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# Optimize the position of distributed generations in distribution grid by using improved loss sensitivity factor

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**ABSTRACT**

This research proposed a method to determine the optimal position of distributed generations in a distribution grid. The method is improved from the loss sensitivity factor method. An algorithm is developed to determine both the position and size of distributed generations. This algorithm is validated via IEEE 33 bus distribution grid in two cases of distributed generation size including unknown size and constant size. The results were analyzed and compared to other previous algorithms including loss sensitivity factor-based algorithm and other algorithms. Results indicated the optimal position of each distributed generation to minimize the power loss. Results also indicated that with the proposed algorithm, the loss reduction rate (LRR) is the highest in comparison to that with other previous algorithms.



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## 1. INTRODUCTION

Power loss is an interesting issue in the operation of the distribution grid. The power loss in the distribution grid is often high. The main reason is that the power loss depends proportionally on the line's resistance and inversely on the square of voltage while with this grid, the resistance of line is often high and its voltage level is often low. Conventionally, to reduce the power loss, we can renovate the grid by increasing the line cross-section, installing new lines to share the load, optimizing the grid's reconfiguration [1], [2] optimizing the capacitor installation [3]. The reconfiguration optimization is often applied to distribution grids existing closed-loop or more than one power supply. The optimal capacitor placement method can lead to the overvoltage phenomenon because the reactive power flows from the load to the source during low-demand periods. With the development of technology, the integration of distributed generators (DG) like diesel, PV, and wind, in to the distribution grid is also a possible method to reduce power loss. However, if the DG position is not suitable, the power loss on the grid is reduced insignificantly, even, it can become worse [4].

Many researchers focused on proposing algorithms to determine the size and location of DG in distribution grids [5]-[30] to obtain a desired objective. In these researches, DG can be installed solely [5]-[8], [10]-[16], or combined with capacitors [17], with energy storage [18], with reconfiguration [19], [20]. In terms of cost function, the objective of DG installation can be sole or multi-objective [21], they come from the reduction of power loss, the improvement of voltage quality, and the enhancement of reliability. In terms of algorithms, many methods are used such as particle swarm optimization, genetic, intelligent water drop, whale optimization, and bacterial foraging optimization [5]-[21]. Some algorithms are developed based on loss sensitivity factor (LSF) to choose the best position and size of DG [5]-[8], [22]-[25]. By using the LSF method, both position and size of DG is determined quickly. However, depending on the LSF implementation, researchers can give different results [9], [22], [26], [27]. In most of the research, DG was suggested to be installed at one node, two nodes, or three nodes and the size of DG is not foreknown.

This research is to determine the optimal position of DG to minimize the power loss in a distribution grid. The proposed idea is to improve LSF method. This algorithm is used to determine the position of DG in the case of a given DG size or both the position and the size of DG in the case of an unknown DG size. The proposed algorithm is coded in Matlab environment, and we use the IEEE 33-bus distribution grid for validation. Validating results are compared to that of other research using either LSF or other algorithms.

The outline of this paper includes five sections. After the introduction section, we will state the optimal problem in the section 2. In the section 3, we indicate how we improve the LSF method and we propose an algorithm. In the next section, we verify the proposed algorithm. The conclusion of this research will be stated in the last section.

## 2. OPTIMAL PROBLEM STATEMENT

The position and DG size are determined to obtain the cost function:

$$\Delta P_{\Sigma} = f(S_{DG}, x_{DG}) \rightarrow min \tag{1}$$

constraints,

$$V_{min} \leq V_i \leq V_{max} \tag{2}$$

$$I_{ij} \leq I_{ijmax} \tag{3}$$

where, $S_{DG}, x_{DG}$ are DG size and the position of DG, respectively; $V_{min}$ and $V_{max}$ are the lower and upper boundary of the node voltage; $I_{ij}$ and $I_{ijmax}$ are the current on the line segment from the $i^{th}$ node to the $j^{th}$ node and its limitation. In this research, the optimal position is determined by improving LSF while the DG size is defined based on the condition of LSF equal to zero and optimal power factor (pf).

