Research on DG Capacity Selection Based on Power Flow Calculation

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Abstract. It is important to study the access location and capacity of the distributed power supply in the distribution network to reduce the active loss and raise the voltage level. The influence of DG access on power flow in the distribution network is analysed in this paper. It is concluded that the proper location and capacity of DG will change the current distribution in distribution network, and reduce the power loss caused by distribution network of voltage level. The DG test is carried out with IEEE33 node test system, which validates the validity of this paper.

1. Introduction
Distribution system is a bridge between the end user and the grid system. Power distribution system is the most important part of the power system, because it will cause the failure of the user's power supply terminal, most of the power outages are due to the failure of the distribution network. The current load distribution system is facing increasing load demand. These increasing load of the system has also brought more and more loss, while the system voltage is becoming lower and lower, so the power distribution system is very energy-saving and worth of our in-depth discussion. A typical characteristic of the distribution system is that as the increasing distance between the node and the substation, the voltage at the node is also reduced. The ratio of power distribution system X/R is very low compared with transmission system, but it can cause high power loss and low voltage in radiation type power distribution system [1-2]. Since the voltage level is lower than the transmission system, the power loss in the system is also higher than that of the transmission system. The loss in the system directly affects the economic benefits and energy efficiency of the whole system. Therefore, in order to improve the energy efficiency of the system, we must start from the energy-saving problem of power distribution system. For the power distribution system of energy, there are many technical means can be applied, such as the distribution network reconstruction, the configuration parallel capacitor bank in the system, install distributed power and so on. Distributed power supply can provide part of the active power demand in the system, thus reducing the line current and loss. Distributed power supply in the distribution system can reduce the energy consumption of the system, improve the voltage range of the system, improve the stability and the power factor of the system, and so on. DG's location and capacity impact on the distribution system's energy savings will be examined in this paper.

Distributed Generation (DG) is a small power generation unit, it is an important part of the power system. DG installation can not only bring many benefits to the distribution system, but also bring a lot of threats to power distribution, the power outage mostly caused by the failure of the distribution
network, in the event of power outages, DG can continue to provide some of the load power to improve system reliability. DG is an optional small power generation unit in the system, which can provide some of the energy required for the load. Today the world has developed a number of different DG types and technologies, such as Photovoltaic (PV), Wind Turbine Generator (WTG), Microturbines (MT), Fuel Cells (FC). Among them, PV and wind turbines are the typical new energy generation applications of DG, because they do not need fossil fuels. PV uses solar power and wind turbines make use of wind energy, so they do not cause pollution problems. In this paper, the DG model is also the main research in the wind turbine and PV systems.

Economic factors, environmental factors, and technological factors affect the development of the DG.

The existence of DG in the distribution system, whether in technology or in security issues, is a challenge for the distribution system. If the DG is installed in an unreasonable location, or does not select a suitable DG capacity, then it may lead to the system fault current becomes larger, the voltage deviation from serious, increased power distribution system loss, increase operating costs and so on [3-5]. Therefore, how to choose DG's capacity and location reasonably will be the main purpose of this study.

Many researchers have made contributions to the study of the location and capacity of distributed power supplies and their operating characteristics [6-28]. In literature [6], the problem of distribution network planning with distributed power supply were studied, the author considered the load model can be increased in the distribution network, and used the weight variable to establish the multi-objective optimization model of distributed power supply capacity and location. In literature [7], from the point of view of distribution companies, this paper studied the problem of distributed power source location and constant volume for distributed power investment, operation cost and loss, which was the objective function. In literature [10], the author used the genetic algorithm to optimize the distributed power supply when planning the distribution network expansion. The influence of each optimization scheme on the load and power flow was studied. The effectiveness of the algorithm was verified in practical examples. In literature [11], in the IEEE 16-node system, with the goal of minimizing the loss of active power, the position and capacity of a single DG cell are optimized by three different PSO algorithms. In the three PSO algorithms, DG is modelled as having three different Inertia weight, the authors compared the three modelling DG after the impact of the distribution system. The literature [12] proposed a new population algorithm, artificial ant colony algorithm named as amended, this algorithm validates the DG optimization in the IEEE 33-bus system. It has a positive effect on reducing the loss of the radiation system, increasing the voltage and reducing the greenhouse effect. In literature [13], for the DG installed in the distribution system, the author uses the genetic algorithm to optimize the objective function, and the author uses the voltage control and reactive power control respectively in the DG inverter, and analyses and compares the steady state, Influence of DG on feeder.

