Optimal Placement of Distributed Generation in Power System for Power System Loss Reduction Using ETAP

Suliman Khan*, Salim Ur Rehman, Anees Ur Rehman, Hashmat Khan

Department of Electrical Engineering, Sarhad University of Science & IT Peshawar, Pakistan
engr_sulimankhan_131@yahoo.com

Keywords: Distributed Generation, Power System Losses, Load Flow Analysis, Electrical Transient Analyzer Program ETAP.

Abstract. Because of increasing interest in renewable energy sources in recent times, the studies concerning integration of Distributed Generation (DG) to power grid have been increased rapidly. Apart from other benefits, loss reduction and voltage profile improvement are its salient features. Non-optimal locations of DG units may lead to increase power losses. Optimal location of DGs in power systems is vital to maximizing overall system efficiency. In this approach, optimization techniques have been applied to determine the optimal allocation and impact of DG on electric power system in terms of power loss reduction is analyzed. The Newton Raphson load flow analysis has been carried out on 10 bus systems using ETAP software which shows that active power losses were reduced from 3302.2 KW to 400.7 KW after the installation of 5MW.

I. Introduction

In all sectors around the world, electricity consumption is rapidly increasing. One possible means of satisfying the rapid growth in electricity demand is to promote the widespread employment of distributed generation (DG) as there continues to be strong interest in operating it in parallel with a utility distribution system [1].

Some positive benefits of the installation of DG incorporate system energy loss reduction, voltage profile augmentation and reliability enhancement [2]. DG provides lower operating costs and is flexible to install in terms of investment and time. Furthermore, renewable energy based DG can play a vital role in building sustainable energy infrastructure. In general, distribution systems are designed purely to deliver power to consumers, and by introducing DG will change a distribution network’s characteristics due to its bi-directional power flow [3]. If its penetration level is too high, a voltage rise problem may occur by dint of its reverse power flow [4], while improper size and improper sizing and inappropriate placement of DG may lead to higher power losses in a system than the one having no DG [5]. Therefore, the integration of a significant large amount of distributed energy resources (DER) may cause operational conflicts for a power distribution network [6]. Consequently, in order to ensure the reliable, stable and efficient operation of a power distribution system, DG planning is part and parcel

II. Newton-Raphson Method

The first Gauss-Seidel method (G-S) is simpler but the second Newton-Raphson (NR) is reported to have better convergence characteristics as well as faster than (G-S) method. The Newton-Raphson procedure is as follows:

Step1: Choose the initial values of the voltage magnitudes $|V|^{(0)}$ of all np load buses and $n - 1$ angles $\delta^{(k)}$ of the voltages of all the buses except the slack bus.

Step-2: Use the estimated $|V|^{(k)}$ and $\delta^{(k)}$ to calculate a total $n - 1$ number of injected real power $P_{\text{calc}}^{(k)}$ and equal number of real power mismatch $P^{(k)}$.

Step-3: Use the estimated $|V|^{(k)}$ and $\delta^{(k)}$ to calculate a total np number of injected reactive power $Q_{\text{calc}}^{(k)}$ and equal number of reactive power mismatch $\Delta Q^{(k)}$. 
Step-4: Use the estimated $|V|^{(k)}$ and $\delta^{(k)}$ to formulate the Jacobian matrix $J^{(k)}$.

$$
\begin{bmatrix}
\Delta \delta_2 \\
\vdots \\
\Delta \delta_{n_2} \\
\Delta |V|_2 \\
\vdots \\
\Delta |V|_{1+np} \\
\end{bmatrix} = 
\begin{bmatrix}
\Delta P_2 \\
\vdots \\
\Delta P_n \\
\Delta Q_2 \\
\vdots \\
\Delta Q_{1+np} \\
\end{bmatrix}
$$

for $\Delta \delta^{(k)}$ and $\Delta |V|^{(k)}$.

