\, f_1(P_l), f_2(Q_l), f_3(\,\Delta V), f_4(AC)\,] \quad (14)$$

f_1: The system active power loss
f_2: The system reactive power loss
f_3: loa voltage deviation
f_4: Annual investment cost

The voltage constraints:

$$V_{min} \le V_j \le V_{max} \quad (15)$$
$$S_{min} \le S_j \le S_{max} \quad (16)$$

S : the transmission capacity of branch j
V : the voltage of branch j

The forth objective is to minimize the annualized investment cost

In this paper, three cost components are considered: (a) the capital cost of DGs installation C_1 ($/kW); (b) the annual variable operating and maintenance cost of DGs C_2 ($/kWh);(c) the fixed operation and maintenance costs of DGsC_3 ($/kW-year)

$$Min\, f_4(\,AC) = P_{dg} \quad (17)$$

$$C_1 = \sum_{j=1}^{NDG} \left(\left(\frac{r*(1+r)^m}{(1+r)^m - 1}\right) \times C_{Cap.}\right) P_{dg} \quad (18)$$

C_1: Annual equipment installation cost ($/kW)
r: Annual interest rate.
m: number of years during which equipment installation cost take 5 years

NDG: number of DGs installed in the buses

$$C_2 = \sum_{j=1}^{NDG} (h \times C_{Variable}) * m) P_{dg} \quad (19)$$

C_2 the annual variable operating and maintenance cost ($/KWh) of DGs
H the number of operating hours in year , take 8 hours in day (8*8760) in year

$$C_3 = \sum_{j=1}^{NDG} (h \times C_{Fixed}) * m) P_{dg} \quad (20)$$

C_3: the fixed operating and maintenance cost ($/KW-year of DGs

V. APPLICATION AND RESULTS

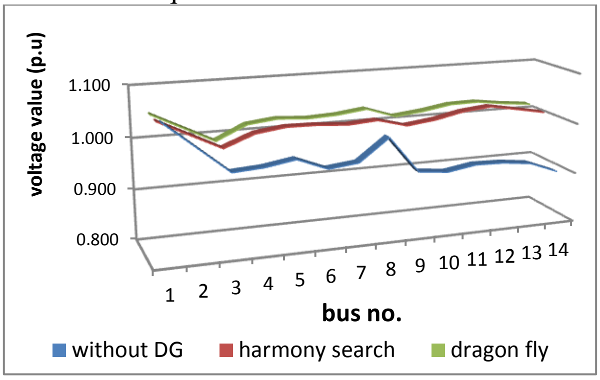
In this paper, Moth Flame optimization technique and Harmony Search algorithm are suggested to solve the DGs optimization allocation problem and find the optimal size and Location according to the type of DGs unit and the developed algorithm. Four Different types have been studied in this paper, namely, biomass, wind turbine, Combined Cycle Power Plant and hydro power plant [10]. The constants of DGs are illustrated in Table(1). These suggested optimization techniques are applied on two standard test systems a) IEEE 14- bus system and b) IEEE 39 –bus system [10].

Table (1)Constantsof the DGs Technologies

	C1($/KW)	C2 ($/KWh)	C3($/KWh)
Combined cycle power	1230	3.67	6.31
Hydro power	3500	6	15
Biomass	3830	15	95
Wind	1980	0	60

a) Results of IEEE14-bus system

MFO and HAS have been implemented and applied on IEEE 14 bus system with two different types of DGs technologies with small size (biomass and wind) less than 10Mwas mentioned in Table (1). The voltage profiles for the proposed techniques are presented in Fig.4.The results show that the voltage profile after DGsinstallationis improved and the voltage of all busesbetween constrain level (0.95-1.05).It is found that the best voltage profile is obtained when applying the MFO technique.