The effect of distributed power access on power loss and voltage levels in the grid will be analyzed in this paper to determine the optimal DG capacity and access location. The following part will analyze the influence of DG access on the voltage and power loss of the distribution network. The third part will introduce the method to determine the optimal capacity of DG from the distribution network current. The fourth part will The optimal DG access point and capacity of the distribution network are simulated and verified by the IEEE33 node network.

2. Problem Statement and Preliminaries
DG access to distribution power flow impact analysis

2.1. Influence of DG Access on Distribution Network Voltage
In the distribution network, DG will provide energy to the grid, will increase the voltage of the access point, the access point voltage even higher than voltage substations. If the DG injected enough power, which in addition to the load to provide power, and even feedback to the power grid. Therefore, we
should pay attention to DG after accessing to the system voltage control. Figure 1 shows the distribution network of one-line diagram containing DG, through which you can calculate the distribution network voltage drop problem containing the DG.

\[
\Delta U = U_1 - U_2 \approx \frac{R(P_G - P_L) + X(\pm Q_G - Q_L)}{U_2}
\]  

(1)

Where, \( P_G, Q_G \) were generated active and reactive power of DG; \( P_L, Q_L \) the active and reactive load respectively. When DG injection of active distribution grid, the voltage drop \( \Delta U \) will be reduced. However, if the load is greater than the active DG provide active, the trend will reverse the direction of flow into the grid. At this time voltage \( U_2 \) will rise, and then greater than the transformer secondary voltage \( U_1 \). In addition, the DG injects or consumes reactive \( Q_G \), the voltage can also rise or fall. The purpose of adding the DG is to stabilize the system voltage within a reasonable voltage range.

2.2. Analysis of the Impact of DG Access on Distribution Network Loss

If the transmission line is not long, here does not consider the voltage drop, only from the loss point of view. Distribution network, load, DG relationship shown in Figure 2.

\[
P_{Loss(S,DG)} = I_s^2 r_G = \frac{r_G \left[ (P_L - P_G)^2 - (Q_L - Q_G)^2 \right]}{3U_{Ph}^2}
\]  

(2)
The second part is the access point to the DG load point loss, circuit loss is:

$$P_{\text{Loss}(DG, \text{load})} = I_i^2 r (L - G) = \frac{r (L - G) (P_i^2 + Q_i^2)}{3U_{ph}^2} \tag{3}$$

So the total loss is the sum of the two parts:

$$P_{\text{Loss}(\text{withDG})} = \frac{R}{3U_{ph}^2} \left[ P_i^2 + Q_i^2 + \left( P_i^2 + Q_i^2 - 2P_iP_G - 2P_G^2 \frac{G}{L} \right) \right] \tag{4}$$

Where, $R = rL$. The amount of system loss after DG is:

$$P_{\text{Loss(saving)}} = P_{\text{Loss(withDG)}} - P_{\text{Loss(withDG)}} = \frac{RG}{3U_{ph}^2 L} \left( 2P_iP_G + 2Q_iQ_G - P_G^2 \frac{G}{L} \right) \tag{5}$$

3. Determine the DG optimum capacity from the distribution network current

3.1. Consider the DG capacity when the active power loss of the distribution network is minimum

A power distribution system with n nodes is studied in this part, and only one power supply-substation is used to supply power when the system is not connected to DG. If the m-th node access DG, then there are some branches to make DG and power access node m on together, the set of these branches can be defined as $\alpha$. DG produces a current of $I_G$. It will change the active current on the set $\alpha$, while the other branches of the active current $I_G$ is not affected, and other branches of the active current is not affected influences. When not involved in the distribution network DG, the power losses of the system are:

$$P_{\text{LossDG}} = \sum_{i=1}^{n} I_i^2 r L_i \tag{6}$$

$I_i$ is the current of the i branch, $r$ is the resistance of the line unit length, and $L_i$ is the length of the i branch.