## 3. IMPROVEMENT OF LOSS SENSITIVITY FACTOR AND PROPOSAL OF ALGORITHM

### 3.1. Improvement of LSF

LSF is used quite popularly to determine the optimal position of DG in distribution grids [5]-[8], [22]-[25]. Injeti and Kumar [5], LSF is defined as the derivative of the power loss of the line. LSF of the $i^{th}$ node that is the end node of the $(i-1)^{th}$ line segment in Figure 1 is defined as:

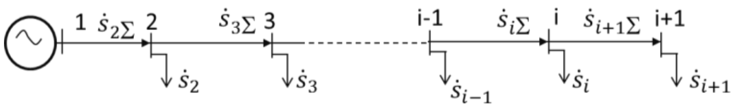


Figure 1. A simple of distribution grid

$$LSF_{i,P} = 2\frac{P_i R_{i(i-1)}}{V_i^2} \tag{4}$$

$$LSF_{i,Q} = 2\frac{Q_i X_{i(i-1)}}{V_i^2} \tag{5}$$

where, $\dot{S}_{i\Sigma} = P_i + j\,Q_i$ is the power flow on the line segment from the $(i-1)^{th}$ node to the $i^{th}$ node and $Z_{i(i-1)} = R_{i(i-1)} + j\,X_{i(i-1)}$ is the impedance of this line segment. With this definition, the optimal location to install DG is the node in which $LSF_{i,P}$ value is the highest. Hence, the optimal position of DG depends on the node voltage, active power injecting to the node, and the resistance of the line segment. With a simple grid as shown in Figure 1, if the resistance of all line segments is equal and the difference in the voltage at nodes is insignificant, the optimal position will be the 2$^{nd}$ node because the power injected to the 2$^{nd}$ node is the highest. Acharya *et al.* [6], LSF of the $i^{th}$ node is defined by:

$$\alpha_{i,P} = 2\sum_{j=1}^{N}(P_j \frac{R_{ij}}{V_i.V_j} cos\,(\delta_i - \delta_j) - Q_j \frac{X_{ij}}{V_i.V_j} sin\,(\delta_i - \delta_j) \quad (6)$$

$$\alpha_{i,Q} = 2\sum_{j=1}^{N}(Q_j \frac{R_{ij}}{V_i.V_j} cos(\delta_i - \delta_j) + P_j \frac{X_{ij}}{V_i.V_j} sin\,(\delta_i - \delta_j)) \quad (7)$$

where, $N$ is denoted the branch number in the grid. As can be seen from these equations, LSF is calculated from the impedance of all branches in the distribution grid. From (4) to (7), the definition of LSF is not completely the same in research.

In this research, we propose a new LSF, which improves (4). This is named the improved LSF (ILSF). This factor is also defined by taking the derivative of power loss. However, this power loss is calculated from the source to the considered node. With the radial grid as Figure 1, the active power loss in total $\Delta P_{i\Sigma}$ from the source to the $i^{th}$ node is defined:

$$\Delta P_{i\Sigma} = \frac{(P_{i\Sigma}^2 + Q_{i\Sigma}^2)}{V_i^2} R_{i-1} + \frac{(P_{i-1\Sigma}^2 + Q_{i-1\Sigma}^2)}{V_{i-1}^2} R_{i-2} + \cdots \frac{(P_{2\Sigma}^2 + Q_{2\Sigma}^2)}{V_2^2} R_1 = \sum_{i=2}^{i} \frac{(P_{i\Sigma}^2 + Q_{i\Sigma}^2)}{V_i^2} R_{i-1} \quad (8)$$

where, $Q_{i\Sigma}$ is reactive power injected into the $i^{th}$ node; $R_{i-1}$ is the resistance of the line segment where $P_{i\Sigma}$ and $Q_{i\Sigma}$ flow through, and the $i^{th}$ node is the end node of this line segment. The power injecting to the $(i-1)^{th}$ node is the summation of the power injecting to the $i^{th}$ node, power loss, and load power at the $(i-1)^{th}$ node. By neglecting the loss on the line segments, power injecting to the $(i-j)^{th}$ node on the route from the source to the $i^{th}$ node:

