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# Optimal Distributed Generation Site and Size Allocation for loss reduction and voltage stability enhancement in distribution systems

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***Abstract*— This paper concentrates on the impacts of distributed generation (DG) placement on the radial distribution system. Distributed generation is a term that refers to the generation of energy close to the point of consumption, in order to improve the performance of the electricity grid. It is a well proven fact that if the DGs units are placed in the right place in the distribution system and operating at optimal size, it will help in reducing the line losses and improving the voltage profile and as a consequence the reliability, stability and efficiency of the electrical system are preserved. In this paper, three types of DG units are considered and both Moth-flame optimization (MFO) and Grasshopper optimization (GOA) are applied to find the optimal DG sizing for a typical radial distribution system (IEEE-85 bus radial distribution test systems). The required location of the DG unit bus is selected using the index vector method (IVM) and the voltage stability index (VSI). The obtained results show that the two algorithms produce very same values. The best result in loss reduction and minimum bus voltage is attained for the DG unit at a power factor of 0.93 when compared to other DG types. However, this requires a large DG versus the other types.**

***Keywords- Radial distribution network, Voltage stability, Power loss, Distributed generation (DG), Moth-flame optimization (MFO), Grasshopper optimization (GOA)***

## 1. Introduction

A power system has three main components, the generating stations, the transmission lines and the distribution systems. These last connects the high voltage transmission system to the low voltage consumer service point. In general, the radial distribution network operates at low voltage levels, which implies high current, resulting in higher power losses and poor power factor with voltage dips. It is established that most of the losses, about 70% of the total losses, occur at the distribution level in the form of line losses and constitute 13% of the total electrical production [1].

To overcome these problems and improve the efficiency of distribution systems, new strategies have been developed. Among the solutions used is the installation of distributed generation sources (DG) [1-5].

Distributed generations are small generation units connected directly to the distribution systems. DG units can be grouped into three kinds according to their ability to generate real and reactive energy or only real or reactive energy: the first type generates real and reactive power example synchronous generators, the second type generates only real power (unity pf) example PV cells and third type generates only reactive power (capacitors) [3].

In recent years, the installation of distributed generation units in radial networks has revealed its effectiveness. In fact they have a significant impact on the power flow, voltage profile, stability, and quality of power supply for customers and electricity suppliers. In order to take full advantage of their benefits, it is important to determine the appropriate capacity and location because improper selection can result in system losses greater than those without DG [2-5].

Many meta-heuristic and heuristic methods are used to solve the DG allocation problem. Among these methods, we can mention the whale optimization algorithm (WOA) [3,4], grey wolf optimizer (GWO) [3,5], modified particle swarm optimization (PSO) [6], flower pollination algorithm (FPA) [7], artificial bee colony (ABC) [8], heuristic curve-fitted technique [9], modified honey bee mating [10], discrete particle swarm optimization (DPSO) [11],multi-objective harmony search [12], gravitational search algorithm (GSA) [13], cuckoo search algorithm (CSA) [14], Pareto front differential evolution [15], backtracking search algorithm (BSA) [16], krill herd algorithm (KHA) [17], genetic algorithm (GA) [18], big bang big crunch [19].

The present paper investigates the sizing and allocation of DG to reduce power losses and improve the voltage profile and stability of the radial distribution system. Single DG allocation and sizing have been determined in the basis of index vector method (IVM) and voltage stability index (VSI). The performance of the developed method is verified in the 85-bus distribution system.

In this study, two optimization algorithms are applied namely the Moth-flame optimization (MFO)[20] and the Grasshopper optimization (GOA) [21]. These algorithms are investigated on standard IEEE 85 bus test systems by considering the voltage stability improvement and the active power losses minimization.

## 2. Problem Formulation

In this investigation, the size and the sitting of distributed generation units in radial distribution networks is formulated as a multi-objective problem by considering as objectives the improving the voltage stability and minimizing the active power losses.