Step-5: Solve

$$
\begin{bmatrix}
\Delta \delta_2 \\
\vdots \\
\Delta \delta_{n_2} \\
\Delta |V|_2 \\
\vdots \\
\Delta |V|_{1+np} \\
\end{bmatrix} = 
\begin{bmatrix}
\Delta P_2 \\
\vdots \\
\Delta P_n \\
\Delta Q_2 \\
\vdots \\
\Delta Q_{1+np} \\
\end{bmatrix}
$$

Step-6: Obtain the updates from

$$
\delta^{(1)} = \delta^{(0)} + \Delta \delta^{(0)} 
$$

(1)

and

$$
|V|^{(k+1)} = |V|^{(k)} \left[1 + \frac{\Delta |V|^{(k)}}{|V|^{(k)}}\right] 
$$

(2)

Step-7: Check if all the mismatches are below a small number. Terminate the process if the condition is satisfied. Otherwise go back to step-1 to start the next iteration with the updates given by (1) and (2).

III. ETAP For Load Flow Analysis

The ETAP 400 Power station possesses a unique quadratic convergence characteristic. Usually, it has a very fast convergence speed compared to other load flow calculation techniques. It has also the advantage that the convergence criterion specified to ensure convergence for bus real power and reactive power mismatch. This criterion gives you direct control of the accuracy you want to specify for the load flow solution. The convergence criterion for the Newton-Raphson method is typically set to 0.001 MW and MVAR.

The Newton-Raphson method is highly dependent on the initial values of bus voltage. A careful selection of bus voltage initial values is strongly recommended. Before running load flow using the Newton-Raphson method, ETAP PowerStation makes a few Gauss-Seidel iterations to establish a set of sound initial values for the bus voltages. The Newton-Raphson method is recommended for use with any system as a first choice.

A. Simulation Phase I:

Power System without DG installation:

The main grid with the power rating of 850MVA is connected to bus-1 of power system shown in Fig. 1. The nominal voltage of the power grid is 220KV which is fed entire buses of given 10 buses power system.
The transformer T1 is connected to bus-1 which steps down the for entire power system buses. The voltage and power rating of T1 is 220/11KV and 400MVA respectively. No load is connected directly to bus-1 while remaining buses are loaded. The detail of the load on each bus is shown in Table 1.

<table>
<thead>
<tr>
<th>Bus No</th>
<th>Load (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus-2</td>
<td>119</td>
</tr>
<tr>
<td>Bus-3</td>
<td>148</td>
</tr>
<tr>
<td>Bus-4</td>
<td>113</td>
</tr>
<tr>
<td>Bus-5</td>
<td>37.8</td>
</tr>
<tr>
<td>Bus-6</td>
<td>7.9</td>
</tr>
<tr>
<td>Bus-7</td>
<td>20</td>
</tr>
<tr>
<td>Bus-8</td>
<td>6.8</td>
</tr>
<tr>
<td>Bus-9</td>
<td>8.95</td>
</tr>
<tr>
<td>Bus-10</td>
<td>35.63</td>
</tr>
</tbody>
</table>

In Phase-I of optimization, the load flow analysis was executed on power system without being installing the DG so that the impact of power losses was studied. The simulation shows total losses of entire power system as shown in Fig. 2.
The overall system losses after execution of load flow analysis without DG were 3302.2 KW. This is the huge power losses for any power system that must be minimized by insertion of distribution generation. We have selected DG with the rating of 5 MW. The said DG must be placed in optimal location so that DG may be connected to the bus which gives lowest overall power system losses.

B. Simulation Phase II.

Power System with DG:

Distributed generation having capacity 5MW is now connected to the power system and find out the effect of DG on the entire system. Bus-1 is connected to the main grid station so its voltage rating is 220KV; while the remaining buses are rated with 11KV.

Power system with DG to Bus-3:

The voltage profile, active and Reactive power at each bus is shown in Fig. 3 after the DG is connected to Bus-3.
The losses of the power system when DG is connected to bus-3 are shown in Table 2.

