REDUCE POWER LOSS IN DISTRIBUTION GRID CONSIDERING THE INSTALLATION EFFICENCY OF DISTRIBUTED GENERATORS

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Abstract - This paper proposes an algorithm to reduce the power loss in distribution grids. The suggested method is based on the distributed generator installation. We propose a new algorithm to optimize the number, position, size, and power factor of distributed generators so that the installation eficiency is maximized while the power loss in the grid is minimized. This algorithm is developed in Matlab software, and we use the IEEE-33 bus and IEEE-69 bus distribution grids to verify. Verifying results indicated that the optimal distributed generator number and its information, such as the position, size, and power factor. Thanks to these distributed generators, the power loss can be reduced by up to 86% and 89% for the IEEE-33 bus and IEEE-69 bus distribution grids, respectively, and the installation efficiency is as high as possible. Compared to another research, with the suggested mumber of distributed generators, the installation efficiency is better.

Key words – AOA; DG; Installation efficiency; Power loss reduction; Optimization

1. Introduction

For electrical energy transmission, it is desired that the electrical energy loss is as low as possible. This request is for the power company to suggest efficient methodologies to reduce power loss on the grid. Normally, the power loss in the distribution grid often accounts for a high percentage because of the low voltage and the line's small cross-section. Therefore, in the distribution grid, power loss reduction is always interesting. Capacitor installation was considered a popular method, but it impacts the node voltage quality. Nowadays, with the development of distributed energy resources, the installation of distributed generators (DG) into the distribution system has become an inevitable trend. The power loss in the distribution grid can be reduced significantly if we carefully choose their position and size [1].

Until now, many algorithms to determine the DG's optimal position in distribution grids have been recommended [2-13]. These algorithms include conventional algorithms, artificial intelligence algorithms, or hybrid algorithms. Generally, modern algorithms have better performance than conventional algorithms but they often run slowly. Some intelligent algorithms are Particle Swarm Optimization [3], Ant Colony [4], Ant Lion [5], and so on. Some algorithms are formed by hybridizing the above two intelligent algorithms or hybridizing one traditional algorithm and one intelligent algorithm [6, 7]. Regarding the objective function, either a single-objective approach or a multi-objective function that combines these single objectives can be pointed out [2]. Some famous single-objective functions are minimizing power loss or electrical energy loss [11-13], improving power quality, etc. Normally, to obtain a low power loss, the total DG capacity is often high. In general, when the total DG capacity increases, power loss decreases. However, beyond a certain threshold, the reduction in power loss becomes negligible compared to the additional DG capacity. This means that the DG installation efficiency declines. Therefore, it is important to consider the efficiency of DG installation as we install DG in the distributed grid to reduce power loss.

The Archimedes Optimization Algorithm (AOA) is a recently developed meta-heuristic algorithm [14]. This algorithm was applied to determine the optimal placement of DG in distribution systems [8-10]. In these applications, multi-objective functions were used. In [8], the objective functions aim to minimize power loss and maintain voltage stability. In [9], two cases were analyzed: a single-objective function focusing on power loss minimization and a multi-objective function that minimizes both power loss and total voltage deviation. In [10], a multi-objective function was utilized to reduce both grid power dependency and greenhouse gas emissions by integrating solar-based DG. Until now, we have not yet had an AOA application to minimize power loss and consider the efficiency of DG installation.

This paper aims to identify the optimal number, placement, capacity, and power factor of DG to minimize power loss, considering DG installation efficiency. To achieve this, we suggest an algorithm developed from AOA. The IEEE-33 bus and IEEE-69 bus distribution systems are used for validation, and the results are analyzed and compared with previous studies.

2. Problem and statement

2.1. Power loss in a distribution grid

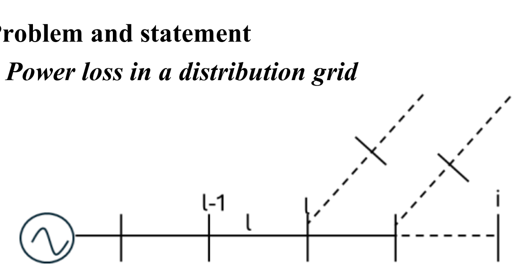


Figure 1. *The sample of a distribution grid*

We suppose that the sample of a distributed grid as Figure 1. The power loss of a distribution grid is described