The objective function is given as:

$$OF = \min(f_1, f_2)(1)$$

Where $f_1$ and $f_2$ are respectively the total power loss of the system and the stability index

### 2.1 The Active Power Losses

The optimal sizing and sitting of DG units in radial distribution networks is formulated as an optimization problem to reduce the total active power losses. As Shawn in Figure.1, each receiving bus is fed by solely one sending bus. Well, the line active power losses between the two buses *i* and *i*+1 is given by Eq. 2[1]:

$$PL(i) = r_i|I_i|^2 = r_i\frac{(P_i^2+Q_i^2)}{V_i^2} \qquad (2)$$

Therefore, the total system power loss can be calculated by Eq. 3:

$$\sum_{i=2}^{N_{bus}} PL(i) = \sum_{i=2}^{N_{bus}} r_i\frac{(P_i^2+Q_i^2)}{V_i^2}(3)$$

Where $r_i$ is the line resistance connected between the node *i*-1 and the node *i*; I current of branch *i*; *Vi* voltage of node *i*; $P_i$ and $Q_i$ active and reactive power load fed through node *i*.

The total system loss reduction (TLR) can be determined by Eq. 4.

$$TLR\% = \frac{\sum_{i=1}^{N_{bus}} PL_{woutDG} - \sum_{i=1}^{N_{bus}} PL_{wDG}}{\sum_{i=1}^{N_{bus}} PL_{woutDG}} 100\% \qquad (4)$$

Where, $PL_{wDG}$ and $PL_{woutDG}$ are the line losses in the system with and without DG respectively.

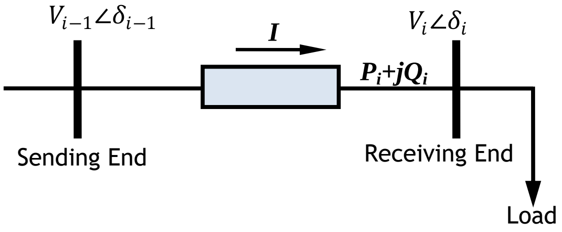

**Fig. 1** Electrical equivalent of two node system

### 2.2 Index vector method

The optimal placement of distributed generation is determined using the index vector method (IVM)[3, 19]. The *IV* for bus is given by:

$$IV(i) = \frac{1}{V_i^2} + \frac{I_q(k)}{I_p(k)} + \frac{Q_{eff}(i)}{Q_T}(5)$$

$V_i$ is the voltage at the *i*bus, $I_p(k)$, $I_q(k)$ are the real and imaginary parts of the current in the kth branch. $Q_{eff}(i)$ and $Q_T$ are the reactive load at the *ith* bus and the total reactive load respectively.

### 2.3 Voltage stability index

Among the many indices which are used to check the power system security level. In this study, the voltage stability index (*VSI*) [3, 20] is used to find the most sensitive bus to voltage collapse in the system. To reduce the risk of voltage collapse, the *VSI* of all buses must be closer to zero. Buses with the highest *VSI* values are the most sensitive and so are considered candidates for DG placement [22].

The voltage stability index (*VSI*) which can be defined at each node as follows [22]:

$$VSI_{i+1} = \frac{4X_i}{V_i^2}\left(\frac{{P_{i+1}}^2}{Q_{i+1}} + Q_{i+1}\right)(6)$$

Where $VSI_i$ is the stability index for node *i* (2,3,.., N bus), *Xi* is reactance of the *ith* branch, $V_i$ is voltage of the *ith* node, $P_i$ and $Q_i$ are total active and reactive power load fed through at *i* bus.

### 2.4.1 Constraints

1) Equality Constraints:

The equality constraints are power balance (active and reactive power) equations, which are in presence of distributed generation units expressed as follows [23]:

$$\begin{cases}\sum_{i=1}^{NG} P_{Gi} + \sum_{i=1}^{ND} P_{DGi} = P_D + P_L \\ \sum_{i=1}^{NG} Q_{Gi} + \sum_{i=1}^{ND} Q_{DGi} = Q_D + Q_L\end{cases} \quad (7)$$

2) Inequality Constraints

- The voltage magnitude which must be keeped within the specified limits at each bus:

$$V_{min} \leq V_i \leq V_{max} (8)$$

- The power limit generated by the DG unit.

$$\begin{cases}P_{DGi}^{min} \leq P_{DGi} \leq P_{DGi}^{max} \\ Q_{DGi}^{min} \leq Q_{DGi} \leq Q_{DGi}^{max}\end{cases} \quad (9)$$

Where $P_{DGi}$ and $Q_{DGi}$ are the active and reactive power injected by the DG at the ith bus.