**Table 2. Power Losses between Buss when DG at Bus-3**

<table>
<thead>
<tr>
<th>Bus to Bus</th>
<th>Distance (KM)</th>
<th>Losses (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B&lt;sub&gt;12&lt;/sub&gt;</td>
<td>55</td>
<td>354.8</td>
</tr>
<tr>
<td>B&lt;sub&gt;23&lt;/sub&gt;</td>
<td>20</td>
<td>16.2</td>
</tr>
<tr>
<td>B&lt;sub&gt;24&lt;/sub&gt;</td>
<td>30</td>
<td>90.4</td>
</tr>
<tr>
<td>B&lt;sub&gt;45&lt;/sub&gt;</td>
<td>18.5</td>
<td>1.4</td>
</tr>
<tr>
<td>B&lt;sub&gt;46&lt;/sub&gt;</td>
<td>6</td>
<td>1.0</td>
</tr>
<tr>
<td>B&lt;sub&gt;67&lt;/sub&gt;</td>
<td>14.45</td>
<td>0.9</td>
</tr>
<tr>
<td>B&lt;sub&gt;78&lt;/sub&gt;</td>
<td>40.80</td>
<td>3.2</td>
</tr>
<tr>
<td>B&lt;sub&gt;89&lt;/sub&gt;</td>
<td>38.8</td>
<td>0.7</td>
</tr>
<tr>
<td>B&lt;sub&gt;710&lt;/sub&gt;</td>
<td>38.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

When DG was connected to Bus-3 the overall system losses recorded were 468.9KW (i.e. reduced to 85.80%).

**Power System with DG connected to Bus-4:**

The voltage profile, active and Reactive power at each bus are shown in Fig. 4 after the DG is connected to Bus-4.
At this stage, the losses of the power system when DG is connected to Bus-4 is 400.7KW shown in Table 3.

Table 3. Power Losses between Buss when DG at Bus-4

<table>
<thead>
<tr>
<th>Bus to Bus</th>
<th>Distance (KM)</th>
<th>Losses (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_{12}</td>
<td>55</td>
<td>385.5</td>
</tr>
<tr>
<td>B_{23}</td>
<td>20</td>
<td>3.0</td>
</tr>
<tr>
<td>B_{24}</td>
<td>30</td>
<td>1.8</td>
</tr>
<tr>
<td>B_{45}</td>
<td>18.5</td>
<td>3.4</td>
</tr>
<tr>
<td>B_{46}</td>
<td>6</td>
<td>1.0</td>
</tr>
<tr>
<td>B_{67}</td>
<td>14.45</td>
<td>1.0</td>
</tr>
<tr>
<td>B_{78}</td>
<td>40.80</td>
<td>2.4</td>
</tr>
<tr>
<td>B_{89}</td>
<td>38.8</td>
<td>0.2</td>
</tr>
<tr>
<td>B_{710}</td>
<td>38.4</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Above table shows the power losses of the power system are high (i.e. 400.7KW), which is 87.86% as compared to when there was no DG to the system.

Power System with DG at Bus-5:

The voltage profile and active & Reactive power at each bus are shown in Fig. 5 after the DG is connected to Bus-5.
The losses of the system when DG is connected to Bus-5 bus are 439.7KW which is 86.68% shown in Table 4.

Table 4. Power Losses between Buss when DG at Bus-5

<table>
<thead>
<tr>
<th>Bus to Bus</th>
<th>Distance (KM)</th>
<th>Losses (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_{12}</td>
<td>55</td>
<td>384.8</td>
</tr>
<tr>
<td>B_{23}</td>
<td>20</td>
<td>3.0</td>
</tr>
<tr>
<td>B_{24}</td>
<td>30</td>
<td>28.4</td>
</tr>
<tr>
<td>B_{45}</td>
<td>18.5</td>
<td>14.2</td>
</tr>
<tr>
<td>B_{46}</td>
<td>6</td>
<td>1.4</td>
</tr>
<tr>
<td>B_{67}</td>
<td>14.45</td>
<td>1.4</td>
</tr>
<tr>
<td>B_{78}</td>
<td>40.80</td>
<td>2.4</td>
</tr>
<tr>
<td>B_{89}</td>
<td>38.8</td>
<td>0.3</td>
</tr>
<tr>
<td>B_{110}</td>
<td>38.4</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Power System with DG at Bus-6:

The voltage profile, active and reactive power at each bus are shown in Fig. 6 after the 5MW DG is connected to Bus-6.
Figure 6. Load flow Analysis of Power System when DG to Bus-6

While the losses of the power system when DG is connected to Bus-6 is 402.7KW, which are 87.80% shown in Table 5.

