American Journal of Engineering Research (AJER)
E-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-8, Issue-2, pp-101-110
www.ajer.org
Research Paper Open Access

Evaluating the Impact of Optimal Sizing and Allocation of Distributed Generation Units Using New Multi-Objective Optimization Techniques

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ABSTRACT : *This paper presents the determination of the optimal location and size of Distributed Generation Units in power system networks. Their optimal allocation was very important to improve the voltage profile, and minimize the system loss, with ensuring a minimum cost of the units. Three novel optimization techniques have been employed to choose the most appropriate one. Two different IEEE benchmark standard systems, IEEE-14 Bus system and IEEE-30 Bus system, were used to validate the effectiveness of the proposed optimization techniques. The simulation results showed that the proposed techniques had a good performance. The mine blast algorithm had the best performance when testing the IEEE-14 Bus system, while the flower pollination algorithm was the best when IEEE-30 Bus system was tested.*

KEYWORDS: *Multi-objective optimization, Mine Blast Algorithm, Harmony Search, Flower Pollination Algorithm, Voltage Drop, Distribution generators.*

Date of Submission: 26-01-2019 Date of acceptance: 09-02-2019

I. INTRODUCTION

According to the rapid growth of electricity consumption, Distributed Generation Units (DGUs) are acting as a significant part in distribution networks due to their merits, such as increasing the reliability, distribution loss reduction, voltage profile improvement, more economic and environmentally friendly. Thus, the term DGUs also suggests the use of any flexible technology that is sited throughout a utility's service area, which is interconnected to the distribution or sub-transmission system, to decrease the cost of the facility. Although, several models and methods have been suggested in many researches to obtain the optimal solution of size and allocation of DGUs, which improves the efficiency of distribution networks [1], but no research could studied all the advantages of DGUs for improving the voltage profile and reducing system losses using the most economic type and size of DGUs in distribution networks.

To meet this goal, the solution techniques for selecting the appropriate size and location of DGUs, number of approaches have been developed. There are certain mathematical and computational characteristics of the techniques were discussed in the previous years. These techniques were classified to three categories: conventional methods, intelligent search-based methods, and fuzzy set based method [2]. This paper presents new different methodologies, which have been applied to two IEEE benchmark standard systems, IEEE-14 Bus system and IEEE-30 Bus system.

II. PROBLEM FORMULATION

In a distribution system, the power flow study is a significant tool involving numerical analysis applied to a power system. The aim of this analysis is finding both magnitude and phase angle of the bus voltage and the active and reactive power flowing in each transmission line, which analyze the power systems at normal steady state operation. A conventional technique was used to solve the load flow problem, such as the iteration method using Newton-Raphson (NR) due to its accuracy. Matlab- 2017 programming is used [3].

III. LOAD FLOW EQUATIONS

Assuming a system having (n) buses, the injected current to the bus j can be expressed as:

$$I_j = \sum_{n=1}^{N} Y_{jn} \ V_n$$

Where Y_{jn} is the element in the bus admittance matrix Y bus

$$Y = |Y|\angle\theta \quad , \quad V = |V|\angle\theta$$

The complex power at bus j where (j = 1,2, ..,n) is given as:

$$S_j^* = V_j^* \, I_J = P_j - jQ_j$$

$$P_j - jQ_j = V_j^* \sum_{n=1}^{N} Y_{jn} \ V_n$$

$$I_j = \frac{S_j^*}{V_j^*} = \frac{P_j - jQ_j}{V_j^*} \quad j = 1, 2, 3, \dots \dots \dots., n$$

Where,

P_j : The active power injection in the bus j

Q_j : The reactive power injection in the bus j

V_j : The terminal voltage of the j^{th} generator

n : The number of buses.

IV. CASE STUDY

In this paper, two IEEE benchmark standard systems, IEEE-14 Bus system and IEEE-30 Bus system have been implemented [4], [5]. These systems present many vertices such as number of busses, numbers of generators, branches, the total values of real losses and voltage profile.