$$\dot{S}_{(i-j)\Sigma} = \dot{S}_{i\Sigma} + \sum_{k=1}^{j} \dot{S}_{i-k} \quad (9)$$

where, $\dot{S}_{i-k}$ is the total demand power of loads referring to the $(i-k)^{th}$ node, which is the summation of the load at the $(i-k)^{th}$ node and power in total supplying to feeders from the $(i-k)^{th}$ node. Hence, by neglecting the loss on the line segments in (8), we have:

$$\Delta P_{i\Sigma} = \frac{P_{i\Sigma}^2 + Q_{i\Sigma}^2}{V_i^2} R_{i-1} + \frac{(P_{i\Sigma} + P_{i-1})^2 + (Q_{i\Sigma} + Q_{i-1})^2)}{V_{i-1}^2} R_{i-2} + \cdots \frac{(P_{i\Sigma} + \sum_{k=1}^{i-2} P_{i-k})^2 + (Q_{i\Sigma} + \sum_{k=1}^{i-2} Q_{i-k})^2)}{V_2^2} R_1 \quad (10)$$

Hence, ILSF to active power is defined as (11). Likely, ILSF to reactive power is written as (12).

$$ILSF_{i,P} = \frac{\partial \Delta P_{i\Sigma}}{\partial P_{i\Sigma}} = 2\frac{P_{i\Sigma}}{V_i^2} R_{i-1} + 2\frac{P_{i\Sigma} + P_{i-1}}{V_{i-1}^2} R_{i-2} + \cdots + 2\frac{P_{i\Sigma} + \sum_{k=1}^{i-2} P_{i-j}}{V_2^2} R_1 = 2\sum_{i=2}^{i} \frac{P_{i\Sigma}}{V_i^2} R_{i-1} \quad (11)$$

$$ILSF_{i,Q} = \frac{\partial \Delta P_{i\Sigma}}{\partial Q_{i\Sigma}} = 2\sum_{i=2}^{i} \frac{Q_{i\Sigma}}{V_i^2} R_{i-1} \quad (12)$$

To optimize the position of DG, we must calculate the ILSF of all nodes in the distribution grid. The optimal position of DG is the node with the highest value of ILSF.

If we suppose that a DG size with $\dot{S}_G = P_G + jQ_G$ is installed at the $i^{th}$ node, the power loss from the source to the $i^{th}$ node, (10), will be rewritten as (13).

$$\Delta P_{i\Sigma} = \frac{(P_{i\Sigma} - P_G)^2 + (Q_{i\Sigma} - Q_G)^2}{V_i^2} R_{i-1} + \cdots \frac{(P_{i\Sigma} - P_G + \sum_{k=1}^{i-2} P_{i-k})^2 + (Q_{i\Sigma} - Q_G + \sum_{k=1}^{i-2} Q_{i-k})^2}{V_2^2} R_1 \quad (13)$$

To determine the DG size to minimize power loss, we set the derivative of power loss in the grid to zero. Hence, from (13), we have (14), (15).

$$\frac{\partial \Delta P_{i\Sigma}}{\partial P_G} = -2\sum_{i=2}^{i} \frac{(P_{i\Sigma} - P_G)}{V_i^2} R_{i-1} = 2P_G \sum_{i=2}^{i} \frac{R_{i-1}}{V_i^2} - 2\sum_{i=2}^{i} \frac{P_{i\Sigma}}{V_i^2} R_{i-1} = 0 \quad (14)$$

$$\frac{\partial \Delta P_{i\Sigma}}{\partial Q_G} = -2\sum_{i=2}^{i} \frac{(Q_{i\Sigma} - Q_G)}{V_i^2} R_{i-1} = 2Q_G \sum_{i=2}^{i} \frac{R_{i-1}}{V_i^2} - 2\sum_{i=2}^{i} \frac{Q_{i\Sigma}}{V_i^2} R_{i-1} = 0 \quad (15)$$

