WEEK 3: REVIEW OF HORIZONTAL AXIS WIND TURBINES (HAWTs)

- 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.

- HAWTs have their axis of rotation horizontal to the ground. Depending on the number of blades, horizontal axis wind turbines are further classified as single bladed, two bladed, three bladed and multi bladed.

- Based on the direction of receiving the wind, the two and three bladed HAWTs can be also classified as ‘’upwind’’ and ‘’downwind’’ turbines (Figure 1)

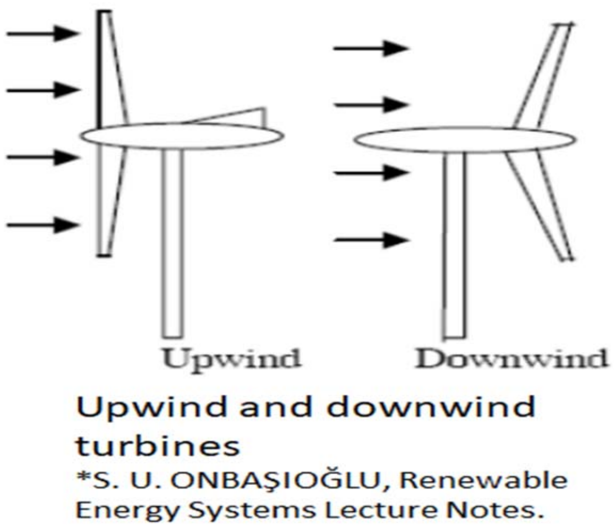

Figure 1. HAWTs

- For the upwind turbines, which are the most common, as the wind stream passes the rotor first, they do not have the problem of tower shadow.

- For the downwind rotors, as the rotors are placed at the lee side of the tower, there may be uneven loading on the blades as it passes through the shadow of the tower.

Kinetic energy of wind particles can be written as;

$$E_K = \frac{1}{2} m v^2$$

E_K= Kinetic Energy (J)

m = Mass of particles (kg)

v = Velocity of wind (m/s)

- While calculating, all of air particles' mass can not be calculated. Therefore instead of mass, mass flow rate (ṁ) is used to calculate mechanical power;

$$P = \frac{1}{2} \dot{m} v^2$$

Mass flow rate (ṁ) is equal to $\rho \times v \times A$, where

P=Mechanical Power (W)

ρ = Air Density (kg/m^3)

A = Area (m^2)

- We use a as swept area by rotate blades in HAWT and *v* is upstream wind velocity of the entrance of the rotor blades. So that, when the power equation is derived:

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

$$P = \frac{1}{2}\rho A v^3$$

The velocity profile of the wind is defined as;

$$u = u_{ref}(\frac{y}{y_{ref}})^{\alpha}$$

u = Velocity at the 'y' height (m/s)

u_{ref}= Velocity at the reference height (m/s)

y_{ref}= Reference height (m)

y = Ground height (m)

α = empirically derived coefficient that varies dependent upon the stability of the atmosphere

- A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the Betz Limit or Betz' Law

- The theoretical maximum power efficiency of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the "power coefficient" and is defined as: C_p [2].

- Also, wind turbines cannot operate at this maximum limit. The C_p value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine - strength and durability in particular - the real world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines. By the time we take into account the other factors in a complete wind turbine system - e.g. the gearbox, bearings, generator and so on - only 10-30% of the power of the wind is ever actually converted into usable electricity [2]. Hence, the power coefficient needs to be factored and the extractable power from the wind is given by:

$$P = \frac{1}{2}\rho A v^3 C_p$$

- Therefore the efficiency of wind turbine, η, can be defined as the ratio of power generated by wind turbine to the total power available in the wind;

$$\eta = \frac{Power\ generated\ by\ the\ wind}{Total\ power\ available\ in\ the\ wind}$$

- The power generated by the wind can be defined as;

$$P_f = \Omega \times \tau$$

Ω = Angular velocity of blades (rad/s)

τ = Torque of the turbine (N.m)

Therefore, The efficiency can be defined as,

$$\eta = \frac{\Omega \times \tau}{\frac{1}{2} \times \rho \times u^3 \times A}$$

- The angular velocity is;

$$\Omega = \frac{2\pi N}{60} = 2\pi f$$

- where;

N= Revolution number of blades per minute (Rev/min

f = Frequency of blades (s-1)

References:

[1] Wind Science: Betz limit, “Understanding Coefficient of Power (Cp) and Betz Limit”, http://learn.kidwind.org/sites/default/files/betz_limit_0.pdf

[2] https://www.raeng.org.uk/publications/other/23-wind-turbine