INTRODUCTION

In recent years, with the rapid development of the distributed generation in power grid system, the DG has been paid close attention in domestic and abroad. The DG is mainly connected into the net through low voltage grid level, with the characteristic of quick construction cycle of investment, environmental protection and flexible installation, etc. DG is mainly accessed at the user side, so it is always locally consumed. The small micro-network is formed by the independent power generation equipment and the local load.

Distributed power can be divided into renewable energy and fossil energy and it is always dispersedly accessed with small capacity. The DG accessed to power system is bound to contribute to the network loss [1, 2] which is determined by the system power flow. The distribution network will be changed into two-way flow mode from the traditional one-way mode with the accession of the DG. The direction of the power flow will inevitably have influence on the distribution network loss calculation [3, 4].

Literature [5] put forward the conceptual model of influencing factors of network loss including the contribution and the distribution rate of the network loss. Literature [6] analyzed the influence of largely accessed distributed power have on the medium voltage distribution network and also researched on the three kinds of typical connections of urban distribution network before and after the micro network accession. Literature [7] put forward the optimization of the best location and capacity of the DG by the firefly algorithm. Literature [8] built the reactive power optimization mathematical model of distribution network of DG from the perspective of network loss and static voltage stability margin.

Therefore, the capacity, the location and the operation mode of the accession of DG should be taken into consideration in the design of power grid planning. This paper quantitatively analyzed the boundary conditions of the city power network loss influences with DG and worked out the rules of the influences. Also, we proposed the suggestions to reduce the distribution network loss with DG, which is empirically verified by a real power feeder in Guangxi.

1 CALCULATION OF DISTRIBUTION NETWORK LOSS

2.1 The network loss without DG

With the line impedance, the network loss always exists which mainly reflects in active power loss [9]. The distribution network loss depends on the current...
flows and the size of the line resistance. Thus the loss can be decreased by reducing the resistance and the current.

The traditional distribution network is mainly the unidirectional power supply mode, and the simplified equivalent power supply model is shown in Figure 1.

![Network system diagram](Image)

Figure 1. The model of the power supply without DG.

As seen in Figure 1, $U$ is the voltage level of the line, $L$(km) is the length of the line, $r + jx$ (Ω/km) means the line impedance of unit length, $I_0$ is the current flowing from the distribution network, $I_L$ is the current flowing into the load, $P_D$ and $Q_D$ are the active power and reactive power sent out from the system, $P_L$ and $Q_L$ are the load power.

$$I_L = \sqrt{P_L^2 + Q_L^2}$$  \hspace{1cm} (1)

$$P_{loss} = (P_D - P_L) = rLL^2 = \frac{rLI (P_L + Q_L)^2}{3U^2}$$  \hspace{1cm} (2)

### 2.2 The network loss calculation containing DG

Since the DG is accessed, the network loss has been divided into two parts. The $P_{lossA}$ is the line loss between the DG and the distribution transformer, the $P_{loss}$ is the line loss between the DG and the load. The simplified equivalent power supply network is shown in Figure 2. The distance between the DG and the load is $l_2$, and the current is $I_G$.

![Network system diagram with DG](Image)

Figure 2. The power supply model with DG.

As seen in Figure 2, $I_D$ is the feeder current injected from the grid system, $I_L$ is the load current, $I_G$ is the current injected from the distributed power, $l_1$ is the electrical distance from the bus to the distributed power, and $l_2$ is the electrical distance from the distributed power to the load.