From (14) and (15), we can get active power $P_G$ and reactive power $Q_G$.

$$P_G = \sum_{i=2}^{i} \frac{P_{i\Sigma}}{V_i^2} R_{i-1} \left( \sum_{i=2}^{i} \frac{R_{i-1}}{V_i^2} \right)^{-1} \quad (16)$$

$$Q_G = \sum_{i=2}^{i} \frac{Q_{i\Sigma}}{V_i^2} R_{i-1} \left( \sum_{i=2}^{i} \frac{R_{i-1}}{V_i^2} \right)^{-1} \quad (17)$$

### 3.2. Proposal of algorithm

In this research, we consider two cases of DG size. In the first case, the capacity of each DG is not limited (or unknown DG size in advance), and in the second case, the capacity of each DG is constant (foreknown). The proposed algorithm is to determine $S_{DG}$ and $x_{DG}$ to obtain the objective function and this algorithm is shown in Figure 2. This algorithm is described as Figure 2.

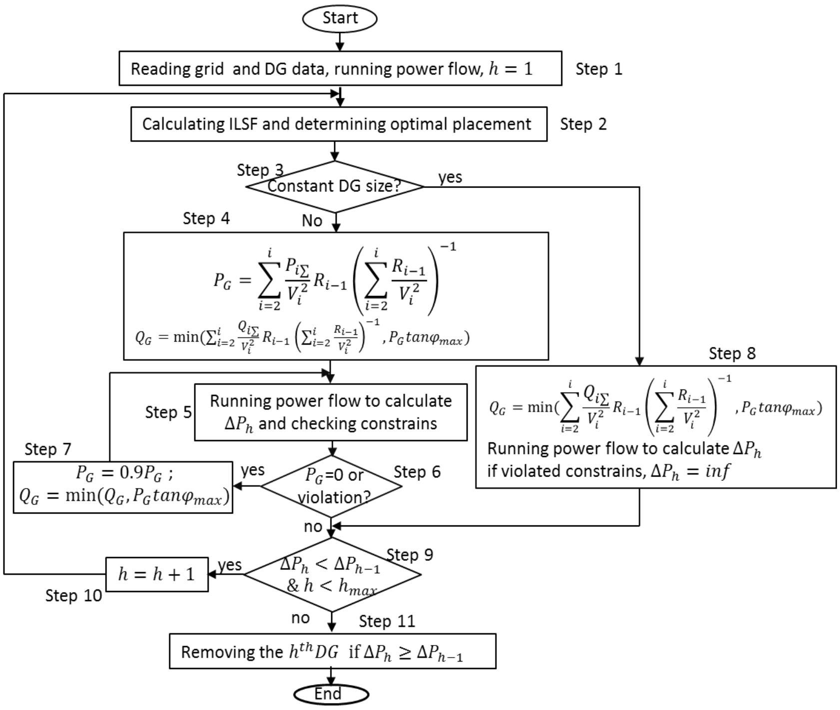


Figure 2. Algorithm to determine optimal position and size of DG

- Step 1: read the data of the grid and DG data including DG size, reactive power capability, and allowable DG number, and run the power flow algorithm without any DG in this grid. We start the first DG, $h = 1$.
- Step 2: calculate ILSF at all nodes and determine the optimal node. The optimal node to install DG is the node with the highest ILSF value to the active power (11).
- Step 3: check the DG rating. If we do not yet know the DG capacity, we run step 4, otherwise, we run Step 9.
- Step 4: determine the $h^{th}$ DG's size according to (16) and (17). The reactive power generated from DG is limited by the reactive power capability of DG, $P_G tan\varphi_{max}$, and hence, it is determined by (18).

$$Q_G = min \left( \sum_{i=2}^{i} \frac{Q_{i\Sigma}}{V_i^2} R_{i-1} \left( \sum_{i=2}^{i} \frac{R_{i-1}}{V_i^2} \right)^{-1}, P_G tan\varphi_{max} \right) \quad (18)$$