V. OPTIMIZATION TECHNIQUES

Several optimization techniques have been applied to DGUs allocation, such as genetic algorithm [6], tabu search [7], heuristic algorithms [8], [9] and analytical based methods [10]. In all these techniques, the problem of DGUs allocation and sizing was solved to minimize or maximize the fitness function. In this paper, three novel optimization techniques will be implemented to validate the results and finding which technique gives the best solution, more accurate and with small time operation:

1- Harmony search optimization technique

The harmony search (HS) is a meta-heuristic algorithm, which was stimulated by the basic principles of the musicians' searching for the harmony with a perfect state to find the best solution in an optimization process [11]. To get the best tune, musicians play different segments of notes with different musical instrument and find the best combinations of music pitches in a music invention progression. This is the same method in the HS algorithm, which is to minimize or maximize the objective function by selecting the best combinations from the existing solutions.

2- Flower pollination algorithm

Flower Pollination Algorithm (FPA) is a meta-heuristic search algorithm of an interesting process in the natural world, which has been suggested by Yang and Deb. [12]. The purpose of the flower pollination process is the optimal reproduction of plants in terms of numbers as well as fitting. This optimization technique is based on flower pollination features, which implying the survival of the fittest plant. This could be used to find the best solution for an objective function.

3- Mine blast algorithm

The detonation of mine bombs is resulting due to thrown pieces of shrapnel, which collide with other mine bombs near the explosion area. This is the main determination of the mine blast algorithm (MBA), which discovers the one with the most explosive influence located at the optimal point [13]. This technique is useful in solving many constrained engineering problems to find an optimal existing solution.

VI. FORMULATION OF MULTI-OPJECTIVE OPTIMIZATION PROBLEM

The construction of DGUs location and sizing problem as a mono-objective optimization is not quite applied. Power system planners aim to get the merits of multi-type DGUs considering several objectives at the same time. This paper recommends a multi-objective optimal placement of multi-type of DG such as biomass, wind turbine and micro turbine sources. These types are selected due to its variety of characteristics for the improvement of the distribution system performance. Multi objective functions include minimize voltage deviation (VD) to improve the voltage profile, minimize the total system power loss, and also reduce the total investment cost [14].

Objective function

The multi-objective optimization technique to determine the best locations and sizes of DGUs in a distribution network system is as follows:

$$f(P_l, Q_l, \Delta V, AC) = [f_1(P_l), f_2(Q_l), f_3(\Delta V), f_4(AC)]$$

Where,

f_1 The system active power loss

f_2: The system reactive power loss

f_3: Load voltage deviation

f_4: Annual investment cost

Firstly, the objective f_1 is to minimize the system active power loss:

$$f_1(P_l) = P_l = V \times I \;\cos\cos\emptyset \approx I^2 R$$

Secondly, the objective f_2 is to minimize the system reactive power loss:

$$f_2(Q_l) = V \times I$$

Thirdly, the objective f_3 is to minimize the bus voltage deviation VD:

$$f_3(\Delta V) = \sum_{K=1}^{nB} \left(\frac{V_j^{ref} - V_j}{V_j^{ref}}\right)$$

The voltage constraints are:

$$V_{min} \le V_j \le V_{max}$$

$$S_{min} \le S_j \le S_{max}$$

Where,

S The transmission capacity of branch j

V_j: The voltage of branch j

Fourthly, the objective f_4 is to minimize the annualized investment cost.

Three cost components are considered: (a) the capital cost of DGUs installation C_1 (\$/kW); (b) the annual variable operating and maintenance cost C_2 (\$/kWh); (c) the fixed operation and maintenance cost C_3 (\$/kW-year).

$$f_4(AC) = P_{dg}$$

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

C_1: Annual equipment installation cost (\$/kW).

r: Annual interest rate.

m: Number of study years (5 years).

NDG: Number of DGUs installed in the buses.

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

C_2: The annual variable operating and maintenance cost ($/kWh).
h: The number of operating hours/year, taking 8 hours/day

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

C_3: The fixed operating and maintenance cost ($/kW-year).