Assumed that the load is running at a fixed power factor, and feeder voltage is always constant. The line loss is:

$$P_{loss} = P_D + P_L = P_{lossA} + P_{lossB}$$  \hspace{1cm} (3)

The current injected into the distribution network from the DG is:

$$I_G = \frac{\sqrt{P_G^2 + Q_G^2}}{\sqrt{3}U}$$  \hspace{1cm} (4)

The active output power is $P_G$; the reactive output power is $Q_G$. The network loss is calculated respectively into two parts. Assume that the other part of the network loss is zero and the load current is constant in the calculation. Then the two parts of network loss $P_{lossA}$ and $P_{lossB}$ are:

$$P_{loss} = r \cdot l_2 \cdot (P_G^2 + Q_G^2)$$  \hspace{1cm} (5)

$$P_{loss} = \frac{r \cdot l_1 \cdot (P_G^2 + Q_G^2)}{3U^2}$$  \hspace{1cm} (6)

Combined with formula (5) and (6), the total network loss for the feeder is:

$$P_{loss} = \frac{r \cdot l_1 \cdot (P_G^2 + Q_G^2) + r \cdot l_2 \cdot (P_G^2 + Q_G^2)}{3U^2} = \frac{r \cdot l_1 \cdot (P_G^2 + Q_G^2)}{3U^2} + \frac{r \cdot l_2 \cdot (P_G^2 + Q_G^2)}{3U^2}$$  \hspace{1cm} (7)

So the variable quantity of the network loss with DG is:

$$\Delta P_{loss} = P_{loss} - P_{loss} = \frac{r \cdot l_1 \cdot (P_G^2 + Q_G^2) - 2P_D \cdot P_L - 2Q_D \cdot Q_L}{3U^2}$$  \hspace{1cm} (8)

### 2.3 The analysis of the impact of the network loss with DG

Formula (8) shows that when $\Delta P_{loss} < 0$, the introduction of DG can reduce the line loss. Conversely, it would increase the original line network loss. The change rate of network loss is set as $K_P$:

$$K_P = \frac{\Delta P_{loss}}{P_{loss}} = \frac{l_1 \cdot (P_G^2 + Q_G^2 - 2P_D \cdot P_L - 2Q_D \cdot Q_L)}{l \cdot (P_G^2 + Q_G^2)}$$  \hspace{1cm} (9)

From formula (9), we can know that, $K_P$ can reflect the influence of DG accession on the network loss. The greater the value of $K_P$ is, the greater influence DG accession have on the network loss and vice versa.

DG can be operated in three modes: leading power factor, unity power factor and lagging power factor. In the leading power factor mode, DG absorbs reactive...
power from the system, namely it sends negative reactive power. Conversely, in the lagging power factor mode, DG sends reactive power. Therefore, the reactive power from the DG can be represented as follows:

\[
Q_n = P_n \cdot \text{tan} \theta = (-1)^n \sqrt{1 - \cos^2 \theta} \cdot P_n
\]

Introducing formula (10) into (9), we can obtain formula (11), in which \(n\) is defined as above:

\[
K_p = \frac{l}{l} \left( \frac{1}{\cos \theta} \right) \left( \frac{P_n - 2P_L - \left(-1\right)^n \sqrt{1 - \cos^2 \theta} \cdot 2Q_L \cdot P_L}{P_n + Q_L} \right) = \frac{l}{l} \left( \frac{P_n - 2P_L - \left(-1\right)^n \sqrt{1 - \cos^2 \theta} \cdot 2Q_L \cdot P_L}{P_n + Q_L} \right)
\]

Assumed that the load power factor is set to 0.95, we plug it into the formula (11), then:

\[
K_p = \frac{l}{l} \left( \frac{1}{\cos \theta} \right) \left( \frac{P_n - 2P_L - \left(-1\right)^n \cdot \sqrt{1 - \cos^2 \theta} \cdot 2Q_L \cdot P_L}{P_n + Q_L} \right) = \frac{l}{l} \left( \frac{P_n - 2P_L - \left(-1\right)^n \cdot 0.657 \cdot \sqrt{1 - \cos^2 \theta} \cdot 2Q_L \cdot P_L}{P_n + Q_L} \right)
\]

As it can be seen from formula (12), the influence of DG accession on the distribution network loss mainly depends on the operation power factor, the accession location and the capacity of DG.