- Step 5: connect the $h^{th}$ DG to the grid and run the power flow algorithm to obtain the power loss, $\Delta P_h$. In this step, we check constraints (2) and (3). Noted that $V_{min}$is determined by the minimal voltage in the grid after connecting the $(h-1)^{th}$ DG while $V_{max}$ is set at 1.05pu.
- Step 6: if $P_G = 0$ or one of the constraints is violated, we move to step 7, otherwise, we move to step 9.
- Step 7: reduce the active power of DG by 10% of the current value and calculate the reactive power corresponding to the new value of $P_G$. We return to step. 5.

– Step 8: calculate the reactive power of DG according to (18). We run the power flow algorithm to calculate the power loss $\Delta P_h$ and check constraints (2), and (3). If one of the constraints is violated, we set $\Delta P_h = inf$.
– Step 9: check the stop condition of this algorithm. If the power loss after installing the $h^{th}$ DG, $\Delta P_h$, is lower than that in the previous case, $\Delta P_{h-1}$, and the DG number is below the allowable value, $h_{max}$, we move to step 10, otherwise, we move to step 11.
– Step 10: consider the next DG by increasing $h = h + 1$ and return to step 2.
– Step 11: remove the $h^{th}$ DG from the grid data if the connection of the $h^{th}$ DG makes the power loss in the grid increase, $\Delta P_h \geq \Delta P_{h-1}$.

We finish this algorithm.

## 4. VALIDATION

To evaluate the proposed method's efficiency, we use the IEEE-33 bus distribution grid, Figure 3, and its data is listed in [25]. Here, we test two cases of DG. In the first case, we do not know the size of DG in advance, which means the DG capacity is not limited. In the second case, the DG capacity is foreknown.

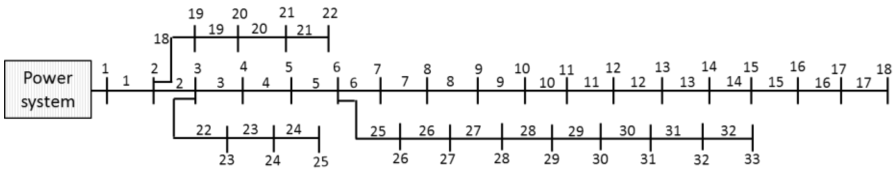


Figure 3. IEEE 33 bus distribution grid

### 4.1. Unknown DG capacity in advance

We suppose that the maximal DG number is three and the lowest pf value of DG is 0.8. By running the proposed algorithm, we can get results in Table 1. From Table 1, we can see that the 18th node, the 33rd node, and the 11th node are suggested to install DG with a total capacity of 1,602 kW. We can see that, only DG at the 33rd node operates at 0.8 pf while others are 0.86 pf. By installing DG at the above nodes in Table 1, the power loss is reduced to 44.323 kW, which means around 157 kW was cut down compared to the based case; the minimal voltage in the grid is increased to 97.63% of the rated value. The voltage at nodes is shown in Figure 4. It is clear that the voltage at nodes is improved significantly; the voltage at almost all nodes is between 97.63% and 100.64% of the rated value. The highest voltage occurs at the 18th node while the node with the lowest voltage is the 30th node. Although DG is not installed on some branches, the voltage at nodes on those branches is improved significantly, taking the branch from the 3rd node to the 25th node as an example. The main reason is that the reduction of the power flow from the source to the 3rd node makes voltage drop on line segments from the source to the 3rd node be reduced. Generally, the voltage at all nodes in the grid is in the normal operation range.

