Impact of Air Humidity on Wind Power Generator's Output

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Abstract. Nowadays, wind power generators have been developed widely in China and cover a wide range of larger humidity areas such as the southern of China, mountains and coastal. However, wind farm’s output calculation has never taken regional air humidity into account at present, which regional air is considered as dry’s one. By theoretical analysis and case calculation, this paper presents air density is inversely proportional to air humidity, which makes wind power be proportional to air density under the same wind velocity and wind power generator. As a result, regional air humidity should be considered in many factors such as unit selection, estimation of unit’s output and wind power prediction.

1. Introduction
In recent years, with increasing awareness of environmental protection, utilization of renewable energy became the focuses especially for wind resources which play more and more important role in China's energy development strategy [1]. New built unit’s number is 7872 in China (excluding Taiwan) in 2012, whose gross capacity is 12960 megawatt and increases by 20.8 percent year on year [2].

Wind power generator has been arranged mainly in the north areas of China (the north China, northwest, northeast), whose air humidity is lower and can be neglected in various design calculation. Nowadays, Wind power generators have been developed widely in china and cover a wide range of larger humidity areas such as the southern of China, mountains and coastal. So it is necessary to analyze the impact of regional air humidity to wind power generator.

2. Dry and Wet Characteristic of China’s Geography
China has vast territory, which covers across wide latitude and different altitude and terrain types and mountains, as a result, there is doomed to be diverse climate characteristic. Dry and wet characteristic vary from different regional and determined by proportion of precipitation to evaporation of region If precipitation is greater than evaporation, then the area is wet, as a result, the opposite is dry area.

Annual regional precipitation is decreases from the southeast coast to the Inland northwest in China and regional differences are very large. Usually, the coastal is larger than inland, the South than the north, the mountains than plain. Rainy season began early and end lately in the southern area, which covers from May to October, on the country the rainy season is short and concentrates between July and April [3].

There can be divided into four areas roughly in China by dry and wet characteristics: arid areas, semi-arid areas, humid areas, semi-humid areas (Table 1). The west and northwest are arid areas and the southeast is humid area.
Table 1. The division of wet and dry areas

| Annual precipitation (mm) | Relation of precipitation to evaporation | Regional distribution |
|---------------------------|------------------------------------------|-----------------------|
| humid areas               | >800 greater                             | Qinling Mountains-to-the southern of Huaihe River, the southern of Qinghai-Tibet Plateau, the northeast of Inner Mongolia, the eastern of three provinces of northeast China |
| semi-humid areas          | >400 greater                             | the Northeast Plain, the North China Plain, the larger areas of the loess plateau, the southeastern of Qinghai-Tibet Plateau, Inner Mongolia plateau, the partial areas of the loess plateau, larger areas of Qinghai-Tibet Plateau |
| semi-arid areas           | <400 lower                               | Xinjiang Uygur Autonomous region of China, the western of Inner Mongolia plateau, the northwestern of Qinghai-Tibet Plateau |
| arid areas                | <200 lower                               |                        |

3. Air Humidity

Humidity is the amount of water vapor in the air. Air humidity depends on water vaporization and condensation. Usually, air humidity can be expressed by the name of Absolute humidity, relative humidity and water gas pressure and relative humidity is used widely in the weather forecast.

Absolute humidity is the mass of water vapor per unit volume of total air and water vapor mixture. The mass of water vapor is proportional to its vapor pressure, so absolute humidity is often expressed as vapor pressure. The mass of vapor per unit in the air is limited under at given temperature, once it is run up to the limited value, the air can be named as saturation vapor, whose pressure is describes as saturated vapor pressure which varies with temperature [4].

Relative humidity is the ratio of the partial pressure of water vapor in an air-water mixture to the saturated vapor pressure of water at a prescribed temperature. The relative humidity of air depends on temperature and the pressure of the system of interest.