Fig(4) Voltage Profile of IEEE-14 Bus System for Biomass DGs Technology

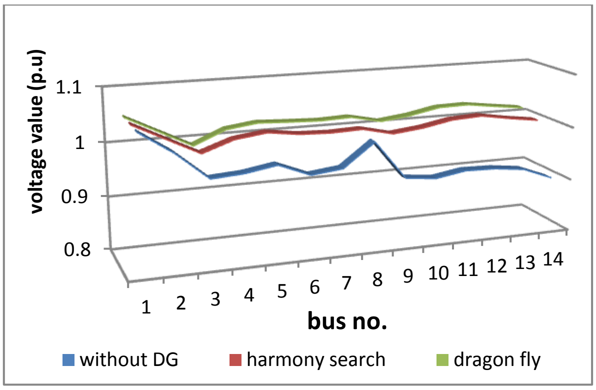
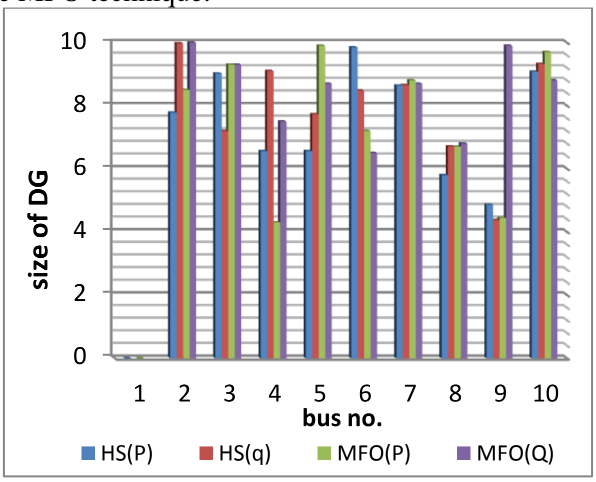


Fig (5) Voltage Profile of IEEE-14 Bus System for windTurbine DGs Technology

Tables (2) and (3)show how the (MFO) technique improve the voltage profile, minimum voltage deviation andreducing the active and reactive loss for three types of DGs units for test system. Through the comparison of simulated results with the harmony search and moth flame, it can be demonstrated that, the MFO has better performance than other technique HS[11].MFO technique has maximum loss reduction also the maximum of annual cost saving in M$.
Fig (6) shows the size of DG units for MFO and HS techniques, when the small and best size of DGs for the MFO technique.



Fig(6) Allocation and Size of the Two Optimization Techniques (MFO) and (HS)

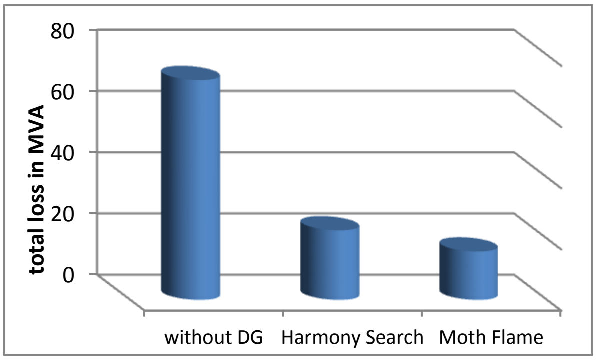
It is demonstrated that wind turbine DGismore economic, while this technique has the minimum cost of DGs units,also it has the maximum cost saving.
Figs(7-8) illustrate the minimization of total system loss in (MVA) and the annual cost saving.With two technologies of DGs units installed,it is concludedthat the wind turbine DG with moth flame algorithm give the maximum percentage loss reduction in the system and the maximum annual cost saving in M$.
Fig (9) illustrates the objective function which meansthat when installing the DGs units the goal is reached,minimumvoltage drop, power system lossreduction and minimum investmentcost of DG units.