Table 1. Results of DG installation in grid

| Node | DG active power $P_G$ $(kW)$ | pf (%) | Power loss $\Delta P_h (kW)$ | Minimal voltage $V_{min}$(%) | Maximal voltage $V_{max}$(%) |
|---|---|---|---|---|---|
| 18 | 549 | 0.86 | 133.199 | 92.87 | 100 |
| 33 | 674 | 0.80 | 59.447 | 96.90 | 100 |
| 11 | 379 | 0.86 | 44.323 | 97.63 | 100.64 |

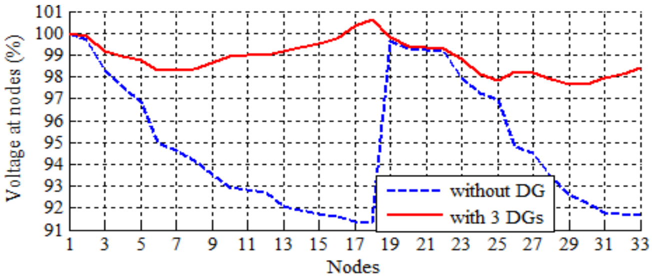


Figure 4. Voltage at nodes after installing three DGs in Table 1

With the DG size installed at nodes in Table 1, Figure 5 indicates the comparison in the efficiency of DG installation when we consider the optimal reactive power generation at DG nodes and reactive power capability of DG (*pf*). We can see that in the case of all DGs operating at a pf, the power loss reduces while the minimal voltage increases as the pf value changes from 1 to 0.8. At 0.8 pf, the power loss and the minimal voltage are 45.13 kW and 97.75%, respectively. The main reason is that the reactive power generated from DGs supplied to vicinity loads, and hence, the reactive power flowing on the line segments is reduced. However, if DG operates at the pf value in Table 1, the power loss is only 44.32 kW while the minimal voltage is 97.63% of the rated value. It means that compared to the case of 0.8 pf, with the proposed algorithm, the power loss in the grid is better while the minimal voltage value cannot be better.

To compare the proposed method to other methods, we use the terms of loss reduction rate (LRR), which is defined by the ratio between the power loss reduction (PLR) and the DG capacity in total in the grid. Note that algorithms considered to compare in this section must be the same in the objective function and DG number; they were applied to the same tested grid; and some of these algorithms used the LSF method. Comparison results are shown in Table 2, in which both the unity pf and the non-unity pf are considered. As can be seen from Table 2, the proposed method has the best performance. The position of DGs is different from others. In both cases of pf, with the proposed method, LRR is the highest although PLR may not be the highest. Obviously, in the case of non-unity pf, PLR of the LSF method and fine-tuned PSO method are up to 93.09% while the data of the proposed method is only 78.06%; however, with the proposed method, PLR is 0.0487%/kW higher than that of other methods, below 0.0428%/kW. This can be seen likely in the case of DGs with the unity pf. The main reason is that PLR depends on both the capacity and the position of DG in the grid. This means that the installation of a higher DG size can lead to a higher PLR but PLR per kW (or LRR) of DG installation is insignificant; the efficiency of installation is not good.

In conclusion, by using the proposed algorithm, we selected the optimal position of DG and calculated the optimal size with the optimal pf of each DG. With the output of the proposed algorithm, the power loss in the distribution grid is reduced significantly. Moreover, the efficiency of DG installation when we use the proposed algorithm is better than that using other algorithms.