VII. RESULTS AND DISCUSSION

Three optimization techniques “HS, MBA, and FPA” are used to solve the DGUs allocation problem, which is to find the optimal size and location according to the type of DGUs. Three different types of DGUs with a small size are studied to choose the most economic one, as they have different constants, namely: Biomass, Micro Turbine and Wind [15] as shown in Table I. Those suggested optimization techniques are applied on two standard test systems: IEEE 14-Bus system and IEEE 30-Bus system. The results are shown below:

Table I: Constants of DGUs technology

	C1 ($/kW)	C2 ($/kWh)	C3 ($/kWh)	No. of study years
Biomass	3830	15	95	5
Micro Turbine	2250	3.67	6.31	5
Wind	1980	0	60	5

Case (1) results: IEEE-14 BUS system

The voltage profiles and the total voltage deviations for all techniques are presented in Fig. 1 and Fig. 2. The results showed that the voltage profile after DGUs allocation were improved, and the voltage (p.u) value of all buses were within the constrain level (0.95-1.05).

Table II illustrates how the optimization techniques chose the best size and allocation of DGUs for improving the voltage profile, minimizing voltage deviation, and reducing the active and reactive loss for the three types of DGUs. Comparing the results of the three algorithms, the MBA had a better performance than the other two techniques.

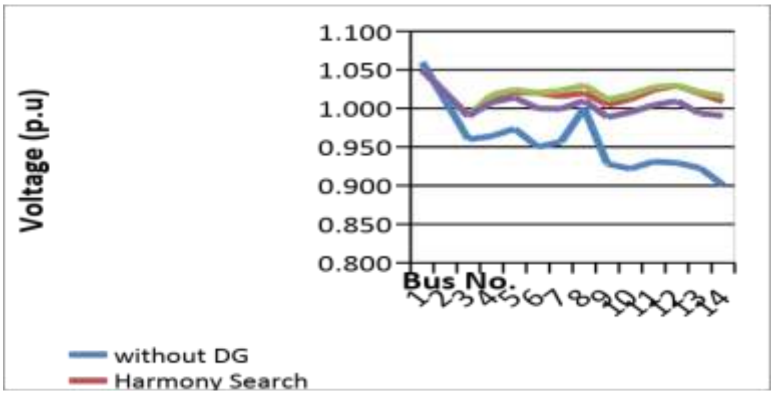

Fig. 1: Voltage profile of IEEE 14-Bus system

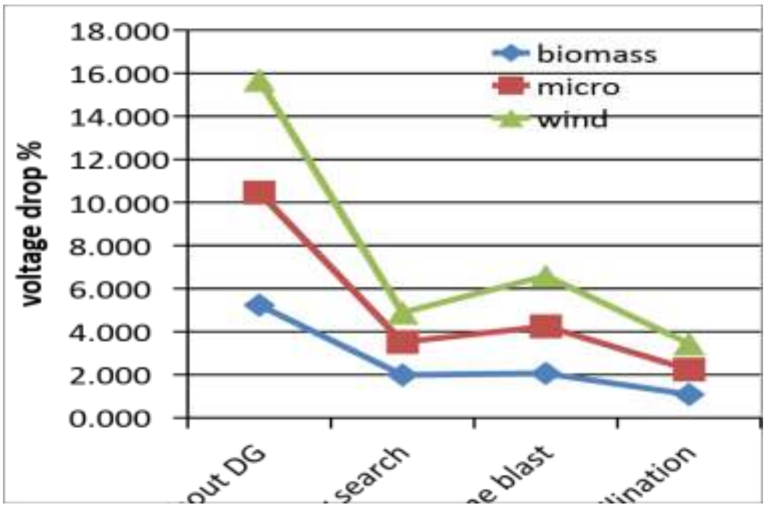

Fig. 2: Voltage drop for IEEE 14-Bus system

The results in Table II showed that MBA had a larger loss reduction percentage than HS and FPA, as MBA decreased the loss reduction percentage more than HS and FPA with 7.2% and 0.65% respectively. However, for minimum voltage deviation, FPA had the best results with a deviation percentage of 1.16% for the micro turbine type as shown in Fig. 2.