## 3. Test Systems Description

In this investigation, the algorithms MFO and GOA are evaluated in the application of DG planning problem with IEEE 85-bus test systems as test case. The algorithms are used to obtain the optimal size of DG.

The IEEE 85-bus radial distribution network is shown in Figure. 2. This system, is an 11 kV network, it consists of one slack bus, 84 load buses and 84 branches. The total power demand of the system is 2570.28 kW and 2,621.936 kVAr. Without installation of DG unit, the real and the reactive power losses are 317.477 kW and 196.616kVarerespectively. Minimum voltage before installation of DG unit is 0.8713.

Three DG types are considered in this paper

Type I: It operates at unity pf (Injects real power) example PV cells.

Type II: Injects reactive power example (capacitors).

Type III: Injects real and reactive powers (synchronous Generator).

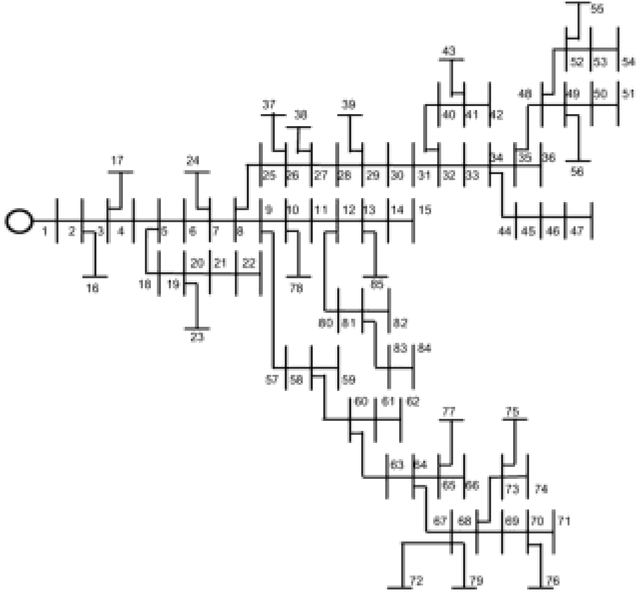

**Fig. 2** The IEEE 85-bus distribution system

## 4. Applied algorithms

The two proposed optimization algorithms for optimal placement and sizing of distributed generation unit in a radial network are introduced by Seyed ali Mirjalili, Moth-flame optimization (2015) [24] and Shahrzad Saremi, Grasshopper optimization (2017) [25].

The MFO basic steps are illustrated in the pseudo-code in Algorithm.1, and the GOA basic steps are summarized within the pseudo-code in Algorithm.2.

The main parameters used in this paper are described in Table.1.

**Algorithm. 2:** The GOA pseudo-code

```
  Initialize the first population of Grasshoppers randomly
Initialize the GOA parameters cmin, cmax and max iteration tmax
Calculate the fitness f(Pi) of all agents
  Set T as the best search agent
  While  t < tmax do
    T the best solution so far
    Update the value of c ($c = c_{max} - t\frac{c_{max}}{c_{min}}$)
      For i=1 to N do
        Normalize the distance between grasshoppers
      Update the position of the current grasshopper
        Bring the current search of grasshopper back if it goes outside the boundaries
      end for
    t=t+1
  end while
  return T
```

**TABLE.1:** THE INPUT PARAMETERS USED

| Algorithm | MFO | GOA |
|---|---|---|
| Search agents No. | 30 | 30 |
| Maximum iteration | 500 | 500 |
| DG sizing limits | $0 \leq P_{DGi} \leq 5MW$ | |
| Voltage limits | $0.9 \leq Vi \leq 1.05$ | |

## 4. Results and Discussion

The presented study was performed on an 85-bus radial distribution test system with a total active and reactive power demand of 2570.28 kW and 2621.936 kVAr respectively. It is subject to rated power losses of 317,477 kW and 196,616 kVA. The minimum voltage is measured at node 54 and has a value of 0.8713pu.