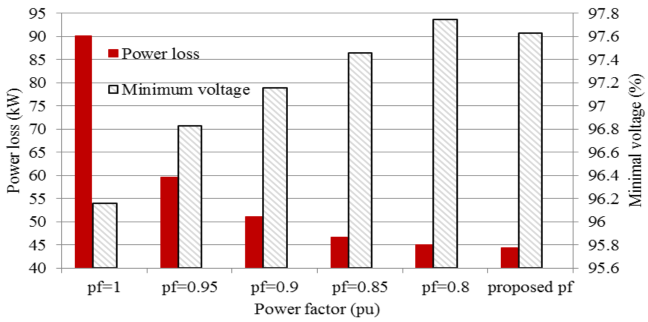


Figure 5. Comparison in the efficiency of DG installation at different pf

Table 2. The result of comparison to other research

| Research/method | DG capacity (Node) | pf | PLR (%) | LRR (%/kW) |
|---|---|---|---|---|
| Ref [23]/LSF | 1,328.2 kVA (6); 850.58 kVA (3); 1,338.8 kVA (28) | 0.850 | 76.42 | 0.0256 |
| Ref [24]/LSF | 679.8 kW (14); 130.2 kW (18); 1,108.5 kW (32) | 0.866 | 82.06 | 0.0428 |
| Ref [25]/LSF | 1,098 kVA (6); 1,098 kVA (30); 741 kVA (14) | 0.820 | 89.09 | 0.0380 |
| Ref [30]/fine-tuned PSO | 738.2 KVA (13); 796.5 KVA (25); 1,364.6 KVA (30) | 0.866 | 93.09 | 0.0370 |
| ILSF method | 549 kW (18); 674 kW (33); 379 kW (11) | | 78.06 | 0.0487 |
| Ref [8]/LSF | 600.3 kW (9); 300 kW (16); 101.2 kW (30) | 1 | 59.34 | 0.0310 |
| Ref [23]/LSF | 1,369 kW (6);791 kW (3); 820 kW (28) | 1 | 52.70 | 0.0177 |
| Ref [24]/LSF | 652.1 kW (14); 198.4 kW (18); 1,067.2 kW (32) | 1 | 57.38 | 0.0299 |
| ILSF method | 549 kW (18); 674 kW (33); 379 kW (11) | 1 | 55.37 | 0.0346 |
| Ref [13]/PIPSO-SQP | 730 kW (13); 1,090 kW (30); 1,070 kW (24) | 1 | 65.48 | 0.0227 |
| Ref [25]/LSF | 720 kW (18); 810 kW (33); 900 kW (25) | 1 | 59.72 | 0.0246 |
| Ref [29]/MRFO | 1,017.1 kW (24); 788.27 kW (13); 1,035.3 kW (30) | 1 | 65.46 | 0.0230 |
| Ref [30]/fine-tuned PSO | 700 kW (16); 1,492.2 kW (25); 1,158.9 kW (30) | 1 | 65.29 | 0.0195 |

### 4.2. Constant DG size

In this section, we suppose that the capacity of each DG is 100 kW, the lowest pf of each DG is 0.8, and the maximum DG number is 16. The result is shown in Table 3. From Table 3, only the 30$^{th}$ node, the 31$^{st}$ node, and the 32$^{nd}$ node are recommended to install two DGs while other nodes are required only 1 DG.

The efficiency of DG installation depends on the pf value of DG as shown in Figure 6. As can be seen from Figure 6, the lower the pf value the better efficiency is. Obviously, with the unity pf, the power loss is around 84 kW while with 0.8 pf, this data is only around 32 kW. Moreover, the minimal voltage in the grid is improved significantly, 96.16% for the unity pf and 97.95% for 0.8 pf. This is explained by the contribution of reactive power from DGs to the reduction of voltage droop on line segments. Hence, in this case, we should set DG with 0.8 pf to obtain the highest efficiency of DG installation. Note that because of the small active power of DG, $Q_G$ is only determined by the limitation of pf, can see in (18).

In the case of DG with 0.8 pf, the prioritized order of DG installation is shown in Table 4. From this table, the 18$^{th}$ node is recommended first and the 10$^{th}$ node is prioritized finally. By comparing to the based case, after the first DG installation, the power loss is reduced from 201.89 kW to 182.48 kW while the minimal voltage is improved insignificantly from 91.34% to 91.93%. However, after the 16$^{th}$ DG installation, both the power loss and the minimal voltage in the grid improved significantly; we saved around 160 kW of power loss while the minimal voltage increased to 97.95%. The voltage at all nodes in the grid is shown in Figure 7. Obviously, the voltage at all nodes is between 100% and 97.95% of the rated value. In the based case, the 18$^{th}$ node has the lowest voltage, below 92% of the rated value, but after installing 16 DGs, it is approximately 99% of the rated value. The voltage at some nodes including the 19$^{th}$-22$^{nd}$ nodes and the 23$^{rd}$-25$^{th}$ nodes is also improved slightly although no DG is installed on these branches. This is explained by the reduction of power flow and voltage droop on the line segments from the source to the 3$^{rd}$ node.