When \(K_p=0\), it is the critical point of the DG’s contribution to the network loss, and then:

Order \(\alpha = \cos \theta + \left(-1\right)^n \cdot 0.657 \cdot \sqrt{1 - \cos^2 \theta} \cdot 2Q_L \cdot P_L \), while \(\alpha\) is decided by the operation power factor of DG, and then \(PG=2\alpha PL\). Obtain the derive of formula (12) and order \(K_p=0\), then we can get \(PG=\alpha PL\).

From above derivations, we can also obtain that:

1. When \(PG<\alpha PL\), \(K_p<0\), \(K_p>0\), the DG accession can reduce the system network loss. The larger the DG capacity is, the more the network loss can be reduced. When \(PG=\alpha PL\) DG accession can maximally reduce the network loss;
2. When \(\alpha PL<PG<2\alpha PL\), \(K_p<0\), \(K_p>0\), the DG accession can reduce the system network loss. While the larger the DG capacity is, the less the network loss can be reduced. When \(PG=2\alpha PL\) DG accession has no effect on the line loss; 
3. When the \(PG>2\alpha PL\), \(K_p>0\), \(K_p<0\), the DG accession will increase the system network loss. The larger the DG capacity is, the more the network loss will be increased.

3 SIMULATION EXAMPLES ANALYSIS

3.1 Network frame based data

In order to further verify the above conclusions, this paper chose a 10 kV circuit in Guangxi as a distribution network frame and built a simulation network. Currently, most of the wiring types of urban distribution network are single-ring network wiring and radiative wiring, and the ring mode is mostly open in loop operation. As the unit of the distribution network is the feeder line and the calculation of the power flow is on the feeder line, the calculation can be significantly simplified without loss of generality. The actual data in the distribution network is referenced for the simulation calculation with proper DG accessed. The simulation network frame is shown in Figure 3:

![Figure 3. The simulation grids.](image)

The actual operation load curve of the 10 kv line is shown in Figure 4:

![Figure 4. The average load curve](image)

Figure 4 shows that the highest peak of the maximum and the average daily load occurs between spring and summer, and the peak load is 4.533 MW. From the annual data of power consumption, the electrical load in July and August is relatively high, and the average power consumption is around 1.24 MW. The lowest peak of power consumption is in October, November and December, which is about 0.4 MW, and the load fluctuation is relatively stable. The power consumption in these three months is the lowest whether from the perspective of the average value, the minimum value or the maximum value.
The local meteorological data is an important reference index to measure whether it is appropriate to access DG. The data of sun radiation and wind resource in this region is shown in Figure 5.

![Figure 5](image1)
(a) Data of the wind speed in one week

(b) Data of the lighting in one week

Figure 5. The meteorological data in this region.

Figure 5 shows that this region has rich solar energy resources; therefore the photovoltaic solar energy resources can be developed. Moderate wind power can be used for compensation for the output fluctuation of photovoltaic power. The capacity of the DG should not be too large in the 10kV power system, and moderate reactive distributed power can be assessed for complementation. By analyzing the load characteristics and meteorological resources, the capacity of the DG and the energy storage of the local distribution network to be accessed are shown in Table 1.

<table>
<thead>
<tr>
<th>Type</th>
<th>Capacity</th>
<th>Parallel type</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>191kW</td>
<td>Inverter</td>
</tr>
<tr>
<td>Wind</td>
<td>60kW</td>
<td>Direct cutting-in</td>
</tr>
<tr>
<td>Storage</td>
<td>230kWh</td>
<td>Inverter</td>
</tr>
</tbody>
</table>

Table1. The capacity of the DG and the energy storage.

3.2 The simulation analysis

Access the DG at some point in the line, and the system network loss before and after the DG accession is shown in Table 2.

<table>
<thead>
<tr>
<th></th>
<th>$P_{DG}$</th>
<th>$P_L$</th>
<th>$P_{loss}$</th>
<th>$P_{L-loss}$</th>
<th>$P_{loss}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P$(kW)</td>
<td>0.00</td>
<td>2040.83</td>
<td>2104.41</td>
<td>63.63</td>
<td>50.47</td>
</tr>
<tr>
<td>$Q$(kvar)</td>
<td>0.00</td>
<td>712.42</td>
<td>638.76</td>
<td>-73.58</td>
<td>59.27</td>
</tr>
</tbody>
</table>

Table 2. The simulation results without DG.