According to the index vector method and the voltage stability index, node 8 is selected as the optimal DG placement. In addition, bus 54 is also selected for the simulation as it has the lowest voltage value before the DG installation.

As mentioned above, the simulation is performed for three types of DGs and once the optimal placement/rate of DGs has been found, the overall results obtained by both methods are presented in Tables 2 and 3. Tables 2 and 3 show the DG sizes, real and reactive power losses, and minimum voltages after placement of different types of DG.

### 4.1 DG operating at unity power factor pf

The DG units installed at the bus 8 as optimal location and the size is identified as 2.401MW.After the DG installation, the minimum voltage is observed in the same bus (bus 54) as 0.934pu. This is better than the base case minimum voltage of 0.8713pu, which is an improvement of 7.2%. The active power lose is decreased to 182.237 kW, with a total loss reduction percentage of 42.60 %. The reactive power lose is also reduced to 106.457kVAr with a total loss reduction percentage of 45.86 %.

The results obtained when DG unit is installed at the bus 54 are also showed in Tables.2 and 3. The losses are higher than in the case where the DG is placed at bus 8. The minimum voltage is also lower and is located at bus 75.

**Algorithm 1:** The MFO pseudo-code

```
  Generate the initial population and initialize the MFO parameters
Initializes the moth position Mi randomly
  For i=1 to n do
      Calculate the fitness f (Pi) of all agents
  end for
  While t < tmax do
      Update the position of current moth
      Calculate the number of flame
      Evaluate the fitness of each moth f (Pi)
    If t= =1
      F=sort (M); OF=sort (OM)
  else
      F=sort (Mt-1, Mt); OF= sort (Mt-1, Mt)
  end if
    For i = 1: n
      For j = 1: d
        Update r, t
        Calculate D with respect to its corresponding moth
        Update M (i, j) respect to its corresponding moth
  end for
  end for
  end while
```

### 4.2 DG operating at zero pf

As in the previous case, the DG unit is placed on bus 8 but the size of the DG unit in this case is 2.43 MVAr. The minimum voltage is recorded in the same bus (bus 54) as 0.9105pu.The minimum voltage is even better compared to the base case with an improvement of 4.5 %. The active and the reactive power losses are reduced to 182,237 kW and 106,457 kVAr, with a total percentage loss reduction of 42.60% and 45.86% respectively.

When the DG unit is installed at bus 54, the results obtained (Tables.2 and 3) show that the losses are higher than in the case where the DG is placed at bus 8. The minimum voltage is also lower and is found at bus 75.

### 4.3 DG operates at 0.93 pf lag placement

As in the two previous cases, the DG unit is positioned on the bus 8. The DG unit size is (2.783+j1.15) MVA and the minimum voltage is improved to 0.9553pu. With the DG is set at 0.93 lag power factor, the active and reactive power losses are minimized to 105.032kW and 54.298kVAr, revealing reductions of 66.92% and 72.38% respectively. Tables.2 and 3shows that the active and reactive losses are higher and the minimum voltage is lower for a DG mounted at bus 54 compared to those obtained when the DG is placed at bus 8.

Based on the results, it is noticed that the DG size is higher at lagging power factor compared to the size of DG operates at unity or zero power factor, however, the power losses are less with DG at lagging power factor rather than DG at unity or zero power factor. This improvement is due to the both active and reactive power locally accessible to the loads and thus the reduction of the both power available from the substation. Furthermore, as shown in Fgure.3, the voltage profile is improved with DG at lagging power factor compared to the voltage profile when the other DG types are installed.