4. Calculation of Wet Air Density

At present, the calculation of the wind farm is based on in dry air without considering the influence of humidity. The air density can be described as equation (1):

$$\rho = \frac{P}{(273.15 + t) R}$$  \hspace{1cm} (1)

Where: \( R \) is gas constant (287 J/kg, K).

The wet air density which covers across the southern of China, mountains and coastal can be described [3] as equation (2):

$$\rho = \frac{1.276}{1 + 0.00366t} \left( \frac{P - 0.378e'}{1000} \right)$$  \hspace{1cm} (2)

Where: \( \rho \) is air density (kg/m³)  
P is atmospheric pressure (hPa)  
e' is vapor pressure (hPa)  
t is air temperature (°C)
The water vapor pressure cannot be measured directly and can get from some formula which is based on relative humidity and temperature can be measured.

According to the temperature range of wind farm, the saturation vapor pressure using Tetens equation[5]:

\[ E = 6.106 \times 10^{\frac{17.269}{237.3 + t}} \]  

Where: \( E \) is saturated vapor pressure (hPa)

The relationship between vapor pressure, saturated vapor pressure and relative humidity is based on equation (4):

\[ \varphi = \frac{e}{E} \]  

Where: \( \varphi \) is relative humidity (%)

It can get equation (5) by equation (3) and equation (4):

\[ e = \varphi \times E = 6.106 \times \varphi \times 10^{\frac{17.269}{237.3 + t}} \]  

5. Impact of Air Density on Wind Power

Wind energy is the kinetic energy of air movement, which can be described as equation (7):

\[ W = FV \left( \frac{\rho V^2}{2} \right) = \frac{1}{2} \rho F V^3 \]  

Where: \( W \) is wind energy (W)  
\( V \) is velocity of wind (m/s)  
\( F \) is area (m²)  

Wind power is the product of wind energy and efficiency of wind turbine.

\[ W' = \eta W = \frac{1}{2} \eta \rho F V^3 \]  

Where: \( W' \) is wind energy (W)  
\( \eta \) is fan efficiency (%)

Under the same type wind turbine, the same wind velocity and wind turbine areas, lower air density means lower output of wind power generator according to equation (8) and vice versa. Usually, the rated power of wind turbine is based on the standard air density. The relationship between actual power and rated power can be described as equation (9) and equation (10):

\[ \frac{W'_1}{W'_0} = \frac{\rho_1}{\rho_0} \]
\[ W' = \frac{\rho'}{\rho_0} \]

Where: \( W' \) is actual power of wind turbine (W)
\( \rho' \) is actual air density (kg/m³)
\( W'_0 \) is rated power of wind turbine (W)
\( \rho_0 \) is standard air density (kg/m³)

The ratio of actual and rated fan power is equal to the ratio of the actual and standard air density according to equation (10).

6. Calculation Examples
The relative humidity is 80% by a wind farm, table 2 provides the concrete calculation results of dry and wet air respectively.

| #1Tower | #2Tower |
|---------|---------|
| Altitude (m) | 2664 | 2750 |
| Atmospheric pressure (hPa) | 738.4 | 731.2 |
| Temperature (°C) | 7.8 | 7.4 |
| Relative humidity (%) | 80 | 80 |
| absolute density of dry air (g/m³) | 916 | 909 |
| relative density of Dry air (%) | 74.8 | 74.2 |
| absolute density of wet air (g/m³) | 912 | 904 |
| relative density of wet air (%) | 74.4 | 73.8 |

According to table 2, ratio of the actual output and rated output of wind power generator is equal to the ratio of the actual and standard air density and the actual output is lower than rated one. As a result, air humidity should be considered in unit selection, estimation of unit’s output and wind power prediction.

7. Conclusion
By analysis and calculation, it is definite that larger air humidity lowers the density of air and affects the output of wind power generator, which is neglected in wind farm calculation. With the development of wind power generator in wet air areas such as the southern of China, mountains and coastal, air humidity should be considered in unit selection, estimation of unit’s output and wind power prediction.

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