Optimal Allocation of Distributed Generation in A Part of The Egyptian Electrical Network Using Whale Optimization Algorithm

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***Abstract*— The Distributed Generation (DG) relaying on generating units with small ratings to be linked into the distribution network close to the consumers. It can provide a promising future for power generation in electric networks. Recently, the demand for distributed generation into the electrical networks is rapidly increasing. Connecting DG units into the distribution networks can provide environmental, economic and technical merits. Those merits can be optimized if the DG unit site and size is properly determined. This paper presents a proposed multi-objective approach for determining the optimal allocation of the DG to enhance the voltage profile and minimizing the total active power loss of the distribution system. A recent optimization technique, Whale Optimization Algorithm (WOA), is presented. A portion of the Egyptian electric network in the East Delta is introduced for testing the proposed algorithm via MatLab software.**

Keywords—Distributed generation, Loss reduction, Radial distribution network, Whale optimization algorithm.

I. INTRODUCTION

Distributed Generation (DG) is a small capacity generating units connected to the distribution network close to the consumers. Distributed generators include wind turbines, solar photovoltaic, small hydro power, Reciprocating Engine, etc., with or without storage elements. Instead of depending on huge power stations in the electricity generation field, nowadays each consumer can generate his need of electricity by his small generating unit and also can connect it with the utility. In addition, some people can invest in the field of electricity generation by constructing their own DG small plants and selling the electricity to the other consumers. Some factories can exploits the empty area of the factory surface by installing photovoltaic modules to feed their loads and sell the rest to the utility. Wherefore, it can be said that DG made a breakthrough in the electricity generation sector. Such matter which made some researchers to predict that the power system trends to be more distributed. DG can be divided into different categories according to the power rating [1]. These categories are showed in Fig. 1.

Connecting the DG units to the distribution network can achieve number of merits such as:

-Reducing the environmental harmful impacts which can be produced from the thermal power stations such as CO2 and SO2,

-Saving in the cost of the transmission and distribution feeders,

-Reducing the power loss in the feeders and enhancing the system efficiency,

-Making competition in the generating electricity market between the government sector and the private sector represented in the investors which in turn improving the product quality and reducing the cost,

-Improving voltage stability, and enhancing the system reliability [2].

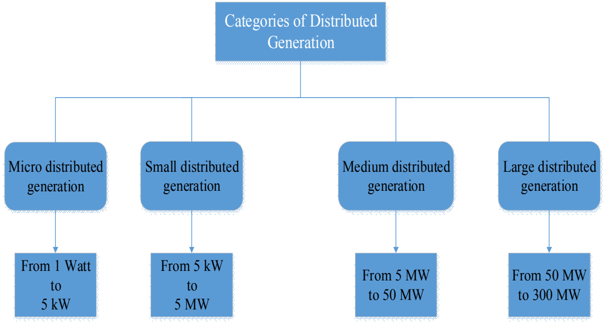

Fig. 1. Categories of distributed generation

Proper selection of the site and capacity of the DG units is very important for achieving these desired benefits. Not favorable impacts could occur if the DG units are connected without considering the study of the inserted units rating and place. These merits can be maximized by obtaining the optimum allocation of the DG units. Wherefore, several optimization techniques are presented for solving this problem [3]. Reduction of total active power loss was considered as the objective function in most of the literatures as [4-6]. ABC technique is presented in [4], however a proposed Selective Particle Swarm Optimization (SPSO) is introduced in [5]. Genetic Algorithm (GA) is presented in [6]. The optimization variables were considered as the generators site, size, and power factor in [4]. However, only sizing optimization is considered in [6], and the DG unit is linked with the bus which has minimum voltage. In [5], the DG units are linked with the buses which have the highest loss sensitivity factor. PSO technique is presented for solving the optimization technique in [7]. While in [2] a recent optimization technique, Crow Search Algorithm (CSA), is presented.

The total active power loss is minimized in the literatures subjected to some constraints. The active and reactive power balance constraints are considered in [8,9], but the voltage profile constraint is considered in [4-5,8-9]. In literature [5] the DG penetration level constraint is taken into consideration.

It is assumed that the maximum DG penetration level is in a range of 0–50% of total load.

