Improving Voltage Quality in Distribution System with Wind Turbines

MASOUD SARGAZIKOOSHEH, BANAFSHEH HASHEMI
Department of Electrical Engineering
Islamic Azad University, Sarvestan Branch
Azad University of Sarvestan, Sarvestan, Fars Province, Post Code: 73451-173
ISLAMIC REPUBLIC OF IRAN
yaahoo_ms@yahoo.com

Abstract: - Increasing number of wind turbines in thin populated areas produces voltage quality problems such as under-voltages and over-voltages. This paper describes a new option for load flow analysis to achieve a better voltage quality and lower grid losses in these areas. The length of the wind turbine blade has been considered as an effective factor to reduce the output power smoothly during the over-voltage periods. This advanced production option give less lost energy, but would probably require complicated installations. A computer program has been developed and implemented based on the Probabilistic Load Flow method to find the potential crisis and weak point of the system operation. For this purpose, a distribution grid with 8 load points and 5 wind turbines was considered. Long term data of wind speed for south-eastern region of Iran was used to simulate the test example.

Key-Words: - Wind Turbine, Distribution System, Load Flow, Grid Losses, Voltage Quality

1 Introduction
Generation of electricity using wind power has received considerable attention worldwide in recent years. Wind turbines are normally connected directly to the utility grid. The power production from a wind turbine depends on the wind conditions. Favorable wind conditions are often found in thin populated areas, where the grid may be “weak”. With an increasing number of wind turbines in such areas, it becomes more difficult to maintain an acceptable voltage quality. Problems such as under-voltages and over-voltages are well known.

Using traditional load flow analysis, it is not possible to achieve a realistic impression of where and when the over-voltage occurs in a distribution system over a whole year. These analyses are normally based on some selected combinations of consumer loads and wind power productions. An investigation of the voltage condition is possible if the variations of both loads and productions are taken into account.

This paper describes a method of determining the voltage conditions based on diminished wind turbine blades in a distribution system calculated over a year. The consumer loads and wind power productions are assumed as normal distributed within a year. The probability of under-voltage and over-voltage within a year is calculated, considering that the phase to neutral voltage at the consumers should be within the range based on the Iranian Standard for voltage quality as given by IEC.

The proposed method is used to analyze which of the following two options is most favorable when a certain number of wind turbines are installed in a distribution system.

Option 1: Stopping of selected wind turbines in short periods of time when over-voltage occurs. This option can easily be implemented at almost negligible cost. The stopping of the wind turbines is assumed as controlled by voltage relays mounted at the wind turbines. If the relay senses a voltage higher than its setting, the wind turbine will be stopped and kept disconnected until the wind turbine controller allows for reconnection.

Option 2: Decreasing the length of wind turbines’ blades during the over voltage periods. This option is assumed as applied by turbines’ model mathematically. The practical design of the actuator and the controller will not be discussed in this paper. It should be noted that this advanced production option give less lost wind energy, but would probably require complicated installations.

In this paper, it is not the purpose to take into account the risk of decreasing the blades’ length on turbine stability and structure. The purpose is to calculate the probability of over-voltage hour-by-hour for a distribution system.

2 Methodology
The Probabilistic Load Flow (PLF) method has been used to find the potential crisis and weak point of the system operation. For example, it can give the probability of line overloading, over-voltage, steady state instability and so on [1].

A computer program named WT-DG-SIM has been developed and implemented. WT-DG-SIM consists of three main parts:
i. The load model,
ii. The Horizontal Axis Wind Turbine (HAWT) model,
iii. Load flow calculations.

The consumer loads and wind power productions for each of the nodes in the assumed distribution system are assumed to be mutually independent normal distributed within the year. Based on detailed input specifications, WT-DG-SIM first generates loads and productions statistics in terms of expected mean value and standard deviations for each node. This is done by means of the load model and wind turbine model.

Theoretically, it is possible to calculate the amount of reduced output power by changing blades’ length. In defining the blade shape the blade is divided into N elements (usually 1 - 20). By decreasing the elements of the blade, we can estimate the tip speed of the ith blade with a midpoint radius of \( r_i \) [2].

\[
\lambda_{r,i} = \lambda (r_i/R) \tag{1}
\]

\[
C_{p,\text{max}} = \left( \frac{16}{27} \right) \lambda_{r,i} \left[ \lambda_{r,i} + \frac{1.32 \left( \lambda_{r,i} - \frac{\pi^2}{29} \right)^2}{B^2} \right] - \left( \frac{0.57}{C_{d,c}} \frac{L_{d,i}^2}{r_i^2} \right) \tag{2}
\]

Fig.1 based on this equation, shows the maximum achievable power coefficients \( C_{p,\text{max}} \) for a turbine with 3 different elements’ number (10, 15 and 20). Therefore the output power can decrease smoothly by adjusting the blade’s length.

\[
\lambda_{r,i} = 0.5i(N = 10 \text{ segments})
\]

\[
\lambda_{r,i} = 0.75i(N = 15 \text{ segments})
\]

\[
\lambda_{r,i} = \lambda (N = 20 \text{ segments})
\]