Table II: The results of case (1)

DG type	Parameters	Without DG	With DG allocation using optimization techniques		
			HS	MBA	FPA
Bio-mass	Active loss (MW)	21.7861	11.706	10.750	10.700
	Reactive loss (MVAR)	67.7726	19.330	15.513	15.780
	Voltage deviation (%)	5.2312	1.984	1.790	1.080
	Total Loss reduction (%)	0	68.255	73.488	73.218
	Cost of DG installed (M$)	0	1.984	1.790	1.791
	Annual cost saving (M$)	0	23.030	24.825	24.732
Micro Turbine	Active loss (MW)	21.7861	11.72	10.81	10.80
	Reactive loss (MVAR)	67.7726	19.57	15.59	16.07
	Voltage deviation (%)	5.2312	1.54	2.18	1.16
	Loss reduction (%)	0	67.96	73.35	72.79
	Cost of DG installed (M$)	0	0.39	0.44	0.44
	Annual cost saving (M$)	0	24.1154	26.1156	25.9168
Wind	Active loss (MW)	21.7861	11.7178	10.7791	10.7842
	Reactive loss (MVAR)	67.7726	19.5436	15.5880	15.9959
	Voltage deviation (%)	5.2312	1.3664	2.3399	1.2056
	Loss reduction (%)	0	67.9901	73.3777	72.9005
	Cost of DG installed (M$)	0	0.0068	0.0071	0.0071
	Annual cost saving (M$)	0	24.5060	26.5634	26.3899

Table III shows the size and allocation of the DGUs in the buses to achieve the minimization of the objective function. DGUs were not installed on generator buses and with a value of 30% of the total power generation in the system.

Table III: The optimal size and allocation of DGUs in IEEE-14 Bus system

Bus No.	HS		MBA		FPA	
	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
4	7.78	9.981	8.5	10	10	9.9
5	9.02	7.196	9.3	9.3	8.05	10
7	6.56	9.135	4.3	7.5	10	10
8	6.56	7.724	9.9	8.7	9.9	9.9
10	9.85	8.484	7.2	6.5	9.4	10
11	8.63	8.654	8.8	8.7	8.4	10
12	5.79	6.704	6.7	6.8	2.8	3.5
13	4.85	4.373	4.44	9.9	7.06	8.5
14	9.07	9.321	9.7	8.8	10	9.8

When analyzing the results with respect to the running time in seconds, Fig.3 showed that MBA had the minimum operation time.

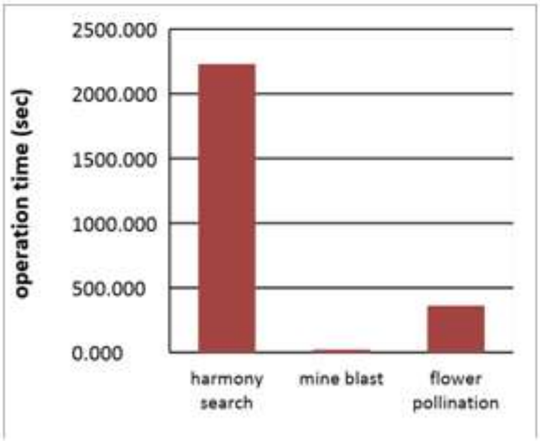

Fig. 3: The operation time

Figs. 4 and Fig. 5 illustrated the percentage of reduction in total active and reactive power loss with installing the DGUs, and annual cost saving. The results analysis concluded that the wind type of DGUs using MBA got the maximum percentage in loss reduction as well as the maximum annual cost saving with values of 73.3777% and 26.5634 M$, respectively.