On the other hand, different case studies are considered to test the solution proposed in each literature. A practical radial distribution system of Iraqi network consisting of 30 buses is considered in [8], but in [6], a standard system of IEEE 30 bus test distribution system is presented. The IEEE 33 and 69 standard bus systems are considered in [4-5].

In some literatures, the impact of DG is studied without using optimization techniques as [10-11]. The impact of DG on voltage profile and power losses is studied in [10]. The DG unit is located once at the bus which has the minimum voltage and another with the loading center. However, in [11], the effect of three different models of DG types on real power loss, reactive power loss and the voltage profile have been presented.

In addition, some literatures took into consideration number of objectives forming a multi-objective function by weighting factors as in the literatures [2,7]. In reference [2], the multi-objective function was based on the cost, and the voltage profile was not taken into the objective function. While, the study in reference [7] depended on only one type of DG units which inject both of P and Q.

In this paper, a recent optimization technique, Whale Optimization Algorithm (WOA), is proposed for determining the optimal size and site of the DG units. A proposed multi-objective function is developed to enhance the voltage profile and minimizing the total active power loss of the distribution system. Different types of DGs are considered and compared according to the total active power loss reduction, voltage enhancement via determining the minimum bus voltage, and the proposed multi-objective function. The proposed algorithm is tested by a practical distribution system, a portion of the Egyptian electrical network in the East Delta, using MATLAB software.

The problem is formulated using the power flow equations, and the simultaneous non-linear equations in power flow analysis are solved via Newton Raphson method.

The rest of the paper is organized as follows: section 2 presents the problem formulation. Section 3 gives a brief summery of the WOA technique. While the system under study and the obtained results for each DG type are given in section 4. The calculations are presented in section 5.

II. PROBLEM FORMULATION

Power-flow, or load flow, studies are of great importance in studying power system operation, planning, and protection in steady state. In power flow analysis, it is assumed that the system under study is in the three phase equilibrium conditions, so that one phase of the system can be represented in calculations. The power flow problem, mainly, is the calculation of voltage magnitude and phase angle at each bus in the system. As a result of this calculation, active and reactive power flows in transmission lines, as well as losses, can be computed [6,12].

A. Objective function

In optimal DG sizing and location problem, the objective is selected to minimize the total active power loss and to improve the voltage profile. Wherefore, two indices are proposed: The Active Power Loss Reduction Index (APLRI), and the Voltage Deviation Index (VDI). Thus, the multi-objective function can be formulated as:

Minimize (MOF)

$$MOF = w_1 APLRI + w_2 \, VDI \tag{1}$$

Where,

$$APLRI = \frac{P_{loss,DG}}{P_{loss,base}} \tag{2}$$

Where $P_{loss,DG}$ is the total active power loss after connecting the DG units (kW), $P_{loss,base}$ is the total active power loss for the base case (without DG) (kW), and w_1 and w_2 are weighting factors. The total active power loss can be formulated as [8]:

$$P_{loss} = \sum_{k=1}^{NB} G_{ij}[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)] \tag{3}$$

Where NB is the branches number, G_{ij} is the conductance of the line between the two buses i and j.

To maximize the enhancement of the voltage profile, the VDI is considered into the objective function. This index excludes the DG size–site pair which gives higher voltage deviations from the nominal value. In this way, closer the index to zero, better is the voltage profile. The VDI can be formulated as [7]:

$$VDI = max_{i=2}^{N}\left(\frac{V_{nom} - V_i}{V_{nom}}\right) \tag{4}$$

Where V_{nom} is the nominal voltage magnitude and N is the buses number.

B. Constraints

In this paper, the following constraints are considered:

1. Equality Constraints:

The equality constraints considered in this paper are the following:

- *Active power generation limitations*

The total active power losses and loads should be covered by the generated real power from conventional generators and DG units [3].

$$P_i = P_{DG_i} - P_{D_i} = V_i \sum_{k=1}^{n} V_k[G_{ik}\cos(\delta_i - \delta_k) + B_{ik}\sin(\delta_i - \delta_k)] \tag{5}$$

Where G_{ik} is the conductance of the line between the two buses i and k, B_{ik} is the susceptance of the line between bus i and bus k., and P_i is the net injected active power at bus i,

- *Reactive power generation limitations*

The total reactive power losses and load demand should equal to the total reactive power generated from conventional generators and all DG units.

$$Q_i = Q_{DG_i} - Q_{D_i} = V_i \sum_{k=1}^{n} V_k[G_{ik}\sin(\delta_i - \delta_k) - B_{ik}\cos(\delta_i - \delta_k)] \tag{6}$$

Where Q_i is the net injected reactive power at bus i.