After gaining access DG, the i branch current becomes:

$$I_i^{\text{new}} = I_i + D_i I_G \tag{7}$$

Where, if $i \in \alpha, D_i = 1$; otherwise $D_i = 0$.

At this point in the line of active loss becomes:

$$P_{\text{LossDG}} = \sum_{i=1}^{n} \left( I_i + D_i I_G \right)^2 r L_i \tag{8}$$

Then the reduced active power loss after the DG is the difference between the expressions (6) and (8):

$$P_{\text{saving}} = P_{\text{LossDG}} - P_{\text{Loss}} = \sum_{i=1}^{n} \left( 2D_i I_i I_G + D_i^2 I_G^2 \right) r L_i \tag{9}$$

Using the reducing quantity of electric energy to get the derivation of 1, and make it equal to zero:

$$I_G = -\frac{\sum_{i=1}^{n} D_i I_i r L_i}{\sum_{i=1}^{n} D_i r L_i} = -\frac{\sum_{i=\alpha}^{n} I_i r L_i}{\sum_{i=\alpha}^{n} L_i} \tag{10}$$
Corresponding DG capacity:

\[ P_G = V_m I_G \]  

(11)

Among them, \( V_m \) is the voltage amplitude of the DG access point \( m \). Formula (11) can be used to determine the optimal capacity of each DG in the system. If the electrical resistivity of each wire in the distribution network is the same, the current and active power loss in the system can be obtained by running the power flow calculation, and then the DG capacity can be calculated according to the specific position.

3.2. Consider voltage distribution network systems to enhance the capacity and location of DG

Only consider reducing the active power loss of the system may not be able to improve the system voltage level. Therefore, when calculating the DG access capacity of each location, it is also necessary to consider whether DG access can improve the system voltage level. Therefore, before access DG, should get the voltage range of the system, the voltage of each node, especially the low voltage level of several points, should focus on DG before and after access to the distribution network voltage level, combined with the voltage increase and active loss reduction to determine the DG's best access location and capacity.

3.3. Study on the Algorithm of Position and Capacity of Single

- Firstly, the power flow calculation is carried out for the DG system without access to DG, and the original data of the system are obtained, including the data of node voltage, current, power loss;
- According to (10), (11) to determine the capacity of each node to access DG, DG access location should start from node 2 to all nodes;
- In each node are connected to the calculated capacity of the DG, the power flow in this analysis, the system voltage, active and reactive power loss and other data;
- Compare the reduction of active power loss before and after DG connection, and find the optimal position of DG in combination with the increase of system voltage.

4. Simulation and Analysis

In this paper, IEEE33BUS test system, which includes overhead lines and a variety of equivalent load. The system has 32 branches, 5 contact switch circuit, the reference voltage is 12.66Kv, the total load of active 3965KW, reactive power is 2640KVAR. Figure 3 shows the 33-node system topology. First, make some assumptions about the system:

- In the calculation, the bus 1 is not within the scope of the calculation;
- The type of DG is the fan model;
- The type of fan is double-fed induction generator
Figure 3. Chart of IEEE23 nodes test system.
In figure 3, the thick solid line is the substation; the solid line is the bus; the thin solid line is the branch; and the dotted line is the contact switch line. Taking the 14th node as an example, according to the current situation in the power flow analysis of the original system without DG, the DG capacity of the 14th node should be:

\[
P_G = \frac{\sum_{i=1}^{14} I_i L_i}{\sum_{i=1}^{14} L_i} = 1073 \text{ (KW)}
\]  

(12)

Figure 4 shows the results of system power flow calculation after DG connection.