Table 3. The number of DGs at each node

| Node | 10 | 12 | 13 | 14 | 16 | 17 | 18 | 25 | 29 | 30 | 31 | 32 | 33 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DG number | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 |

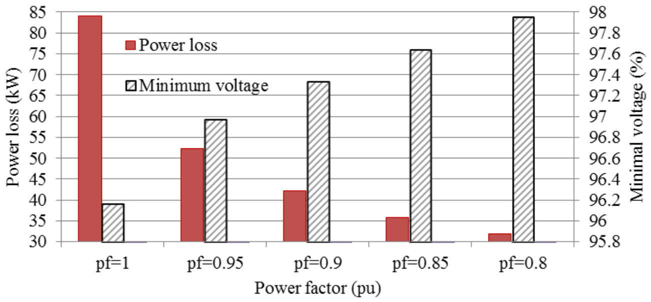


Figure 6. Comparison of the efficiency of DG installation with different pf

Table 4. Efficiency of DG installation when the pf of DG is 0.8

| Node | $\Delta P_h(kW)$ | $V_{min}(\%)$ | Node | $\Delta P_h(kW)$ | $V_{min}(\%)$ |
|---|---|---|---|---|---|
| 18 | 182.4812 | 91.93 | 13 | 76.183 | 95.51 |
| 17 | 166.1238 | 92.17 | 31 | 66.775 | 96.02 |
| 33 | 148.309 | 92.90 | 30 | 58.3970 | 96.53 |
| 32 | 132.343 | 93.59 | 12 | 52.453 | 96.74 |
| 16 | 119.647 | 93.82 | 30 | 45.754 | 97.24 |
| 32 | 106.051 | .94.48 | 10 | 41.314 | 97.45 |
| 14 | 95.717 | 94.70 | 25 | 36.690 | 97.50 |
| 31 | 84.269 | 95.29 | 29 | 31.770 | 97.95 |

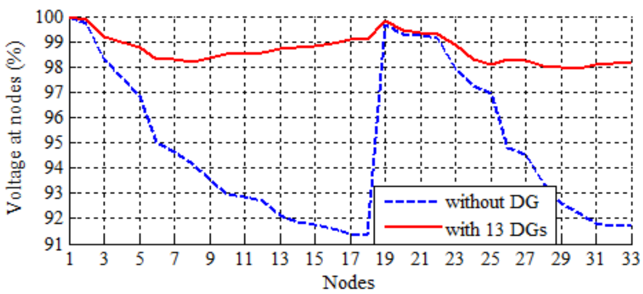


Figure 7. Voltage at all nodes after installing 14 DGs of 100 kW and pf=0.8

Compared to the case of three large DGs as subsection 4.1, it is clear that with the same DG capacity in total, if we use a small DG size to install at many nodes, the performance of the grid is better. By using a 100 kW DG size, the installation efficiency is higher; the PLR is approximately 84% while by using three large DGs, the data is 78.06%. Moreover, the minimal voltage in the grid is higher; 97.63% and 97.95% of the rated value for using 100 kW DG size and using three large DGs, respectively. In conclusion, the proposed algorithm is also effective in selecting the optimal position of DG with a known size. With the suggested position, both the power loss and minimal voltage in the distribution grid were improved. Moreover, this algorithm also allows us to determine the optimal pf of each DG.

## 5. CONCLUSION

This research proposed a method to determine the optimal position of DG in a distribution grid. The proposed method improved the LSF method. This algorithm is validated via IEEE 33-bus distribution grid in two cases of DG size including unknown DG size and constant DG size. The results indicated the optimal position of each DG to minimize the power loss in the grid. We compared the results to that of previous methods including LSF-based algorithm and other algorithms. Comparison results indicated that the proposed algorithm gives us the highest LRR. It means that with the proposed method, the efficiency of DG installation to obtain power loss minimization is the highest. Therefore, this research provides a more effective algorithm for selecting DGs' optimal position to minimize power loss in the grid.

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