2. *Inequality Constraints:*

The inequality constraints considered in this paper are the following:

- *Voltage profile limitations:*

$$V_i^{min} \le V_i \le V_i^{max} \tag{7}$$

In this paper, the maximum allowable variation in the magnitude of the bus voltage is considered to be 5%.

- *DG unit capacity constrains:*

$$P_{DGi}^{min} \le P_{DGi} \le P_{DGi}^{max} \tag{8}$$
$$Q_{DGi}^{min} \le Q_{DGi} \le Q_{DGi}^{max} \tag{9}$$

The real and reactive power consumed from the DG unit i must be limited with its maximum and minimum limits of generation.

III. WHALE OPTIMIZATION ALGORITHM

WOA is a recent optimization technique developed by Mirjalili [13]. The hunting method of a special kind of whales, called the humpback, gave the idea to develop an optimization technique simulating it as shown in Fig. 2.

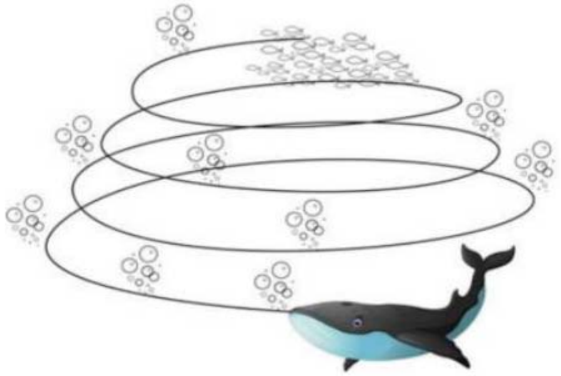

Fig. 2. The hunting method of the humpback whale

The following equations describe briefly the algorithm:

$$\vec{x}(t+1) = \overrightarrow{x^*}(t) - \vec{A}\,.\vec{D} \tag{10}$$
$$\vec{D} = \left|\vec{C}\,.\,\overrightarrow{x^*}(t) - \vec{x}(t)\right| \tag{11}$$
$$\vec{A} = 2\,.\vec{a}\,.\vec{r} - \vec{a} \tag{12}$$
$$\vec{C} = 2\,.\vec{r} \tag{13}$$

The vector of the search agents positions at the next iteration, $\vec{x}(t+1)$, can be obtained from equation (10) from the current positions, $\overrightarrow{x^*}(t)$, and the coefficient vectors $\vec{A}$ and $\vec{C}$ which are calculated in the equations 12, and 13. Where $\vec{a}$ is decreased linearly from 2 to 0 over the iterations, and $\vec{r}$ is a vector of random values from 0 to 1.

The bubble-net hunting method have two approaches:

A. *Encircling prey mechanism*

In this approach $\vec{A}$ takes a random value from -a to a. The new positions of the search agents could be obtained by varying the value of $\vec{A}$ in the interval [-1,1]. Fig. 3 illustrates how the agents can move from (x, y) to the new positions at (x^*, y^*) by $0 \le A \le 1$.

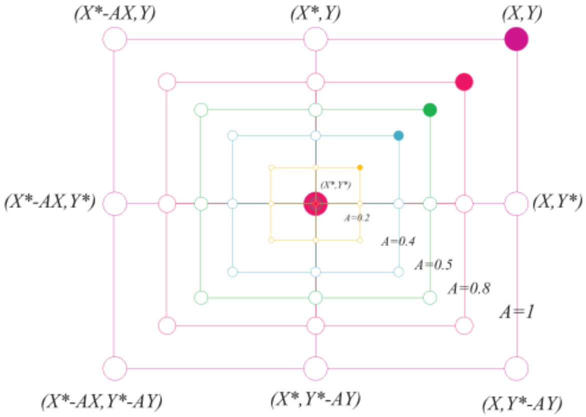

Fig. 3. Encircling prey mechanism

B. *Spiral updating position*

In this approach the movement of the whale towards the prey is in helix-shaped path as shown in Fig. 4.