**TABLE.2:** SIMULATION RESULTS USING MFO

| | *WithoutDG* | *With DG Type I* | *With DG Type II* | *With DG at 0.93 pf lag* |
|---|---|---|---|---|
| DG Location | - | 8 | 8 | 8 |
| DG Size(MW) | - | 2.401 | 2.43 | 2.783+j1.15 |
| Ploss (kW) | 317.477 | 182.237 | 181.106 | 105.032 |
| TLR % | - | 42.60 | 42.95 | 66.92 |
| Qloss (kVAr) | 196.6164 | 106.457 | 104.818 | 54.298 |
| TLR % | - | 45.86 | 46.69 | 72.38 |
| Vmin (Bus) | 0.8713(54) | 0.934(54) | 0.9105(54) | 0.9553(54) |
| DG Location | - | 54 | 54 | 54 |
| DG Size (MW) | - | 1.013 | 1.017 | 1.154+j0.462 |
| Ploss (kW) | 317.477 | 213.946 | 216.614 | 93.163 |
| TLR % | - | 32.61 | 31.77 | 70.66 |
| Qloss (kVAr) | 196.6164 | 127.065 | 128.024 | 162.077 |
| TLR % | - | 35.37 | 34.89 | 17.57 |
| Vmin (Bus) | 0.8713(54) | 0.9165(75) | 0.9062(75) | 0.9249(75) |

**TABLE.3:** SIMULATION RESULTS USING GOA

| | *Without DG* | *With DG Type I* | *With DG Type II* | *With DGat 0.93 pf lag* |
|---|---|---|---|---|
| DG Location | - | 8 | 8 | 8 |
| DG Size (MW) | - | 2.401 | 2.429 | 2.783+j1.148 |
| Ploss (kW) | 317.477 | 182.237 | 181.106 | 105.032 |
| TLR % | - | 42.60 | 42.95 | 66.92 |
| Qloss (kVAr) | 196.6164 | 106.457 | 104.818 | 54.298 |
| TLR % | - | 45.86 | 46.69 | 72.38 |
| Vmin (Bus) | 0.8713(54) | 0.934(54) | 0.9105(54) | 0.9553(54) |
| DG Location | - | 54 | 54 | 54 |
| DG size (MW) | - | 1.013 | 1.017 | 1.154+j0.461 |
| P loss (kW) | 317.477 | 213.946 | 216.614 | 162.078 |
| TLR % | - | 32.61 | 31.77 | 48.95 |
| Q loss (kVAr) | 196.6164 | 127.066 | 128.024 | 93.171 |
| TLR % | - | 35.37 | 34.89 | 52.61 |
| V min (Bus) | 0.8713(54) | 0.9165(75) | 0.9062(75) | 0.9249(75) |

It is therefore important to note that the installation of DGs Type I or Type II reduces the losses to the same value, while the DG Type I provides a significant improvement in voltage

The active and reactive power losses in the branches of the 85-bus test system are shown in Figures.4 and 5 for the all types of DGs and for the base case. For the IEEE 85 bus test system, branch 7 has the highest losses, especially in the case without DGs. Branch 5 has the 2nd highest loss rate.