$$\Delta P_0 = \sum_{l=1}^{N} \Delta P_l = \sum_{l=1}^{N} R_l I_l^2 = \sum_{l=1}^{N} R_l \frac{P_l^2 + Q_l^2}{U_l^2} \quad (1)$$

where, $\Delta P_l, R_l, I_l, P_l, and\ Q_l$ are the power loss, resistance, current, active power, and reactive power in the l^{th}line, resptively; U_l is the volage at the node injecting current or power into the l^{th}line. It means that the power loss depends on the power flow on the line. We suppose that a DG with $P_{DGi} + j\ Q_{DGi}$ is installed at the i^{th} node, and it makes the power on the l^{th}line is changed from $P_l + j\ Q_l$ to $P'_l + j\ Q'_l$. This causes changes in the power loss in the l^{th}line and the whole grid is calculated

$$\Delta P_{DG} = \sum_{l=1}^{N} R_l \frac{P'^2_l + Q'^2_l}{U'^2_l} \quad (2)$$

Depending on the i^{th} node, DG size, the ΔP_{DG}value can be higher or lower than the ΔP_0 $value$. Hence, we should determine the optimal position, capacity, and power factor of DG to obtain an optimal power loss.

2.2. Efficiency of DG installation

We suppose that we install DG with capacity in total $P_{DG\Sigma}$ in the grid and this makes the power loss in the grid reduce from ΔP_0 to ΔP_{DG}. The efficiency of DG installation (EDI) is defined

$$EDI = \frac{\Delta P_0 - \Delta P_{DG}}{P_{DG\Sigma}} \quad (3)$$

From (3), it is clear that the higher $P_{DG\Sigma}$ the lower the EDI value is. The main reason is that the reduction of power loss ΔP_{DG} is lighter than the increase in $P_{DG\Sigma}$. Therefore, we need to determine the optimal number, position, capacity, and power factor of DGs such that the power loss is minimized while the EDI is high.

3. Optimization and Algorithm to determine

3.1. Optimization problem

The objective is to determine the optimal number (n_{DG}), location (l_{DG}), size (P_{DG}), and power factor (pf_{DG}) of DG such that the efficiency of DG installation (EDI) is highest but the power loss minimization is still ensured. Therefore, the general cost function is defined as

$$EDI = f(n_{DG}, l_{DG}, P_{DG}, pf_{DG}) \rightarrow max \quad (4)$$

Constraints:

$$U_{min} \le U_i \le U_{max} \quad (5)$$

$$I_{ij} \le I_{max} \quad (6)$$

$$pf_{min} \le pf \le 1 \quad (7)$$

$$n_{DG} \le n_{DGmax} \quad (8)$$

where, $U_i$is the voltage at the i^{th}node and it must be in between U_{max} and U_{min}; I_{ij} is the current on the l^{th}line, it can not be over the line's allowable capacity I_{max}; the DG power factor should be between the minimum value, pf_{min}, and 1 (the unity power factor); the DG number must be below the maximal DG number, n_{DGmax}. To obtain the above objective (4), we divide the optimal problem (4) into n_{DGmax} sub-optimal problems, where in each sub-optimal problem, we determine the optimal position, size, and power factor of DGs corresponding to a specific DG number. By solving n_{DGmax} sub-optimal problems, we determine the optimal DG number based on the EDI value of n_{DGmax} sub-optimal problems. The sub-optimal problem is defined as

$$\Delta P_{DG} = \sum_{l=1}^{N} \Delta P_l = g(l_{DG}, P_{DG}, pf_{DG}) \rightarrow min \quad (9)$$

So that (5)-(7) are satisfied.

3.2. Algorithm proposal

To solve the optimal problem (4), we suggest an algorithm as Figure 2. In this algorithm, AOA is utilized to solve the sub-optimal problems (9) and from the EDI values of the sub-optimal problems, we determine the optimal DG number. In AOA, we define variables as (10). The proposed algorithm is described as follows

$$X = [l_1, \dots, l_{nDG}, P_1, \dots, P_{nDG}, pf_1, \dots, pf_{nDG}]^T \quad (10)$$

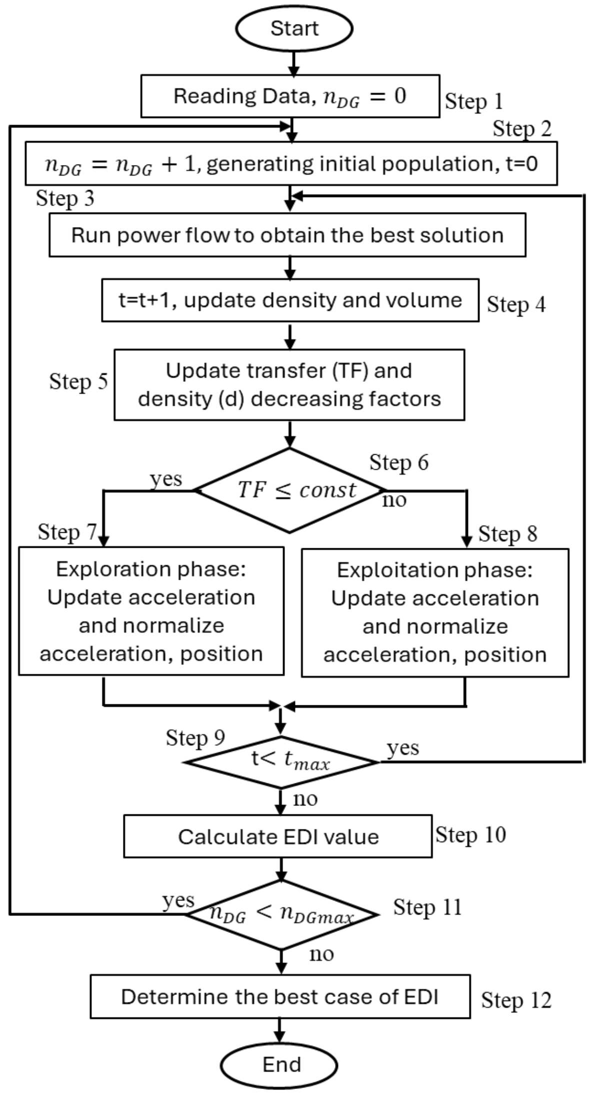


Figure 2. *The proposed algorithm*

Step 1. **Data Initialization:** Start by reading the grid data and setting $n_{DG} = 0$.

Step 2: **Population Initialization:** Increment n_{DG} by 1, randomly generate the initial population, and set $t = 0$.

Step 3. **Rounding and Boundary Validation:** Ensure DG locations and sizes are integers, check the boundary constraints of the vector $\boldsymbol{X}$, and run the power flow to find the optimal vector $\boldsymbol{X}$ that minimizes the cost function (9).

Step 4. **Density and Volume Update:** Adjust the density and volume of each objective as described in [14].

Step 5. **Factor Adjustment:** Update the transfer factor (TF) and density decreasing factor (d).

Step 6. **Transfer Factor Condition Check:** If $TF \leq const$ (where const is a predefined threshold), proceed to the exploration phase (Step 7); otherwise, move to the exploitation phase (Step 8).

Step 7. **Exploration Phase:** Update acceleration, normalize it, and adjust the position according to [14], then proceed to Step 9.

Step 8: **Exploitation Phase:** Similar to Step 7, update and normalize acceleration, adjust position as [14], and then proceed to Step 9.

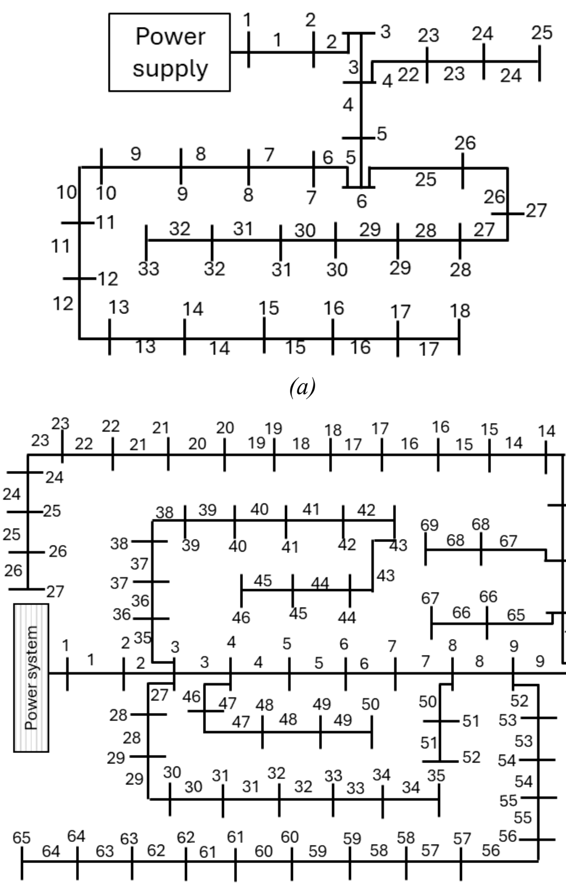
Step 9. **Iteration Condition Check:** If $t < t_{max}$, return to Step 3; otherwise, proceed to Step 10.

Step 10. **EDI Computation:** Calculate the EDI value using equation (3).

Step 11. **DG Number Validation:** If $n_{DG} < n_{DGmax}$, return to Step 2; otherwise, proceed to Step 12.

Step 12. **Optimal DG Selection:** Identify the optimal DG number by comparing EDI values and selecting the case with the highest EDI. The algorithm is terminated.

4. Result analysis



(a)

(b)

Figure 3. *Sample distribution grids: (a) IEEE 33-bus and (b) IEEE 69-bus grid*

To evaluate the efficiency of the above-proposed algorithm, the IEEE 33-bus and 69-bus distribution grids, as Figure 3, are utilized. These grids' data are listed in [15-16]. In the IEEE 33-bus grid, the rated voltage is 12.66 kV and the total load is 3715+j2300 kVA, while in the IEEE 69-bus grid, the total load is 3801.9 kW and 2694.1 kVAr. Here, two scenarios of DG power factor are considered, including the unity power factor (UPF) and the optimal power factor (OPF). We suppose that the maximal DG number is 3. The maximal DG size is 3000kW, and the DG's power factor is limited to 70% and 100%. Results are analyzed and compared to the CBO method [13]. Note that we only compare the results with research in which the objective function is power loss minimization because it is hard to find other research with the same objective function; EDI values with the superscript "*" are calculated from the data in [13] by using equation (3).

4.1. IEEE 33-bus grid

The IEEE 33-bus grid is shown in Figure 3a. In this grid, the rated voltage is 12.66 kV, and the total load is 3715+j2300 kVA. In the base case, the total active power loss is around 210 kW, and the minimal voltage at the 18th node is 90.32% of the rated value. The verifying results are shown in Table 1 and Figure 4.

Table 1. *Verifying results in the IEEE 33-bus grid*

Scenario	n_{DG}	Node	Size/pf (kW/pu)	ΔP_{DG} (kW)	EDI (%)
UPF	2	30 13	1188/1 859/1	84.05	6.13
OPF	2	30 13	1139/0.73 847/0.9	28.5	9.13

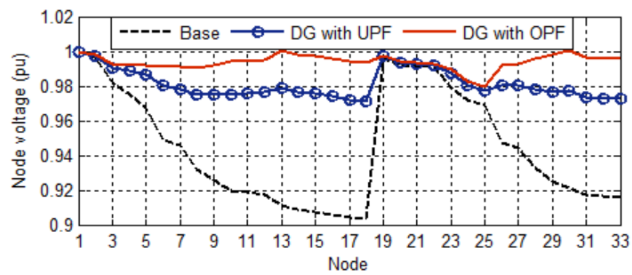
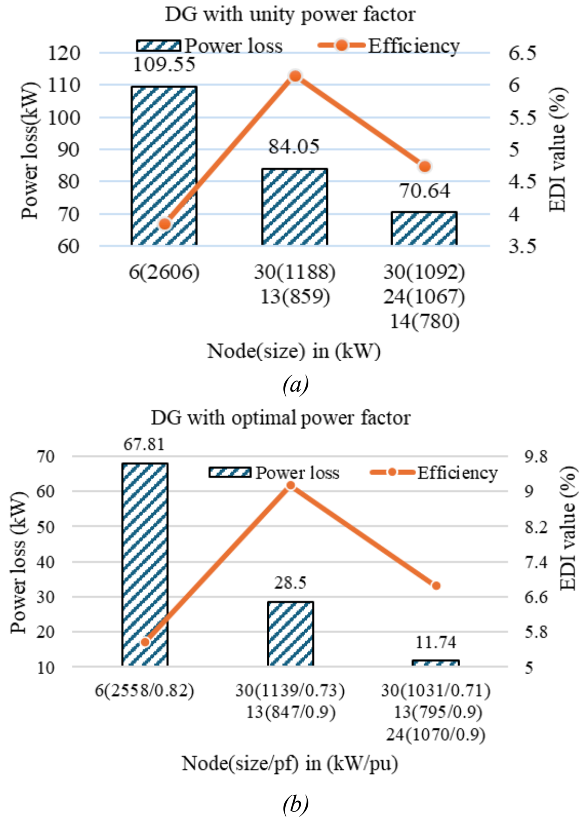


Figure 4. *The voltage at nodes in the IEEE 33-bus system before and after DG installation*

We can see from Table 1 and Figure 4 that in both scenarios of unity power factor and optimal power factor, the optimal DG number is 2; these DGs are suggested to be installed at the 30th and 13th bus; with these DGs, the power loss and the voltage in the grid are improved significantly. The power loss reduction is over 50% while the node voltage is always between 97% and 100% of the rated value. The difference in the DGs' size in the two scenarios is insignificant, but the power loss, EDI, and node voltage improvement in the two scenarios are different. Thanks for utilizing the reactive power of DGs in the case of optimal power factor, the power loss is 28.5 kW, lower than that of the unity power factor case, and hence, the EDI value is much higher than the unity power factor. The details of power loss and EDI corresponding to other DG numbers are shown in Figure 5. Generally, the higher DG number, the power loss is reduced, but the DG size in total is so high therefore the installation efficiency is quite low.

To compare our algorithm to the CBO method [13], we use three cases of DG number in [13], and the results are shown in Table 2. If we only consider the power loss, in two cases of power factor, the power loss in our research can be competitive with that in the CBO method with 2 DG. Regarding the EDI value, our method gives a higher value than that of the CBO method in the same power factor case. This means that our proposal is better than the CBO method.



(a)

(b)

Figure 5. *The power loss and EDI value in different DG numbers in the IEEE 33-bus grid: (a) DG in unity power factor and (b) DG with optimal power factor*

Table 2. *Comparing results in the IEEE 33-bus grid*

Method	Node(size/pf) (kW/pf)	ΔP_{DG} (kW)	EDI (%)
Proposed	30(1188/1) 13(859/1)	84.05	6.13
	30(1139/0.73) 13(847/0.9)	28.5	9.13
CBO [13]	6(2575.315/1)	103.97	4.12*
	26(2410.084/0.819644)	68.98	5.85*
	13(851.5087) 30(1157.632)	87.16	6.11*
	13(819.6654/0.88) 30(1243.126/0.8)	29.31	8.76*
	13(801.7063/1) 24(1091.329/1) 30(1053.64/1)	72.787	4.66*
	14(739.0424/0.882467) 24(1048.879/0.883921) 30(1156.484/0.8)	12.744	6.70*

4.2. IEEE-69 bus grid

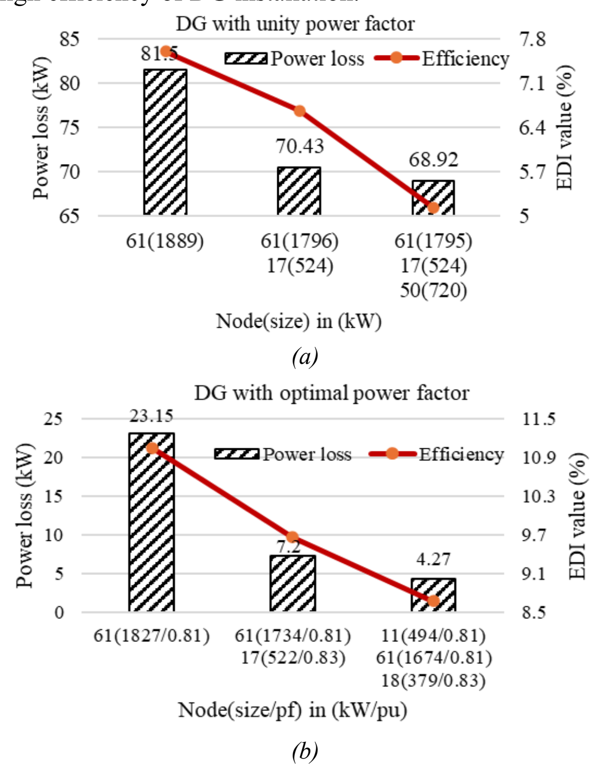
The IEEE 69-bus grid in Figure 3a has a rated voltage of 11 KV, and its total load is 3801.9 kW and 2694.1 kVAr. Without DG installation, the total active power loss of this grid is around 225 kW, and the minimal voltage occurs at the 65th node with 91.02% of the rated value. By running the algorithm, we obtain the results in Table 3.

Table 3. *Verifying results*

Scenario	n_{DG}	Node	Size/pf (kW/pu)	ΔP_{DG} (kW)	EDI (%)
UPF	1	61	1889/1	81.5	7.59
OPF	1	61	1827/0.81	23.15	11.05

From Table 3, we can see that the optimal DG number is 1, and the 61st node is suggested to install DG no matter DG's power factor. The size of DG in the case of the unity power factor is quite similar to that in the optimal power factor. However, with the optimal power factor, the DG installation efficiency is higher than the unity power factor, thanks to the reactive power generated by DG.

With other cases of DG number, the power loss and EDI value are shown in Figure 6. It is clear that with one DG, the power loss is a little higher, but the DG capacity in total is lower than that in the case of two or three DGs. Therefore, the EDI value in the one DG case is higher than in other cases. As a result, one DG is suggested to obtain a high efficiency of DG installation.



(a)

(b)

Figure 6. *The power loss and EDI value in different DG numbers in the IEEE 69-bus grid: (a) DG in unity power factor and (b) DG with optimal power factor*

The voltage at nodes in this grid after installing DG, as Table 3, is shown in Figure 7. Generally, the voltage at all nodes is improved, and it is between 96% and 100%. A significant improvement can be seen from the 56th node to the 65th node because the DG is installed at the 61st node. Compared to the unity power factor case, in the optimal power factor, the difference in the node voltage is insignificant, except for nodes from the 56th node to the 65th node.

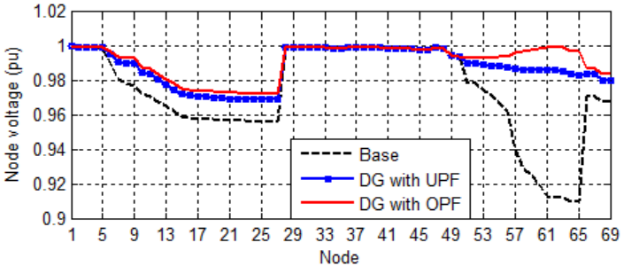


Figure 7. *The voltage at nodes in the IEEE 69-bus system before and after DG installation*

Compared to the CBO method, with one DG, the DG size in the two methods is a little different, but the proposed method gives a lower power loss in both cases of power factor; moreover, with the proposed method, the efficiency is a little higher. Regarding EDI value, with the same power factor, the proposed method gives a higher EDI value than the CBO method. This means the proposed method is better.

Table 4. *Comparing results in the IEEE 69-bus grid*

Method	Node(size/pf) (kW/pu)	ΔP_{DG} (kW)	EDI (%)
Proposed	61(1889/1)	81.5	7.59
	61(1827/0.81)	23.15	11.05
CBO [13]	61(1872.689/1)	83.224	7.57*
	61(1828.451/0.81474)	23.17	11.04*
	17(531.4872/1) 61(1781.461/1)	71.677	6.63*
	17(522.3443/0.828229) 61(1734.68/0.813865)	7.204	9.65*
	11(526.8575/1) 18(380.3413/1) 61(1718.967)	69.428	5.92*
	11(537.029/0.831323) 21(346.5029/0.83261) 61(1673.16/0.81302)	4.277	8.63*

5. Conclusion

This research proposed an algorithm developed from AOA to determine the optimal DG number, location, size, and power factor such that the power loss in the grid is minimized, but the efficiency is still high. This algorithm is verified via IEEE 33-bus and 69-bus distribution grids. Results indicated that the optimal DG number and DGs' optimal parameters should be used to obtain the above objective. Compared to other research, our method still gives a higher value of the DG installation efficiency.

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