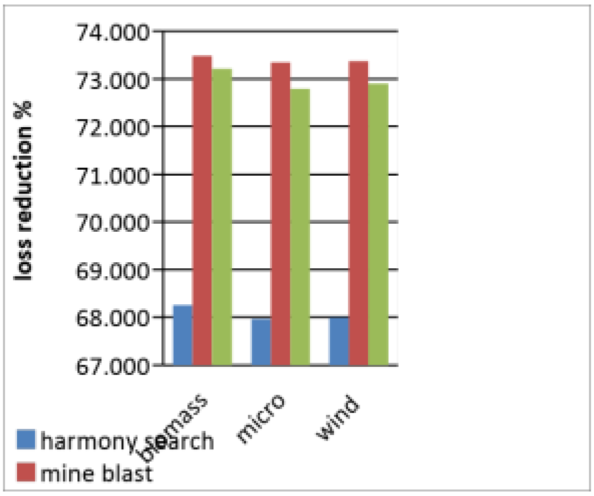

Fig. 4: % Loss reduction for all techniques

Case (2) results: IEEE-30 BUS system

The voltage profiles and the total voltage deviations for all techniques are presented in Fig. 6 and Fig. 7. The results also showed improved voltage profile after DGUs allocation within the constrain level (0.95-1.05) of the voltage at all buses. Comparing the results of the three algorithms, the FPA had a better performance than the other two techniques as shown in Table IV.

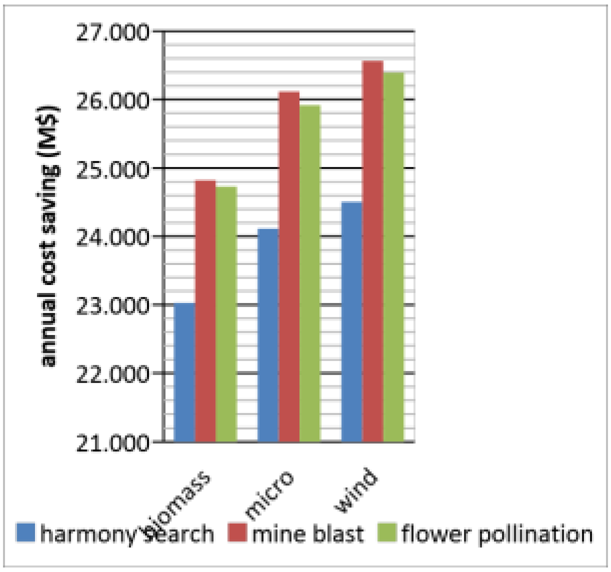

Fig. 5: Annual cost saving (M$) for all techniques with DGUs types

The results in Table IV showed that FBA had a larger loss reduction percentage than MBA and HS, as FPA decreased the loss reduction percentage more than MBA and HS with 14% and 14.55% respectively. For minimum voltage deviation, FPA had the best results with a deviation percentage of 1.242% for the wind type as shown in Fig. 7.