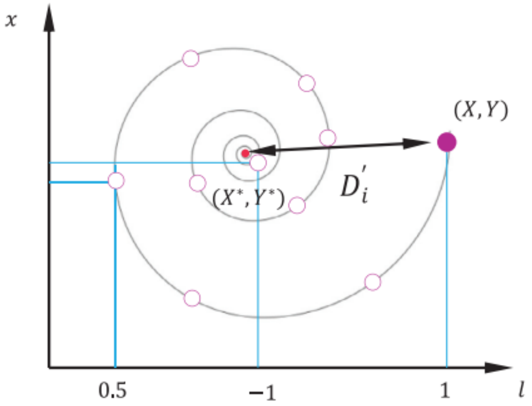

Fig. 4. Spiral updating position

The global search can be achieved by the following two equations:

$$\vec{D} = \left|\vec{C}\,.\overrightarrow{x_{rand}} - \vec{x}\right| \tag{14}$$
$$\vec{x}(t+1) = \overrightarrow{x_{rand}} - \vec{A}\,.\vec{D} \tag{15}$$

IV. CASE STUDY AND SIMULATION RESULTS

The system under study is a portion of the electrical network in the East Delta in Egypt [14]. The one-line diagram of the case study is presented in Fig. 5. The base values are 0.027221 MVA, and 11 kV. The total active power loss is calculated at the base case. It is approximately 839.9827 kW. The minimum voltage is obtained at bus 30, the farthest bus from the substation which has the largest voltage drop, with a magnitude of 0.946 p.u. which is lower than the allowable limit considered in this paper. The multi-objective function at this case equals approximately 0.858.

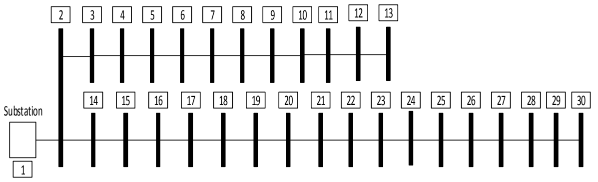

Fig. 5. One line diagram of the east Delta network.

In this paper, the optimal allocation of the DG units are determined to minimize the multi-objective function for one, two, and three DG units. The weighting factors are considered to be w_1=0.85, and w_2=0.15. In addition, different types of DG are considered as follows:

DG type 1: injects P only, i.e. operates at unity power factor, such as conventional PV panels

DG type 2: injects Q only, i.e. operates at zero power factor, such as shunt capacitors.

DG type 3: injects both of P and Q and operates at power factor of 0.85 such as diesel generators.

A. DG type 1: injects P only

First, all units are assumed to inject P only, and the optimal allocation of the units are determined by WOA. The results presented at table I. The optimal site for one DG is obtained at bus 18 with an optimal capacity of 12391 kW. Inserting this unit achieved total active power loss reduction by 52.2%, and the voltage magnitude at all buses became accepted. While the optimal sites for two DG units are obtained at bus 2 and bus 19 with a total capacity of 23201 kW. Inserting these two units achieved total active power loss reduction of 60%, and the voltage profile at all buses became accepted compared with the base case. For three DG units, the optimal sites are at the buses 2, 4, and 19 with 63.3% reduction in the total active power loss, and the voltage magnitude at all buses became accepted. It can be noticed that the greater the number of DG units, the less in MOF, but the maximum number of the DG units is assumed to be three units in this paper. In addition, considering both of APLRI and VDI in the MOF enhances the voltage profile with achieving minimum total active power loss. Figure 6 shows the voltage profile at the base case and after connecting the DG units of type 1. The voltage profile is accepted for all buses.