Table (2)Analysis of the proposed techniques for IEEE-14bus system with Biomass DGs

Parameters	Without DG	With DG	
		HSA	MFO
Active loss (MW)	21.7861	11.706	10.750
Reactive loss (MVAR)	67.7726	19.330	15.487
Total Loss reduction (%)	5.2312	1.984	2.106
Cost of DG installed(M$)	0	68.255	73.518
Annual cost saving (M$)	0	1.984	1.794

Table (3)Analysis of the ProposedTechniques for IEEE-14bus system with wind turbine DGs

Parameters	Without DG	With DG	
		HSA	MFO
Active loss (MW)	21.7861	11.72	10.7455
Reactive loss (MVAR)	67.7726	19.57	15.4870
Total Loss reduction (%)	5.2312	1.54	2.0864
Cost of DG installed(M$)	0	67.96	73.5212
Annual cost saving (M$)	0	0.39	0.0071



Fig(7)Valuesof Total System Losses for the Proposed Techniques

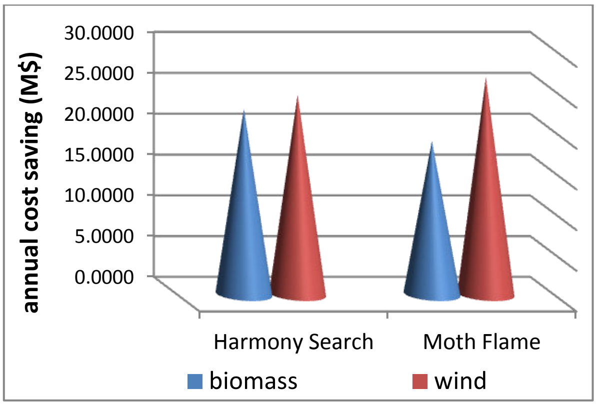
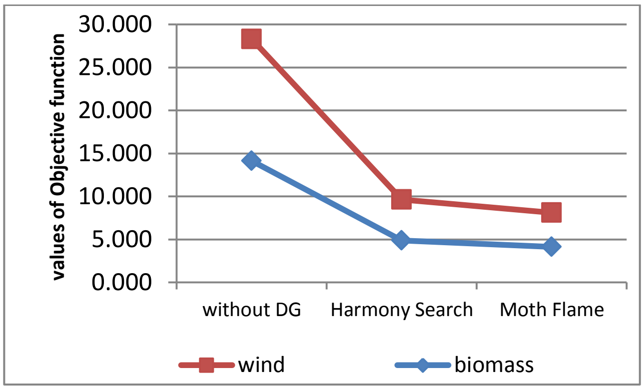


Fig (8) Annual Cost Saving For the Techniques

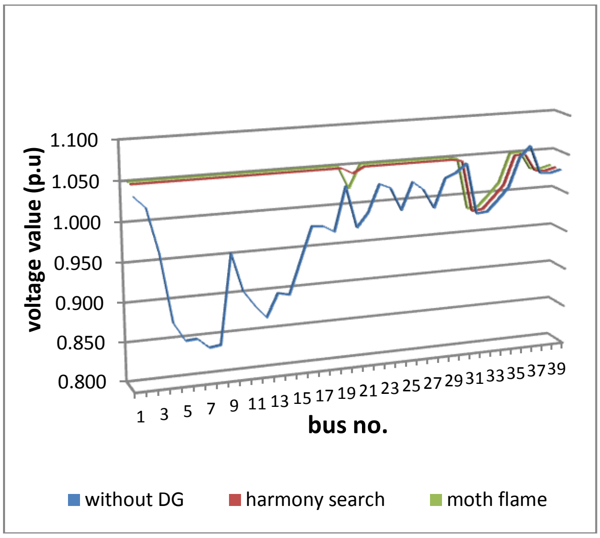


Fig(9)The Objective Function for the Proposed Techniques

b) Results Of IEEE 39-Bus System

MFO and HShave been implemented and applied on IEEE 39 bus system with two different types of DGs technologies (combined cycle and hydro power).With size less than 50 MW,voltage profiles for all techniques are presented in Fig (9), the results show that the voltage profile after DG units allocation is improved and the voltage for all buses is between constrain level (0.95-1.05)p.u, it is found that the best voltage profile is obtained with MFO.Tables (4) and (5) show how (MFO) technique improves voltage profile, minimizing voltage deviation and reducing total power system loss. For two types of DGs technologies applied on IEEE-39 bus test system.