![Figure 4](image)

Figure 4. The power flow result (with DG installed at node 14).

Compared with the original power flow without DG, it can be seen that the DG access has an effect on the branch current between the access point and the power supply while the current of the other branch is not affected.

In order to verify whether the DG capacity at each node is the optimal capacity, the first node 14 is set to calculate the best capacity value, access system, calculated by running power flow power loss; and then re-access to the node of different capacity of the DG, so that the capacity of DG capacity before and after the optimization of 500KW, verify the capacity interval of 100KW, by running the power flow calculation can be the corresponding power loss, as shown in Figure 5:
Figure 5. Power loss for different size of DG (DG installed at node 14).

It can be seen from Figure 5, when the DG capacity in the vicinity of 1100KW, the system's active loss is the lowest, about 54.6KW, ah calculated the best DG capacity 1073KW consistent.

Through calculated for each node corresponding optimal DG capacity and corresponding system power loss as shown in Table 1 and Figure 6:

Table 1. The optimal size of DG for all of the nodes and power losses.

| Insert position | Capacity (kW) | Power loss (kW) | Insert position | Capacity (kW) | Power loss (kW) |
|-----------------|---------------|-----------------|-----------------|---------------|-----------------|
| 2               | 2649          | 79.5            | 18              | 911           | 57.8            |
| 3               | 2426          | 73.2            | 19              | 889           | 84.3            |
| 4               | 2247          | 69.8            | 20              | 377           | 83.9            |
| 5               | 2131          | 66.6            | 21              | 305           | 83.9            |
| 6               | 2045          | 63.7            | 22              | 214           | 84.9            |
| 7               | 1895          | 63.3            | 23              | 552           | 72              |
| 8               | 1566          | 60.6            | 24              | 382           | 72.6            |
| 9               | 1482          | 59.6            | 25              | 260           | 74.1            |
| 10              | 1325          | 57.8            | 26              | 1042          | 61.5            |
| 11              | 1217          | 56.1            | 27              | 919           | 61.6            |
| 12              | 1133          | 54.8            | 28              | 826           | 61.9            |
| 13              | 1131          | 54.4            | 29              | 805           | 62.1            |
| 14              | 1073          | 54.5            | 30              | 723           | 63              |
| 15              | 1050          | 54.7            | 31              | 651           | 64.3            |
| 16              | 959           | 56.4            | 32              | 589           | 65.5            |
| 17              | 936           | 57              | 33              | 511           | 67.2            |

Figure 6. Power loss for different locations of DG.
It can be seen from the figure, when the DG is located at node 12 - 15, the system's active loss is relatively low, which reduces about 40% compared with the original system. And as the distance between the DG and the substation increases, the required DG capacity becomes smaller.

The DG location and capacity are then determined by analysing the effect of DG access on system voltage. The voltage range of the original system without DG is 0.9356~1.0 (pu), among which the operating voltage of nodes 11~18 is lower than 0.95pu. The voltage of the system is improved when the nodes are connected to DG, especially when nodes 12~18 are connected to DG, the voltage range is ideal. By combining the analysis of power loss, the losses are low at 12~15 node accesses. So only need to compare the DG at these points when the access voltage could be. After the DG is installed on these nodes, the system voltage increase significantly and stably, and by calculating the number of nodes connected to the DG for the reduction of system loss has also been significant results. So consider at these nodes access DG.

5. Conclusion
Power flow analysis is a basic method to study the loss and voltage of power system. For the current distribution in the distribution network and the voltage of the branch conductor length, the optimal capacity of the DG in the radial distribution network is proposed in this paper. Then, the power distribution of DG and DG is analysed by IEEE33, and the performance of the system before and after accessing DG are compared and analysed. Then the reasonable location of DG access is found with the improvement of system voltage and capacity. The results show that the proposed method is effective, DG access can reduce the power consumption of the distribution network and increase the voltage of each node in the distribution network.

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