WT-DG-SIM gives the annual expected time with under- and over voltages as well as the annual expected loss of wind energy output. The total expected time with over voltage, \( T_{\text{over}} \), is calculated as [3]:

\[
T_{\text{over}} = 8760 \sum_{i=1}^{n} Pr(V_i > V_{\text{rated}}) \tag{3}
\]

Where

\[
Pr(V_i > V_{\text{rated}}): \text{ The probability that the voltage } V_i \text{ is greater than } V_{\text{rated}}.
\]

The total expected time with under voltage, \( T_{\text{under}} \), is calculated as:

\[
T_{\text{under}} = 8760 \sum_{i=1}^{n} Pr(V_i < V_{\text{rated}}) \tag{4}
\]

Fig.2: Specification of the assumed distribution grid with 5 wind turbines

The total expected loss of wind energy output, \( \bar{E}_{w,\text{loss}} \), for each of the wind turbines is calculated as:

\[
\bar{E}_{w,\text{loss}} = \bar{E}_{w,\text{av}} \left( \frac{T_{\text{over}} + T_{\text{under}}}{8760} \right) \tag{5}
\]

Where

\[
\bar{E}_{w,\text{av}}: \text{ The expected production.}
\]

3 Model Parameters

Fig.2 illustrates the specified grid with one distributor supplies 8 load points, and 5 wind turbines. The 63/11 kV transformer is specified with a constant voltage regulation.

3.1 Load Parameters

An expected annual value \( \mu \) and a standard deviation \( \sigma \) specify the load at each load point. The standard
deviation is set to 20% of the expected value. The load data are based on different load categories such as farms, industries, shops, and houses.

3.2 Wind Turbine Parameters
The wind power production is calculated based on specification of the individual wind power curve \((C_p - \lambda)\). The hour by hour average wind speed over the year and the PQ curve for the individual wind turbine have been applied. Also, the actual data for 600 kW wind turbine has been assumed.

Long-term data of wind speed for south-eastern region of Iran (Zabol) for 41 years (1963-2004) has been shown in fig.3. This data is used to simulate the test example [4].

The mean wind speeds \(v_{rec}\) are recorded near the ground surface \((h_g)\). Since windmills are several meters high, the mean wind speed at a particular height \(h\) will be greater than \(v_{rec}\). Therefore, to obtained mean winds, \(v\) has to be projected to the hub height. The projected \(v\) is calculated using the power-law equation [5].

\[
v = v_{rec} \left( \frac{h}{h_o} \right)^\alpha
\]

The power-law exponent \(\alpha\) depends upon the roughness of the surface. For open land, \(\alpha\) is usually taken as 0.14.

![Fig.3: Long term wind speed data for 41 years (1963-2004)](image)

4 Analysis of Voltage Variations
In the analysis of wind turbine influence on the voltage quality in the distribution system, load flow analysis is used. In load flow analysis normally four cases are considered:

i. No productions and minimum loads.
ii. No productions and maximum loads.
iii. Maximum productions and minimum loads.
iv. Maximum productions and maximum loads.

Case (ii) gives an indication of the risk of under voltage and case (iii) of the risk of over voltage. In case of under or over voltage the answer is given about how many hours per year under or over voltage can be expected to occur. So that information on the expected number of hour/year with under or over voltage can be estimated for a specific distribution system including wind turbines.

5 Results
Traditionally, grid reinforcement and stopping of the select turbine have been the only solution to over-voltage problems when installing a WT in the distribution system. Using PLF, voltage dependent diminished blades of the WT’s can be investigated. In the following, results from grid voltage dependent disconnection of WT’s and diminished blades are presented and compared.

Table 1, shows the main results with 5 WTs in the assumed network. By stopping wind turbines at points 3 and 5 in short periods of time when over-voltage occurs, least hours with over-voltage were achieved in the year for the whole distribution system. However, this option has higher grid losses and disconnected energy of about 46 MWh/year. In this situation, option 2 is to be preferred because of having higher produced energy, lower grid losses and no disconnected energy.

<table>
<thead>
<tr>
<th></th>
<th>Option 1</th>
<th>Option 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over-voltage</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Under-voltage</td>
<td>1 h/yr</td>
<td>1.3 h/yr</td>
</tr>
<tr>
<td>Produced energy</td>
<td>5861 MWh</td>
<td>6011 MWh</td>
</tr>
<tr>
<td>(E_{W,\text{out}})</td>
<td>25.5 MWh</td>
<td>0</td>
</tr>
<tr>
<td>Grid losses</td>
<td>151 MWh</td>
<td>118.5 MWh</td>
</tr>
</tbody>
</table>

6 Conclusion
Decreasing the blades’ length during the short periods in order to avoid unacceptable high voltages as an alternative to stopping wind turbines can reduce grid losses and produce higher energy. Designing and applying actuators for decreasing wind turbine blades’ length should only after careful analysis, be used as an alternative to stopping wind turbines of the grid. Firstly, because the correctly blade actuator has to be found. Secondly, because the values of the higher wind turbine production has to be compared with the cost of
the wind turbine reconstruction or the grid reinforcement.

References: