MAXIMIZE THE EFFICIENCY OF INSTALLING DISTRIBUTED GENERATORS IN THE DISTRIBUTION GRID

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Abstract - This paper applies the Archimedes Optimization Algorithm (AOA) to determine the optimal position of distributed generators (DGs) in a distribution grid. The cost function is to minimize power loss in the grid and simultaneously maximize the installation efficiency of distributed generator installations. This idea is coded in Matlab and it is used to verify the IEEE-33 bus distribution grid. Results indicated that with the suggested position of DGs, the power loss is reduced significantly and the installation efficiency is the highest. Compared to other research, with the proposed idea, the distributed generator capacity in total is smaller but the installation efficiency is higher.

Key words - Distributed Generation (DG); installation efficiency; optimal position; power loss; sizing

1. Introduction

The power loss in the distribution grid is often high and affects the efficiency of energy transmission in the power system. Therefore, the reduction of power loss in the distribution grid is an interesting issue for power companies. Nowadays, renewable energy has been developed in many countries, and the integration of renewable energy resources or distributed generators (DG) into the distribution system has become more popular. However, if the installing position and size are not calculated carefully the power loss in the grid increases [1].

Many algorithms were suggested to determine the optimal position of DG in distribution grids [2-13]. They can be divided into 2 groups [2], including conventional and artificial intelligence algorithms. Compared to conventional algorithms, modern algorithms are more complex, they can take a long time to run but they can track the global optimal position better. Most modern algorithms are based on the optimal principle of the population such as Particle Swarm Optimization [3], Ant Colony [4], Ant Lion [5], and a hybrid of these algorithms [6, 7]. Regarding the objective function, a single objective function including power loss/electric energy loss minimization, optimal electrical quality, and so on, or a multi-objective function which is a combination of the above single objective function can be used [2]. Generally, power loss minimization is the most popular cost function [11-13]. To obtain this objective, the suggested DG capacity is often high. Generally, if the DG capacity in total is high, the power loss can be low. Normally, if the DG capacity in total is over a range, the rate of power loss reduction becomes insignificant compared to the increase in DG capacity. It means that the DG installation efficiency becomes low. Therefore, we should consider the efficiency of DG installation instead of power loss reduction.

The Archimedes Optimization Algorithm (AOA) is a new meta-heuristic algorithm [14] and there are some applications in determining the optimal position of DG in a distribution grid [8-10]. This algorithm is applied to determine the optimal position of DG to obtain a multi-objective function. In [8], the objective functions are to minimize power loss and ensure voltage stability. In [9], authors considered two cases, including a single and a multi-objective function; the objective function in the single objective is power loss minimization while in the multi-objective function, the objective is to minimize both power loss and total voltage difference. In [10], a multi-objective function is used. The objective function is to minimize both the power exchange from the grid and the greenhouse gas emissions by the installation of solar-based DG.

In this paper, we determine the optimal position and size of DG to minimize the power loss and simultaneously maximize the DG installation efficiency. To obtain this objective, we use AOA to determine the position, size, and power factor of DG. The IEEE-33 bus distribution grid is utilized for validation and verification. Results are analyzed and compared to other research.

2. Problem and statements

The integration of DGs into the grid can increase power loss if their position and size are not optimized. If their position is suitable, the power loss is reduced. Normally, with ideal positions, the higher the DG capacity in total the lower the power loss. However, the higher power loss reduction does not mean the DG installation efficiency is high. For example, the power loss of a distribution grid is 210kW; if we install 500kW of DG in total, the power loss is cut down to 110 kW but if we install 900kW of DG, the power loss is reduced to 100kW, this means that the installation of 500kW DG is more efficient than installation of 900kW DG. Therefore, this research aims to reduce the power loss in the grid while the installation efficiency is still high. It means we consider two objective functions. The first objective is to minimize the power loss, f_2, and the second objective is to maximize the DG installation efficiency, f_2. These single cost functions are defined as (1) and (2)

$$f_1=\frac{\Delta P_\Sigma^{DG}}{\Delta P_\Sigma^0}=\frac{1}{\Delta P_\Sigma^0}\sum_{l=1}^{N}\Delta P_l \rightarrow \min \quad (1)$$

$$F_2=\frac{\Delta P_\Sigma^0-\Delta P_\Sigma^{DG}}{\sum P_{DG}}\rightarrow \max \quad (2)$$

where ΔP_l is the power loss on the l^{th} line, N is the number of lines in the grid, P_{DG} is the DG size installed in the grid,

ΔP_{Σ}^{0} and ΔP_{Σ}^{DG} are power loss in total before and after installing DGs, respectively.