As it can be seen in Table 2 and Table 3, the transmission loss of the distribution line is reduced due to the nearest supply principle of DG accession. The total power loss in the distribution network decreased 4.79 kW, and the demand for feed-in power is reduced.

1) Assuming that $\cos \theta = 1$ ($\alpha = 1$), and the distance between the DG and the line head is 0.2L, 0.4L, 0.6L, 0.8L. The relationship curves of the capacity and position of DG accession and the change rate of feeder network loss are shown in Figure 6.

![Figure 6](image2)

In Figure 6, the horizontal axis is the ratio of DG and load $P_{DG}/P_L$, and the vertical axis is the change rate of network loss $K_p$. Five curves which represent the change rate of the network loss are obtained based on the simulation results. When $K_p$ is negative, the network loss is reduced. Conversely, the network loss increases when $K_p$ is positive. It can be seen from each curve that when $P_{DG}=2P_L$ and $K_p<0$, the extreme point $P_{DG}=P_L$. The nearer the DG accession position is to the line end, the greater impact the DG accession has on the network loss of the feeder.

2) The effect on the network loss varies when the DG accession positions are different. Figure 7 shows the network loss variations with different DG accession positions in the main feeder. The bigger proportion of the position is, the closer the DG accession is to the end of the distribution line.

![Figure 7](image3)

Figure 7 shows the importance of accession position of DG. The distribution network loss can be effectively reduced when the DG is accessed at the end of the line. The nearer the DG accession is to the load, the more obvious the loss deduction effect is.
The loss of the distribution network is different when the DG is operated with different power factors. Figure 8 comprehensively analyzed the effect of different power factors and DG accession positions on the network loss.

Figure 8. The effect of different power factors and DG accession positions.

Compared with the DG operated in the advanced power factor, the distribution network loss can be more effectively reduced in the lagging power factor operation because the power system is injected with the active power and the reactive power in the same time.

To sum up, the network loss can be affected by the accession capacity, the operation mode, and the DG accession positions. The bigger the accession capacity is, the greater the influence is; the nearer the DG accession is to the end of the line, the greater the influence is. The lagging power factor operation is more effective for the loss deduction. When the accession capacity is too large, it’s not conducive to reducing the loss, and even worse, it may increase the loss.

Therefore, it is suggested to avoid centralized accession of large capacity in the end of the line. And its operation mode should be appropriately adjusted according to the output of the DG.

Under the condition that the distributed power is locally used, it’s more beneficial to reduce the network loss when the accession position is nearer to the end of the line. So it is better to set the accession position at the end of the line or nearer to the large load position. When the DG is operated in lagging power factor, it’s more conducive to reducing the network loss. Conversely, the operation of DG in advanced power factor should be avoided as this operation will weaken the capability of reducing the network loss.

4 CONCLUSION

DG was generally accessed to distribution network near the load. The flow direction would be changed after the accession of DG and the entire load of the distribution network will be changed as well. These changes will cause system network loss, which is not only related to the load, but also related with the capacity, the location and the operation mode.

In this paper, the boundary conditions of the influence on the network loss were analyzed from the perspective of network loss calculation. And also the influencing disciplines and suggestions to reduce the network loss were proposed accordingly. The conclusion was verified by simulation on a practical 10kV power feeder. The result shows the DG has a certain impact on the network loss. The greater the capacity is, the more influence it has. The operation of DG in lagging power factor is more conducive to reducing the loss. Moreover, when the DG capacity is too large, the DG is not conducive to reducing the network loss, and it even may increase the loss. With the increase of the DG capacity, the degree of reducing the network loss will tend to be saturated. For the DG with small capacity, it can be set at the end of the transmission line. For the DG with large capacity, the setting at the end of the transmission line is unfavorable to reducing the network loss.

REFERENCE