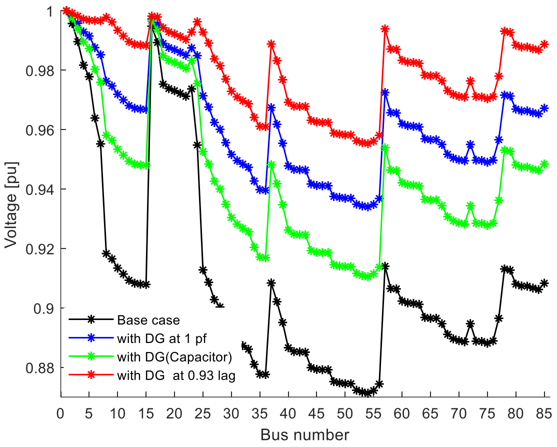

**Fig.3** Voltage profiles of85-bus system before and after different types of DGs installation

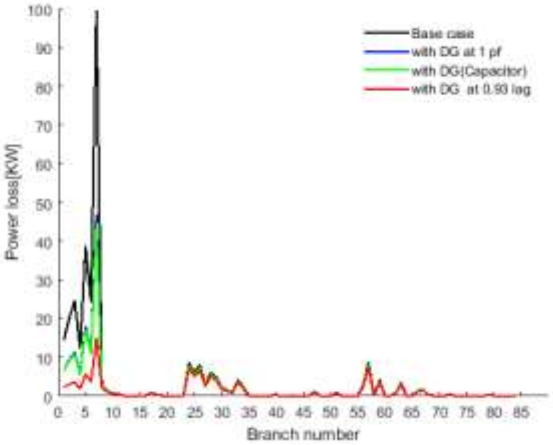

**Fig. 4** Active power loss of 85-bus system before and after different types of DGs installation

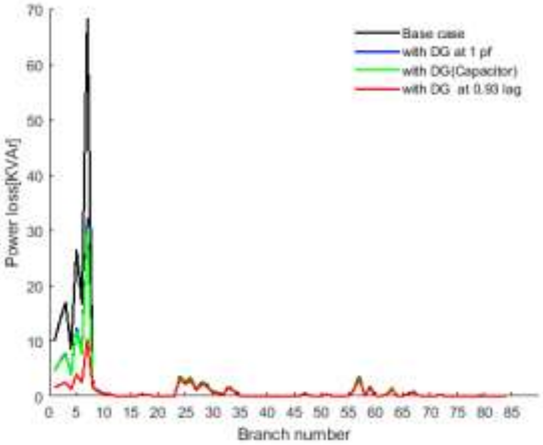

**Fig. 5** Reactive power loss of 85-bus system before and after different types of DG installation

Figures.6 and 7 show the active and reactive power losses of the 85-bus system for the two cases without DG and in the case where the three types of DG are connected one at a time to the selected buses 8 and 54.

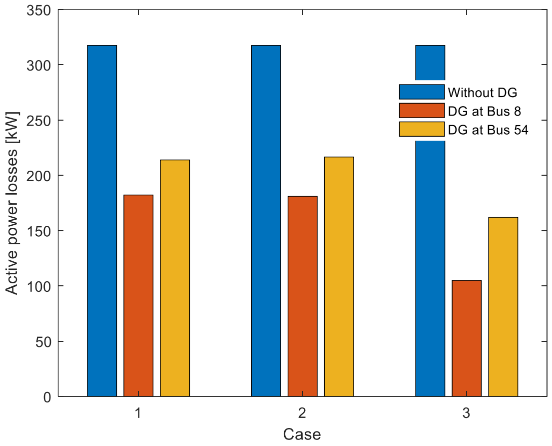

**Fig. 6** Active power loss of 85-bus system

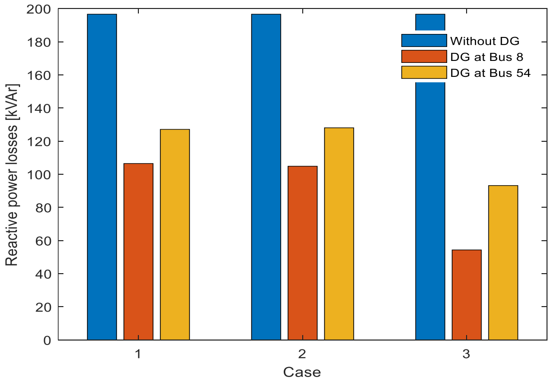

**Fig. 7** Reactive power loss of 85-bus system

## 5. Conclusion

MFO and GOA based active power loss minimization and voltage profile improvement problem is presented to identify the optimum DG placement in a radial distribution power network. The appropriate location of the DG unit bus was selected using the index vector method and the voltage stability index.

The best locations for DG units correspond to the buses with the highest IVM and the highest VSI values.In addition, the bus which has the lowest voltage value before the DG installation is also selected.The investigation is conducted on the IEEE 85 bus distribution system using three types of DG units. It is observed that with the penetration of DGs units placed in the right place and operating at optimal size, the active power loss of the system decreases, while the voltage profile improves greatly. The results obtained show that the two algorithms give very similar values.

The best result in loss reduction and minimum bus voltage is achieved for the DG unit at a power factor of 0.93 compared to other DG types. However, it requires a large DG compared to the other types.

## Future work

For future work, it is planned to use other indices with multi-objective optimization and to compare the results obtained with those of the present work.

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