WEEK 8: WIND ENERGY AND TURBINE

INTRODUCTION

Electricity produced from the wind produces no CO_2 emissions and therefore does not contribute to the greenhouse effect. Wind energy is relatively labor intensive and thus creates many jobs. In remote areas or areas with a weak grid, wind energy can be used for charging batteries or can be combined with a diesel engine to save fuel whenever wind is available. Moreover, wind turbines can be used for the desalination of water in coastal areas with little fresh water, for instance the Middle East. At windy sites the price of electricity, measured in $/kWh, is competitive with the production price from more conventional methods, for example coal fired power plants.

One of the drawbacks of wind energy is that wind turbines create a certain amount of noise when they produce electricity. In modern wind turbines, manufacturers have managed to reduce almost all-mechanical noise and are now working on reducing aerodynamic noise from the rotating blades.

Another disadvantage is that wind energy can only be produced when nature supplies sufficient wind. However, for most countries, which are connected to big grids and can therefore buy electricity from the grid in the absence of wind.

The wind turbine captures the wind's kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture. Numerous wind turbines are installed at one site to build a wind farm of the desired power generation capacity. Obviously, sites with steady high wind produce more energy over the year.

Wind turbines convert the kinetic energy of the air particles to the mechanical or electrical form. Turbine blades are the main tools to realize this conversion.

The efficiency of the conversion depends on the followings:

Meteorological data, Topography of the site, Blade profiles, Number of blades, Tower height.

THEORY

Speed and Power Relatıons

- The kinetic energy in air of mass m moving with speed V is given by the following in joules:

$$\text{kinetic energy} = \frac{1}{2} m V^2$$

- The power in moving air is the flow rate of kinetic energy per second in watts:

$$\text{power} = \frac{1}{2} (\text{mass flow per second}) V^2$$

- If

P= mechanical power in the moving air (watts),

ρ = air density (kg/m^3),

A= area swept by the rotor blades (m^2), and

V= velocity of the air (m/sec),

- then the volumetric flow rate is AV, the mass flow rate of the air in kilograms per second is ρAV, and the mechanical power coming in the upstream wind is given by the following in watts:

$$P = \frac{1}{2} (\rho A V) V^2 = \frac{1}{2} \rho A V^3$$

- This is the power in the upstream wind.
- It varies linearly with the density of the air sweeping the blades and with the cube of the wind speed.
- The blades cannot extract all of the upstream wind power, as some power is left in the downstream air that continues to move with reduced speed.

Power Extracted From the Wind

- The actual power extracted by the rotor blades is the difference between the upstream and downstream wind powers.

- Using the following equation in units of watts:

$$P_o = \frac{1}{2}(\text{mass flow per second})\left\{V^2 - V_o^{\,2}\right\}$$

- where

P_o= mechanical power extracted by the rotor, i.e., the turbine output power,

V= upstream wind velocity at the entrance of the rotor blades, and

V_o= downstream wind velocity at the exit of the rotor blades.

- Macroscopically, the air velocity is discontinuous from V to V_o at the "plane" of the rotor blades, with an "average" of $\frac{1}{2}(V + V_o)$.
- Multiplying the air density by the average velocity, therefore, gives the mass flow rate of air through the rotating blades, which is as follows:

$$\text{mass flow rate} = \rho A \frac{V + V_o}{2}$$

- The mechanical power extracted by the rotor, which drives the electrical generator, is therefore:

$$P_o = \frac{1}{2}\left[\rho A \frac{(V + V_o)}{2}\right](V^2 - V_o^2)$$

  - The preceding expression is algebraically rearranged in the following form:

$$P_o = \frac{1}{2}\rho A V^3 \frac{\left(1 + \frac{V_o}{V}\right)\left[1 - \left(\frac{V_o}{V}\right)^2\right]}{2}$$

- The power extracted by the blades is customarily expressed as a fraction of the upstream wind power in watts as follows:

$$P_o = \frac{1}{2}\rho A V^3 C_p$$

- where

$$C_p = \frac{\left(1+\frac{V_o}{V}\right)\left[1-\left(\frac{V_o}{V}\right)^2\right]}{2}$$

C_p is the fraction of the upstream wind power that is extracted by the rotor blades and fed to the electrical generator.

- The remaining power is dissipated in the downstream wind.
- The factor C_p is called the power coefficient of the rotor or the rotor efficiency.

References:

Andrews J, and Jelley N. Energy Science – Principles, Technologies and Impacts. New York, NY: Oxford University Press, 2007, chapt. 1, p 11.

http://c21.phas.ubc.ca/problemsets/wind-turbines-problem-set-solutions

http://www.windatlas.ca/en/maps.php

http://collaboration.cmc.ec.gc.ca/science/rpn/modcom/eole/CanadianAtlas0.html

http://www.bchydro.com/etc/medialib/internet/documents/info/pdf/rou_wind_garrad_hassan_report.Par.0001.File.rou_wind_garrad_hassan_report.pdf

http://www.vestas.com/en/wind-power-solutions/wind-turbines/3.0-mw.aspx.