Table 5. Power Losses between Buss when DG at Bus-6

<table>
<thead>
<tr>
<th>Buss between</th>
<th>Distance (KM)</th>
<th>Losses (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B12</td>
<td>55</td>
<td>385.5</td>
</tr>
<tr>
<td>B23</td>
<td>20</td>
<td>3.0</td>
</tr>
<tr>
<td>B34</td>
<td>30</td>
<td>2.0</td>
</tr>
<tr>
<td>B45</td>
<td>18.5</td>
<td>3.6</td>
</tr>
<tr>
<td>B46</td>
<td>6</td>
<td>2.7</td>
</tr>
<tr>
<td>B67</td>
<td>14.45</td>
<td>1.0</td>
</tr>
<tr>
<td>B78</td>
<td>40.80</td>
<td>2.4</td>
</tr>
<tr>
<td>B89</td>
<td>38.8</td>
<td>0.2</td>
</tr>
<tr>
<td>B710</td>
<td>38.4</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Power System with DG at Bus-7:

The voltage profile, active and Reactive power at each bus are shown in Fig. 7 after the 5MW DG is connected to Bus-7.
The losses of power system when DG is connected at Bus-7 are recorded 405.2KW, which are 87.72% shown in Table 6. Like other systems, DG can be also connected at bus-7 giving the result about losses. From the above all connection of DG with power system voltage profile and losses of the whole system are different.

**Table 6. Power Losses between Buss when DG at Bus-7**

<table>
<thead>
<tr>
<th>Buss between</th>
<th>Distance (KM)</th>
<th>Losses (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B12</td>
<td>55</td>
<td>385.8</td>
</tr>
<tr>
<td>B23</td>
<td>20</td>
<td>3.0</td>
</tr>
<tr>
<td>B24</td>
<td>30</td>
<td>2.8</td>
</tr>
<tr>
<td>B45</td>
<td>18.5</td>
<td>3.7</td>
</tr>
<tr>
<td>B46</td>
<td>6</td>
<td>2.7</td>
</tr>
<tr>
<td>B67</td>
<td>14.45</td>
<td>2.9</td>
</tr>
<tr>
<td>B78</td>
<td>40.80</td>
<td>2.4</td>
</tr>
<tr>
<td>B89</td>
<td>38.8</td>
<td>0.2</td>
</tr>
<tr>
<td>B710</td>
<td>38.4</td>
<td>2.3</td>
</tr>
</tbody>
</table>

**Power System with DG at Bus-8:**

The voltage profile, active and reactive power at each bus are shown in Fig. 8 after the 5MW DG is connected to Bus-8.
DG to Bus-8 the losses of the power system are recorded 476.8 KW which are 85.56%. DG affects all the buses of the system when DG is installed at any bus, it will reduce the losses of the power system which is shown in Table 7.

<table>
<thead>
<tr>
<th>Bus to Bus</th>
<th>Distance (KM)</th>
<th>Losses (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B12</td>
<td>55</td>
<td>382.8</td>
</tr>
<tr>
<td>B23</td>
<td>20</td>
<td>3.0</td>
</tr>
<tr>
<td>B24</td>
<td>30</td>
<td>63.9</td>
</tr>
<tr>
<td>B45</td>
<td>18.5</td>
<td>6.6</td>
</tr>
<tr>
<td>B46</td>
<td>6</td>
<td>0.1</td>
</tr>
<tr>
<td>B67</td>
<td>14.45</td>
<td>0.1</td>
</tr>
<tr>
<td>B78</td>
<td>40.80</td>
<td>15.6</td>
</tr>
<tr>
<td>B89</td>
<td>38.8</td>
<td>0.2</td>
</tr>
<tr>
<td>B710</td>
<td>38.4</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**Power System with DG at Bus-9:**