B. DG type 2: injects Q only

Here, all DG units are assumed to inject Q only, and the optimal allocation of the units are determined by WOA. All the results are illustrated in table II. It can be noticed that the optimal site of connecting one unit is also bus 18 as the first case with a capacity of 7752 kVAR. A reduction of 20.9% in the total active power loss is achieved, and the voltage profile at all buses became accepted compared with the base case. For connecting two DGs, the optimal locations bus 4 and 19 with a total capacity of 12448 kVAR. The total active power loss reduced by 24.9%, and the voltage magnitude at all buses became accepted. The optimal sites of the three units are the buses 2, 21, and 6 with a total capacity of 15680. The total active power loss reduced by 25.6%, and the voltage profile at all buses became accepted. From the results, it can be noticed that the contribution of this type of DG in reducing the total active power loss and improving the voltage profile is lower than the other types. Figure 7 shows the voltage profile at the base case and after connecting the DG units of type 2. The voltage profile is accepted for all buses.

TABLE I. THE RESULTS OF CONNECTING DG UNITS OF TYPE 1 TO THE DISTRIBUTION NETWORK

Number of DG units	DG units' optimal location	DG units' optimal size (kW)	Sum. Of DG optimal sizes (kW)	MOF	Total active power loss (kW)	Total active power loss reduction (%)	Min. bus voltage (bus no.) in p.u.
One DG unit	DG1 (bus 18)	12391	12391	0.409	401.1	52.2	0.978 (13)
Two DG units	DG1 (bus 2) DG2 (bus 19)	13249 9952	23201	0.342	335.4	60	0.981 (30)
Three DG units	DG1 (bus 2) DG2 (bus 4) DG3 (bus 19)	4838 7732 9942	22512	0.3140	307.9	63.3	0.981 (30)

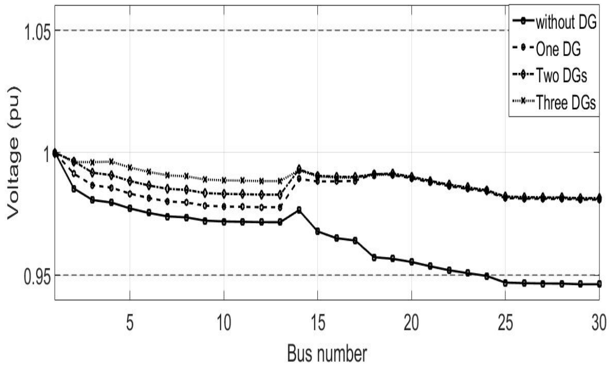

Fig. 6. Voltage profile of the East Delta network at the base case and after connecting DG units of type 1

C. DG type 3: injects P and Q

In this case, all DG units are assumed to inject both of P and Q at 0.85 power factor, and the optimal allocation of the units are determined by WOA. All the results are presented in table III. The optimal site of connecting one DG is obtained also at bus 18 with a capacity of 14575 kVA. The total active power loss reduced by 71.8%, and the voltage profile became accepted for all buses. . Furthermore, the optimal sites of the two units are buses 19 and 5 with a total capacity of 21373 kVA. The total active power loss reduced by 85.7%, and the voltage magnitude became accepted for all buses. The optimal sites of the three units are buses 15, 7, and 21 with a capacity of 22528 kVA. The total active power loss reduced by 90%, and accepted voltage profile was achieved. The results show that this type of DG is the best type for enhancing the voltage profile and minimizing the power loss. Figure 8 presents the voltage profile at base case and after connecting one, two, and three units of type 3. This type achieves the best voltage profile.

TABLE II. THE RESULTS OF CONNECTING DG UNITS OF TYPE 2 TO THE DISTRIBUTION NETWORK

Number of DG units	DG units' optimal location	DG units' optimal size (kVAR)	Sum. Of DG optimal sizes (kVAR)	MOF	Total active power loss (kW)	Total active power loss reduction (%)	Min. bus voltage (bus no.) in p.u.
One DG unit	DG1 (bus 18)	7752	7752	0.680	664.8	20.9	0.955 (30)
Two DG units	DG1 (bus 4) DG2 (bus 19)	5854 6594	12448	0.645	630.4	24.9	0.956 (30)
Three DG units	DG1 (bus 2) DG2 (bus 21) DG3 (bus 6)	7715 4965 3000	15680	0.6386	624.6	25.6	0.956 (30)

The convergence characteristics of the WOA for the proposed MOF is presented in Fig. 9 for one, two, and three DG units of type 1.