Therefore, the problem of this research is defined as (3)-(6)

$$z=wf_1-(1-w)f_2 \rightarrow \min \quad (3)$$

Constraints:

$$U_{min} \leq U_i \leq U_{max} \quad (4)$$

$$I_{ij} \leq I_{max} \quad (5)$$

$$Pf_{min} \leq pf \leq 1 \quad (6)$$

where, w is the weight of the cost function f_1; U_i is the voltage at the i^{th} node and it must be in the range of maximal value U_{max} and minimal value U_{min}; I_{ij} is the current on the line connecting from the i^{th} node to the j^{th} node, it can not over the line's allowable capacity I_{max}; the DG power factor should be between minimal value, pf_{min}, and 1 (the unity power factor).

3. Proposed algorithm

In this research, we use the Archimedes optimization algorithm (AOA). The details of this algorithm are described in [14]. In this research, we applied this algorithm to determine the optimal position of DGs. We suppose that the DG number is n_{DG}, and here we define the variable as

$$X=\{l_1, l_2,.., l_{nDG}, P_1, P_2,.., P_{nDG}, Q_1, Q_2,.., Q_{nDG}, w\} \quad (7)$$

where l_i, P_i, and Q_i are the location, active power, and reactive power of DG installed at the i^{th} node. Noted that, there are some limitations such as $1 \leq l_i \leq N_n$, (N_n is the maximal node in the grid), $P_{min} \leq P_i \leq P_{max}$, $0 \leq Q_i \leq P_i \tan(\text{acos}(pf_{min}))$. Because the location of DG is an integer number hence in the AOA, before running power flow to calculate the cost function, we must round up and then check the boundary of X. Here, w is the percentage unit. The maximal iteration is t_{max}. AOA application is shown in Figure 1 and is described as follows:

Step 1. Reading Data from the grid and generating randomly the initial population. We start the first iteration, t=1.

Step 2. Rounding and checking the boundary of the population. We run the power flow to obtain the optimal value of vector X such that the cost function is minimal.

Step 3. Checking stop condition. If $t<t_{max}$, we move to Step 4 otherwise, we finish the algorithm.

Step 4. Increasing t=t+1 and updating the density and volume of each objective [14].

Step 5. Updating the transfer factor (TF) and density decreasing factor (d).

Step 6. Checking the transfer factor condition. If $TF \leq const$ where *const* is given, the Step 7 is done, otherwise, the Step 8 is done.

Step 7. Exploring phase: We update the acceleration and normalize acceleration and position [14], and then we return to Step 2.

Step 8. Exploiting phase in which we update the acceleration, normalize acceleration, and position [14], and then we return to Step 2.

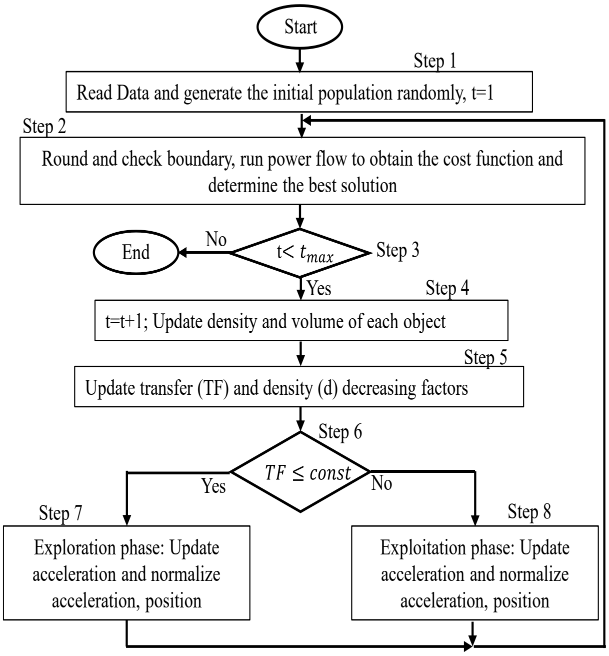

Figure 1. *Application of AOA to determine the optimal position and size of DGs in a distribution grid*

4. Verification

To verify the above algorithm, we use the IEEE 33 bus distribution grid, Figure 2. The data of this grid is listed in Table 1 [15].

Table 1. *The data of IEEE 33 bus distribution grid*

Branch No.	From bus	To bus	R (Ω)	X (Ω)	Load at to bus	
					P (kW)	Q (kW)
1	1	2	0.0922	0.0477	0	0
2	2	3	0.4930	0.2511	100	60
3	3	4	0.3660	0.1864	90	40
4	4	5	0.3811	0.1941	120	80
5	5	6	0.8190	0.7070	60	30
6	6	7	0.1872	0.6188	60	20
7	7	8	1.7114	1.2351	200	100
8	8	9	1.0300	0.7400	200	100
9	9	10	1.0400	0.7400	60	20
10	10	11	0.1966	0.0650	60	20
11	11	12	0.3744	0.1238	45	30
12	12	13	1.4680	1.1550	60	35
13	13	14	0.5416	0.7129	60	35
14	14	15	0.5910	0.5260	120	80
15	15	16	0.7463	0.5450	60	10
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5740	60	20
18	2	19	0.1640	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	40
23	23	24	0.8980	0.7091	90	50
24	24	25	0.8960	0.7011	420	200
25	6	26	0.2030	0.1034	420	200

26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	25
28	28	29	0.8042	0.7006	60	20
29	29	30	0.5075	0.2585	120	70
30	30	31	0.9744	0.9630	200	600
31	31	32	0.3105	0.3619	150	70
32	32	33	0.3410	0.5302	210	100

In this grid, the rated voltage is 12.66kV and the total load is 3715+j2300 kVA. In the base case, the total active power loss is around 210kW and the minimal voltage is 90.32% at the 18th node. Here, we consider two cases of DG power factor including the unity power factor and the optimal power factor. We suppose that the DG number is a constant. The number of DG n_{DG} is set at 1, 2, and 3, respectively. The limitation of DG size is between 100kW and 3000kW and *w* is limited from 10% to 90%. The value of *const* in Figure 1 is set at 0.45.

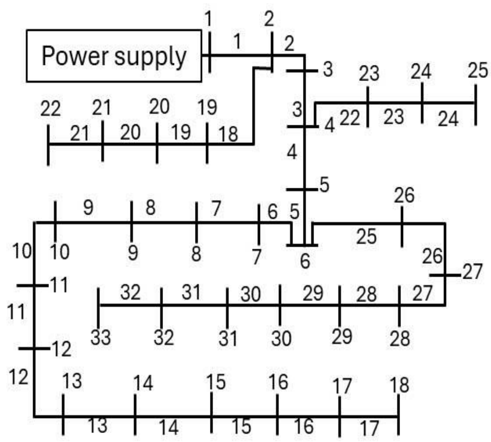

Figure 2. *IEEE-33 bus distribution grid*

4.1. Unity power factor

In this case, we set pf_{min} at 1. Table 2 indicates the optimal position and size of each DG to minimize the cost function.

Table 2. *Verifying results as DG operating in unity power factor*

DG number	Node (size in kW)	f_1 %	f_2 %
1	8(2145)	56.17	4.29
2	16(521) 32(542)	51.87	9.51
3	14(330) 32(538) 18(200)	51.32	9.62

We can see that with 1 DG case, we need to install a DG with 2145kW at the 8th node, which makes the power loss 56.17% of the based case. With the 2-DG case, the optimal position of DG is the 16th node and 32nd node while with the 3-DG case, we should install at the 14th, 32nd, and 18th node. In both cases of 2-DG and 3-DG, the DG capacity in total is quite low, around 1060kW, and the power loss is around 51% of the based case. Regarding the installation efficiency, with the 2 and 3-DG cases, the DG installation is more efficient than with 1-DG case.

Concerning the voltage at nodes, with DG-installed cases, the node voltage improved significantly. The minimal voltage at nodes is over 95%, while without DG installation, this data is 90.32% as Figure. 3. Note that with 1-DG case, because the DG capacity is high and installed at the 8th node, this reduces the power flow from the source to the 8th node. Hence, the voltage at all nodes is improved more significantly than in the cases of 2-DG or 3-DG except for the nodes from the 31st node to the 33rd node.

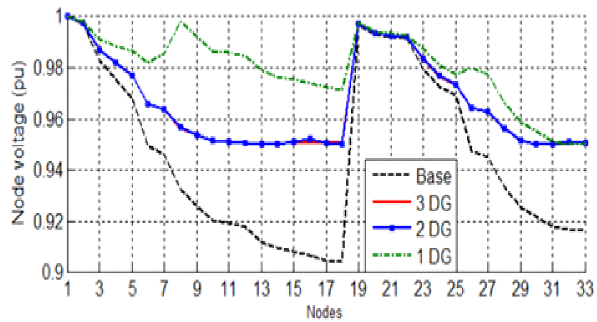

Figure 3. *Voltage at nodes in the grid as DGs operating in the optimal power factor*

4.2. Optimal power factor

In this case, the minimum power factor is set at 0.7pu and results are shown in Table 3 and Figure 4. Likely, with the optimal power factor case, if we install one DG, we need 1349kW at the 8th node and the efficiency is approximate to 9%. With 2 and 3 DG cases, the DG capacity in total is only around 630kW but the installation efficiency is approximately twice that in 1DG case. Note that in all cases, DGs should operate at an optimal power factor of 0.7pu. In the case of 2-DG, the optimal positions are the same as the unity power factor but with 3-DG, the optimal positions are the 15th and 17th nodes instead of the 14th and 18th nodes in the unity power factor. Obviously, compared to the unity power factor case, with optimal power factor, the DG size is smaller and installation efficiency is better thanks to the reactive power output of DGs.

Table 3. *Verifying results as DG operating in optimal power factor*

DG number	Node (size in kW/pf)	f_1 %	f_2 %
1	8(1349/0.7)	42.36	8.97
2	16(291/0.7) 32(338/0.7)	46.31	17.92
3	15(169/0.7) 32(337/0.7) 17(120/0.7)	46.31	18.04

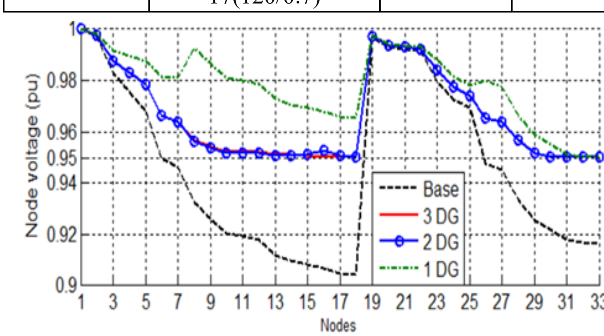

Figure 4. *Voltage at nodes in the grid as DGs operating in the optimal power factor*

Figure 4 indicates the voltage at nodes in the grid in the case of with and without DG installation. From this

Figureure, we can withdraw results like the case of DG operating at unity power factor. We can see that with the optimal power factor of DG, the reactive power from the source to the nodes is also reduced. Hence, though DG capacity is lower the voltage is also improved the same as the case of DG operating at unity power factor.

4.3. Comparison with other research

To compare to other research, we choose research in which the objective function is to minimize power loss. The comparison results for the two cases are presented in Tables 4 and 5. Obviously, with other research, the power loss after installing DGs is lower than that in our research but the installation efficiency is always lower than in our research. Take the Improved Artificial Bee Colony (IABC) in [11] method for example, with 3-DG case, the power loss is 5.59% and 46.31% for the IABC method and our method, respectively while the installation efficiency is 5.65% and 18.04% corresponding to the IABC method and our method. The main reason is that DG capacity in the IABC method is around 3.5MW while in our method, the data is only around 0.63MW. Obviously, with our research, the DG installation is more efficient than other.

Table 4. *Comparison results to other research in optimal power factor case*

Method	Node(size in kW/pf)	f_1 %	f_2 %
Ref [13]	6(2528/0.82)	32.30	5.62
Proposed	8(1349/0.7)	42.36	8.97
IABC [11]	13(935/0.9) 30(1557/0.73)	13.28	7.31
Proposed	16(291/0.7) 32(338/0.7)	46.31	17.92
IABC [11]	13(876/0.9) 24(1189/0.9) 30(1441/0.71)	5.59	5.65
Proposed	15(169/0.7) 32(337/0.7) 17(120/0.7)	46.31	18.04

Table 5. *Comparison results to other research in unity power factor case*

Method	Node(size in kW/pf)	f_1 %	f_2 %
Ref [13]	6(2528/0.82)	32.30	5.62
Proposed	8(1349/0.7)	42.36	8.97
IABC [11]	13(935/0.9) 30(1557/0.73)	13.28	7.31
Proposed	16(291/0.7) 32(338/0.7)	46.31	17.92
IABC [11]	13(876/0.9) 24(1189/0.9) 30(1441/0.71)	5.59	5.65
Proposed	15(169/0.7) 32(337/0.7) 17(120/0.7)	46.31	18.04

5. Conclusion

This research applies the AOA to determine the optimal position and size of DGs such that we can obtain a high installation efficiency. We code this algorithm in Matlab and we use the IEEE 33-bus distribution grid to verify in two power factor cases of DG. Verifying results indicated the position, size of DGs, and the efficiency of DG installation. Compared to other research, our suggestion can make power loss reduction higher but the installation efficiency is higher.

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