Through the comparison of simulated result with the HSA and MFO can be demonstrated that, the MFO has better performance than other technique, when analyzing the results in Table (2).



Fig(9) Voltage Profile of IEEE-39 Bus System with Combined cycleDGs

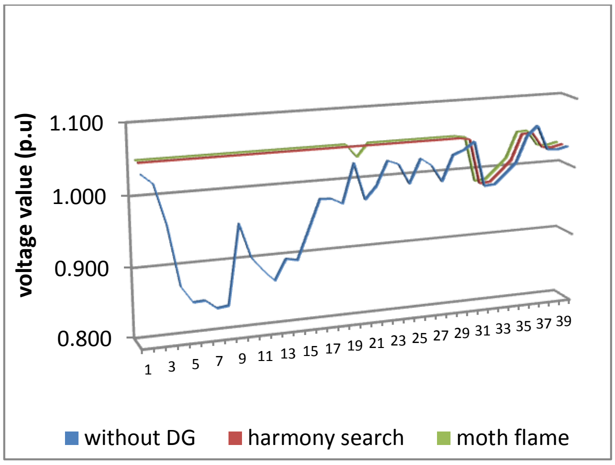


Fig (10) Voltage Profile of IEEE-39 Bus System with Hydro Power DGs

It is demonstrated that in Fig. (11) Combined cycleplant DG is more economical, while this technique has the minimum cost of DGs also maximum annual cost saving in M$.
Fig.(12) shows the total system loss for the suggested techniques, obtain the MFO technique has the less value of total loss.

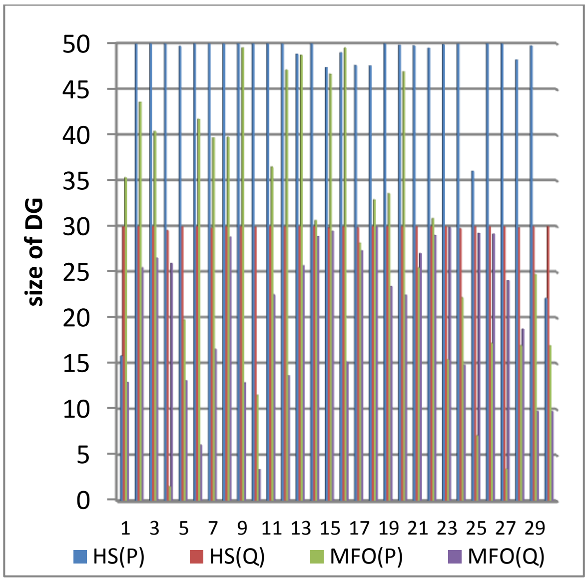


Fig (11) Location and Size of the Two Optimization Techniques (MFO and HS)

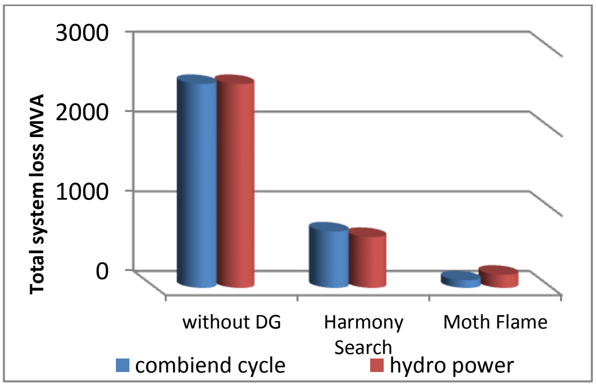


Fig (12) Total System Loss of IEEE-39 Bus System

Fig (12) and (13) illustrates the minimum total system loss in (MVA) and annual cost saving, with two technologies of DGs unitsinstalled. It is concluded that the combined cycle technology with MFO techniquereach to the goal,Maximum percentage loss reduction in the system also the large number of annual cost saving in million dollars.
Fig (14) illustrate the objective function that mean when installed the DGs units the goal is reached minimum voltage drop, total system loss reducing and min investment cost of DGs units allocation.

Table (4) Analysis of the Proposed Techniques for IEEE-39 Bus System with CombinedCycle DGs

Parameters	Without DG	With DG	
		HSA	MFO
Active loss (MW)	85.669	59.92	45.3938
Reactive loss (MVAR)	2557.6	706.4	131.026
Total Loss reduction (%)	0.00	72.29	94.58
Cost of DG installed(M$)	0.00	2.32	4.33
Annual cost saving (M$)	0.00	787.15	1032.91

Table (5) Analysis of the Proposed Techniques for IEEE-39 Bus System with Hydro Power DGs

Parameters	Without DG	With DG	
		HSA	MFO
Active loss (MW)	85.669	59.41	45.41
Reactive loss (MVAR)	2557.60	637.55	146.0
Total Loss reduction (%)	0.00	74.98	94.29
Cost of DG installed(M$)	0.00	3.92	7.09
Annual cost saving (M$)	0.00	814.45	1026.89

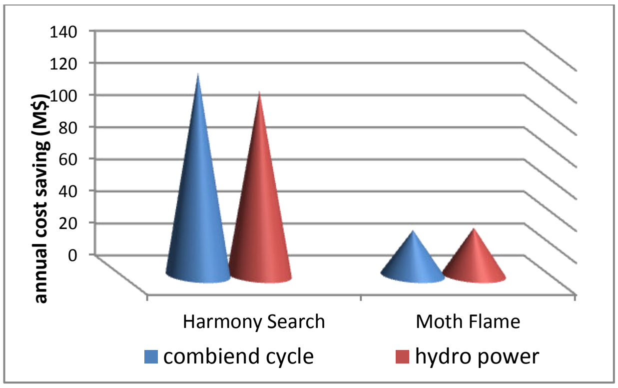


Fig (13)Annual Cost Saving in IEEE-39 Bus with DGs Allocation

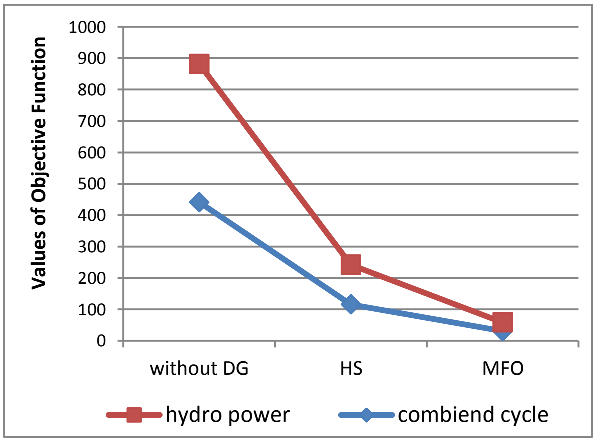


Fig (14) Objective Function Values for the Proposed Techniques

VII. CONCLUSIONS

In this paper, MFO technique is used for determining the optimal size and location of distributed generators in distribution system.The proposed technique is effectively applied to a two benchmark systemsIEEE14-Bus and IEEE39-Bus. The comparison between MFOand HS has been occurred and showed that MFO has the best results a) IEEE14-Busvoltage profile improvement for all buses with min voltage value 1.035,reducing the total power system loss up to 73.5%with annual cost saving 24.8 (M$)of the distribution system, b) IEEE39-Bus system the technique is more effectively with bid distribution systems while thereduction of total system power loss up to 94.58%,with 1032.91M$ annual cost saving

For DGs technology the wind turbine more economically than the biomass with difference in annual cost saving 2.2M$, also the combined cycle power plant has more economically with hydro power in difference value 6.1M$.

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