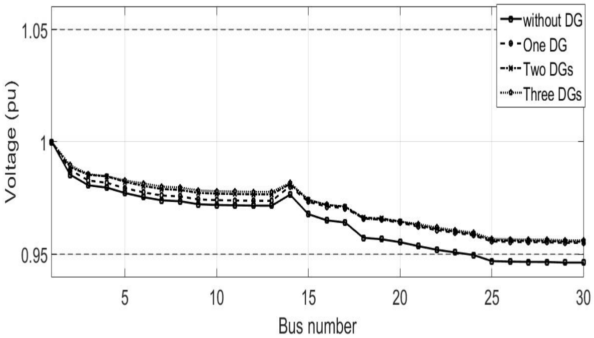

Fig. 7. Voltage profile of the East Delta network at the base case and after connecting DG units of type 2

TABLE III. THE RESULTS OF CONNECTING DG UNITS OF TYPE 3 TO THE DISTRIBUTION NETWORK

Number of DG units	DG units' optimal location	DG units' optimal active power size (kW)	DG units' optimal reactive power size (kVAR)	DG units' optimal apparent power rating (kVA)	Sum. Of DG optimal ratings (kVA)	MOF	Total active power loss (kW)	Total active power loss reduction (%)	Min. bus voltage (bus no.) in p.u.
One DG unit	DG1 (bus 18)	12389	7676	14575	14575	0.2430	237.1	71.8	0.9798 (13)
Two DG units	DG1 (bus 19) DG2 (bus 5)	10923 7244	6767 4488	12851 8522	21373	0.1234	120.5	85.7	0.9901 (30)
Three DG units	DG1 (bus 15) DG2 (bus 7) DG3 (bus 21)	8940 4848 5360	5539 3004 3321	10518 5704 6306	22528	0.0863	83.9	90	0.9914 (30)

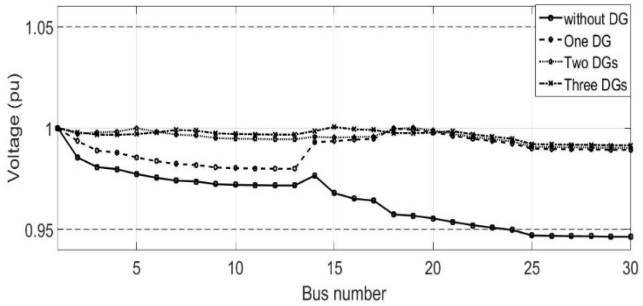

Fig. 8. Voltage profile of the East Delta network at the base case and after connecting DG units of type 3

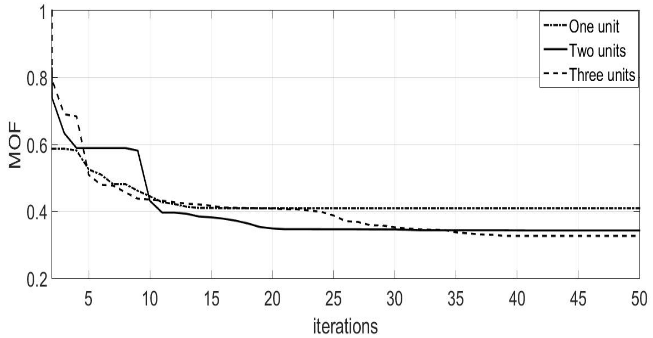

Fig. 9. The variation of the MOF versus the number of iterations for one, two, and three units of type 1

V. CONCLUSIONS

This paper presented a recent optimization technique, WOA, to solve the optimization problem. The proposed algorithm is tested by different types of DG. An index-based multi objective function was minimized by each of the size and place of the units. A portion of the electrical network in the East Delta was presented for testing the proposed algorithm. The obtained results illustrated the effectiveness of the WOA in reducing the total active power loss and improving the voltage profile. It is noticed that the third type of DG, injects both of P and Q, achieved the maximum reduction in the total active power loss and the best voltage profile. It was noticed that connecting one unit of the third type reduced the total active power loss by 71.8%, while connecting two units of the same type made a reduction of 85.7%. In case of connecting three units of the third type the total active power loss reduced by 90%. Such that results could not be obtained by using the first two types of the DG units. Also, the results showed that the second type of DG, injects Q only, was the worst in terms of reducing the power loss or enhancing the voltage profile.

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