The voltage profile, active and reactive power at each bus are shown in Fig. 9 after the 5MW DG is connected to Bus-9.
DG at Bus-9 the losses of power system were recorded 491.8 KW. DG affects all the buses of the system when DG is installed at any bus, it will reduce the losses of power system losses 491.8KW which are 85.10%, which is shown in Table 8.

**Table 8. Power Losses between Buss when DG at Bus-9**

<table>
<thead>
<tr>
<th>Bus to Bus</th>
<th>Distance (KM)</th>
<th>Losses (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_{12}</td>
<td>55</td>
<td>382.6</td>
</tr>
<tr>
<td>B_{23}</td>
<td>20</td>
<td>3.0</td>
</tr>
<tr>
<td>B_{24}</td>
<td>30</td>
<td>79.2</td>
</tr>
<tr>
<td>B_{45}</td>
<td>18.5</td>
<td>7.3</td>
</tr>
<tr>
<td>B_{46}</td>
<td>6</td>
<td>0.3</td>
</tr>
<tr>
<td>B_{67}</td>
<td>14.45</td>
<td>0.3</td>
</tr>
<tr>
<td>B_{78}</td>
<td>40.80</td>
<td>8.5</td>
</tr>
<tr>
<td>B_{89}</td>
<td>38.8</td>
<td>5.6</td>
</tr>
<tr>
<td>B_{710}</td>
<td>38.4</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Power System with DG at Bus-10:**

The voltage profile, active and reactive power at each bus is shown in Fig. 10 after the 5MW DG is connected to Bus-10.
Figure 10. Load flow Analysis of Power System when DG to Bus-10

The losses of power system like the previous systems are also different; here in this case the, losses of the system are recorded 435.2KW, which is 86.82% shown in Table 9.

Table 9. Power Losses between Buss when DG at Bus-10

<table>
<thead>
<tr>
<th>Bus to bus</th>
<th>Distance (KM)</th>
<th>Losses(KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_{12}</td>
<td>55</td>
<td>385.1</td>
</tr>
<tr>
<td>B_{23}</td>
<td>20</td>
<td>3.0</td>
</tr>
<tr>
<td>B_{24}</td>
<td>30</td>
<td>25.7</td>
</tr>
<tr>
<td>B_{45}</td>
<td>18.5</td>
<td>5.0</td>
</tr>
<tr>
<td>B_{46}</td>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td>B_{67}</td>
<td>14.45</td>
<td>0.3</td>
</tr>
<tr>
<td>B_{78}</td>
<td>40.80</td>
<td>2.3</td>
</tr>
<tr>
<td>B_{89}</td>
<td>38.8</td>
<td>0.3</td>
</tr>
<tr>
<td>B_{710}</td>
<td>38.4</td>
<td>13.3</td>
</tr>
</tbody>
</table>

Power Losses at the different placement of DG are shown in Table 10. Connect the 5MW DG to each bus and collect the losses data from each bus.

These power losses at different places are also shown in Fig. 11. For the optimal placement of DG in power system the power losses must be minimized.
Above results of simulation show the losses of the power system. DG is connected at different buses step by step and Bus-4 is the only bus where losses of the power system are least recorded which 400.7KW; therefore, the Bus-4 bus is the optimal placement of distributed generation for power system.

**Conclusion**

In power system of 10 buses, Bus-4 is the optimal placement for DG. When DG connected to Bus-4 then the losses of the system are grandly reduced up to 400.7KW from 3302.2KW (i.e. 87.86%). Consequently, the Bus-4 bus is the optimal placement of the system because at this location the voltage profile is generally improved while losses are drastically minimized.

**Conflict of Interest**

The authors declare that there is no conflict of interest.

**References**