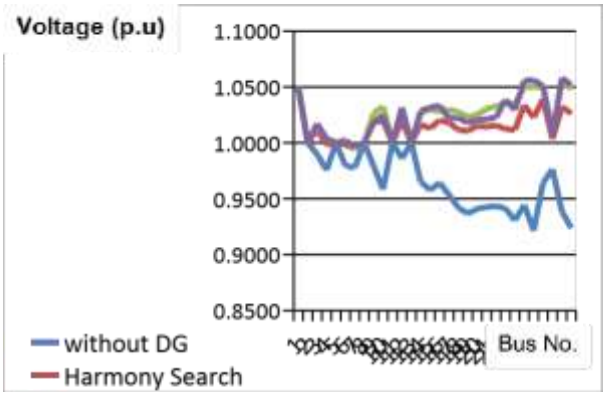

Fig. 6: Voltage profile of IEEE 30- Bus system

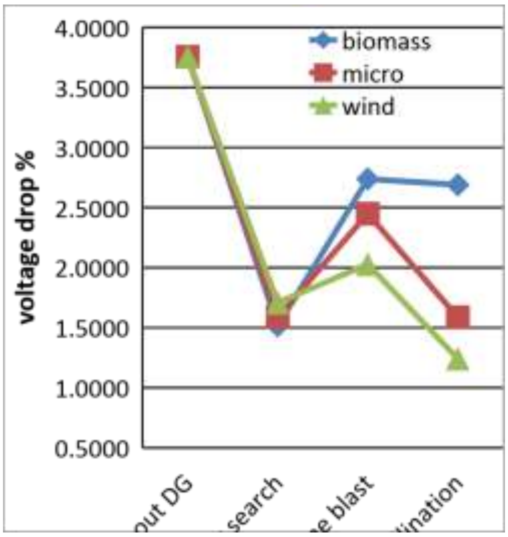

Fig. 7: Voltage drop for IEEE 30- Bus system

Table V shows the size and allocation of the DGUs in the buses to achieve the minimization of the objective function. DGUs were not installed on generator buses and with a value of 30% of the total power generation in the system.

Table IV: The results of case (2)

DG type	Parameters	Without DG	With DG allocation using optimization techniques		
			HS	MBA	FPA
Bio-mass	Active loss (MW)	29.6515	15.9525	15.5243	16.6324
	Reactive loss (MVAR)	83.8846	25.1496	23.6043	27.4031
	Voltage deviation (%)	3.7545	1.5165	2.7382	2.6884
	Loss reduction (%)	0	66.5259	68.2460	63.9706
	Cost of DG installed (M$)	0	1.7563	1.8529	1.6599
	Annual cost saving (M$)	0	28.7007	29.4339	27.5637
Micro Turbine	Active loss (MW)	29.6515	15.6179	15.5860	15.6179
	Reactive loss (MVAR)	83.8846	23.9250	23.6281	23.9259
	Voltage deviation (%)	3.7545	1.5874	2.4486	1.5874
	Loss reduction (%)	0	67.8868	68.1855	67.886
	Cost of DG installed (M$)	0	0.4476	0.4566	0.4476
	Annual cost saving (M$)	0	30.66	30.7940	36.2320
Wind	Active loss (MW)	29.6515	15.84	15.795406	10.761
	Reactive loss (MVAR)	83.8846	24.8061	24.319545	15.955
	Voltage deviation (%)	3.7545	1.70789	2.0281676	1.242
	Loss reduction (%)	0	66.9149	67.4063	78.370
	Cost of DG installed (M$)	0	0.01285	0.01293	0.007
	Annual cost saving (M$)	0	30.632	30.859	36.499

Table V: The optimal size and allocation of DGUs in IEEE-30 Bus system

Bus No.	HS		MBA		FPA	
	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
3	10	10	3.583039	0	10	4
4	10	4	8.545665	3.75	10	3.88
6	10	4	10	0	9.5	2.88
7	10	4	3.74	4	8.99	4.2
9	10	4	8.07	0	0	4
10	0	4	8.88	3.88	4.25	4
12	5.4267	4	9.93	3.83	10	4
14	10	4	0	3.44	2.2	3.99
15	2.27	4	5.36	4	4.07	4.4
16	4.07	4	0.927	4	8.41	3.5
17	0	4	6.65	5.2	0	4
18	4.79	4	3.820	2.814	4.7	3.99
19	0.88	4.7	0.4120	4	0.88	4
20	10	4	0	4	10	4
21	1.97	4	7.55	4	1.97	1.31
22	1.3	3.9	8.404	4	10	4
23	10	3.5	4.9	3.15	2.31	4
24	2.31	4	2.5	4.2	1.35	3.99
25	0	4	9.1	4.3	0.98	4
26	0	3.5	2.4	3.8	1.2	3.88
27	1.2	3.8	3.4	3.7	2.4	3.99
28	1.13	5.3	9.5	4	2.28	4
29	2.45	3.8	4.2	3.9	0.03	3.99
30	7.3	3.8	4.2	4.7	7.5	3.5

Fig. 8 showed that MBA had the minimum operation time. Figs. 9 and Fig. 10 illustrated the percentage of reduction in total active and reactive power loss with installing the DGUs, and annual cost saving. The results analysis concluded that the wind type of DGUs using FPA got the maximum percentage in loss reduction as well as the maximum annual cost saving with values of 78.37% and 36.499 M$, respectively.

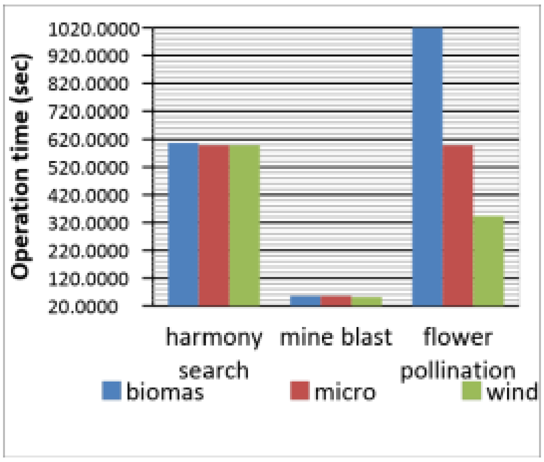

Fig. 8: The operation time

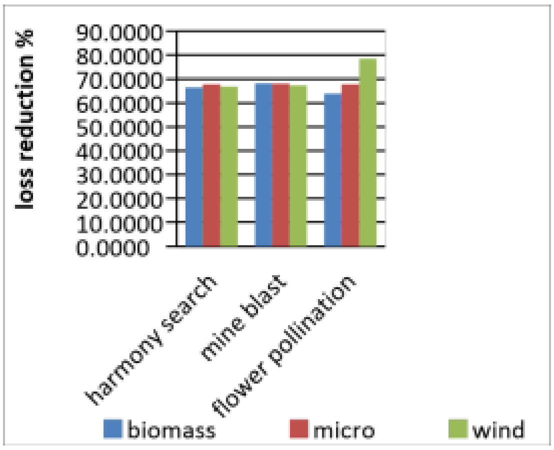

Fig. 9: % Loss reduction for all techniques

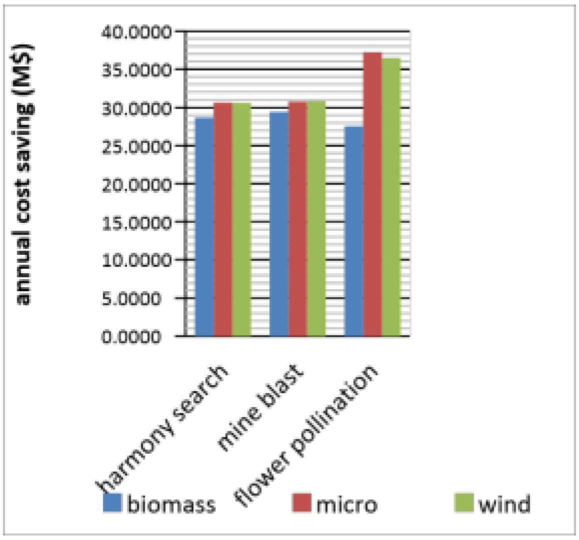

Fig. 10: Annual cost saving (M$) for all techniques with DGUs types

VIII. CONCLUSIONS

In this paper, three meta-heuristic optimization techniques are implemented on a multi-objective function, with installing DGUs. Two bench benchmark test systems: IEEE 14-Bus and IEEE 30-Bus are tested. The used approach was to improve the voltage profile, minimize the active and reactive total system power loss, and minimize the investment cost. The suggested techniques used to find the optimal size and location of DGUs with penetration level of 30% of the total power generation in the system.

The results of testing the IEEE-14 Bus system concluded that MBA had the best performance with loss reduction of 73.3777% and annual cost saving of 26.5634 M$ when using wind turbine technology. However, FPA had the best performance when IEEE30-Bus system was tested, with a loss reduction of 78.37% and annual cost saving of 36.499 M$ when using wind turbine technology as well. However, the minimum execution time was using MBA for both testing systems.

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Shimaa A. Hussien" Evaluating the Impact of Optimal Sizing and Allocation of Distributed Generation Units Using New Multi-Objective Optimization Techniques" American Journal of Engineering Research (AJER), vol.8, no.02, 2019, pp.101-110