ENERGY, ENVIRONMENT AND SOCIETY

Chapter - 10 Wind Energy Assoc. Prof. Manchan Tiwari Kathmandu Engineering College Nepal

LEARNING OBJECTIVES OF THE LECTURE

- Basics of wind energy
- Component of wind turbine
- Types of wind turbine
- Energy from wind
- Environmental impact of wind energy

WIND ENERGY

- Wind energy has been used since far before in time to sail ships, pump water, grinding grain etc.
- Before development of electric power on large scale, wind power was used as major source of energy in many countries (S. Hasan & Sharma, 2009).
- Wind mill were seen extensively in many regions which were predominantly used for milling grain (Boyle, 2013).
- Since, the late nineteenth century, attempts to produce electricity from wind energy were made.
- Small scale wind turbines were used to produce electricity for many years to power houses, farms and rural communities.

WIND ENERGY

- After 1980s, as the cost of wind turbine fell steadily, it resulted rapid growth of the sector.
- The growth in wind energy usage can also be accredited to increase in rated capacity of machines.
- As on now, on a site with reasonable wind availability and accessibility, wind turbines are one of the most cost-effective methods of power generation (Boyle, 2013).
- In today's modern world the wind energy has been extensively used all over in various countries for electricity generation as shown in previous chapter.
- It is expected that the improvements in cost, capacity and reliability of wind turbine systems will result in wind energy being more economically competitive in future.

WIND ENERGY

• The region in equator of the earth receives more solar radiation per year than the region at higher altitudes.

• The curvature of the Earth results in the incident rays of the Sun being more oblique with increasing latitude.

• In addition, the Sun's rays have to travel more through the atmosphere with increase in latitude.

• All of these factors results in uneven heating which results in variations in atmospheric pressure which in turn gives rise to the movement of atmospheric air masses which are the principal cause of the Earth's wind systems.

• The Earth's rotation also effects the direction of wind.

ENERGY AND POWER IN WIND

- The energy contained in the wind is its kinetic energy, which is equal to
- Power from Kinetic Energy (P) = $\frac{1}{2} \times m \times v^2$
- Where,
- P = Power (J/s = W)
- m = mass flow rate of the air (kg/s)
- v = velocity of the wind (m/s)

ENERGY AND POWER IN WIND

- mass of the air flowing per second = air density x volume of air flowing per second
- Volume of air flowing per second = area x velocity of air per second
- Hence,
 - $m = \rho \times A \times v$
- The equation for power from wind can be written as
- $P = 0.5 \times \rho \times A \times v^3$
- It is apparent from the equation above that, the power in the wind is proportional to
- The density of air
- The area through which the wind is passing
- The cube of wind velocity

BETZ LIMIT

- Betz limit is the theoretical maximum efficiency for a wind turbine.
- This limit signifies that only 59.3% of the kinetic energy of the wind can be used to spin the turbine and generate electricity.
- In reality the turbines, have efficiency below the betz limit in around the range of 35-45%.
- Actual Power produced by wind turbine
- $P = Cp \times 0.5 \times \rho \times A \times v^3$

EXAMPLE

Determine the rotor diameter for wind power plant of capacity 1 MW rated output. The design wind speed is 12 m/s, the turbine power coefficient is 0.43 and projected annual duration of utilization is 2400 hours per year. Also calculate the turbine power density at the design speed, annual power generation and torque experienced by the rotor at a speed of 50 m/s. the air density at 20 °C is 1.205 kg/m³.

- Solution:
- The power density per m² of swept area
- $P = 0.5 \ge 0.43 \ge 1.205 \ge (12)^3$
- Rotor area required
- $A = (1 \times 10^6)/447.68 = 2233.74 \text{ m}^2$
- Rotor Diameter
- $D = (4A/\pi)^{0.5} = (4 \times 2233.74)/\pi)^{0.5} = 53.33 \text{ m}$
- Annual Power Generation
- = $1 \ge 2400 = 2400 \text{ MWh/year}$
- The torque on the rotor
- $T = (1 \times 10^6)/(2\pi \times 50) = 3183$ N-m

IMPORTANT TERMS

Flat rating

Rather than designing for maximum wind speed, it is desirable and cost effective to design wind system to produce rated power at less than the maximum prevailing wind velocity to maintain a constant output at all wind speeds variation above the rated capacity. This is called flat rating.

Cut-in velocity

At low wind velocity, the loss in efficiency and power is high due to which it is desirable that the wind turbine come into operation only when wind speed is higher than a certain value which is known as cut-in velocity

IMPORTANT TERMS

Cut-out velocity

As high wind speeds can damage the wind turbine, wind turbines are designed to stop operation when the wind speed exceeds a certain value of wind velocity which is known as cut-out velocity.

Availability factor

It is the fraction of time, during a given period, that the turbine is actually on line. For wind power plants, availability is usually 90%.

COMPONENTS OF WIND TURBINE



Source: (Britannica, 2022)

COMPONENTS OF WIND TURBINE

Rotor

Includes hub and blades attached to the hub. Hub is a solid disc like structure at the center of the rotor to which the blades are attached.

Shaft

Helps transfer the rpm from rotor to gearbox/generator

Gear box

Changes the rpm of the rotor to the required rpm of the genrator

Yaw Drive

Rotates to face the rotor to the direction of wind

COMPONENTS OF WIND TURBINE

Wind vane

Senses the wind flow direction

Generator

Produces electrical power

Anemometer

Measures the wind speed

Tower

Supports the whole wind turbine structure.

TYPES OF WIND TURBINE

- Horizontal Axis Wind Turbines (HAWT)
- Vertical Axis Wind Turbines (VAWT)

HORIZONTAL AXIS WIND TURBINES

- HAWT are axial flow devices, the rotation of the axes is maintained in line with wind direction by yawing mechanism, which constantly re aligns the wind turbine rotor in response to changes in wind direction.
- The axis of rotation of the HAWT is horizontal or parallel to the ground.
- Horizontal axis wind turbines have either two or three blades, but can have many more.

HORIZONTAL AXIS WIND TURBINES



HORIZONTAL AXIS WIND TURBINES

- The turbine consists of a solid disc mounted upon by solid blades.
- Such turbines produce high torque at low rotor speeds.
- These kind of turbine are most employed for electricity generation. HAWT needs to reposition the rotor according to the change in wind direction to face the direction of wind.

VERTICAL AXIS WIND TURBINES

- VAWT unlike HAWT are cross-flow devices
- This means that the direction from which the undisturbed wind flow comes is at right angles to the axis of rotation.
- That is the wind flows across the axis.
- It can harness winds from any direction without the need to reposition the rotor when the wind direction changes.

VERTICAL AXIS WIND TURBINES



Source: (Windfacts, 2022)

VERTICAL AXIS WIND TURBINES

- However, VAWT has little commercial success and are rarely used in major wind energy systems.
- Such turbine has vertical shaft where, curved blades are attached to the top and bottom of the shaft.
- At present, VAWT are not economically feasible when compared with HAWT.

- The power produced from wind turbine is dependent of various factors which are:
- Rotor swept area
- Choice of aerofoil
- Number of blades
- Blade shape
- Optimum tip speed ratio

- The power produced from wind turbine is dependent of various factors which are:
- Speed of rotation
- Cut in wind speed (the speed at which a turbine begins to generate power)
- Rated wind speed (the wind speed at which a turbine generates its rated power)
- Cut out wind speed (the wind speed at which a turbine is shut down and stops generating)
- Gearing efficiency
- Generator efficiency

• The power generated from wind turbine also depends on the wind speed frequency distribution at the site.

• Wind speed frequency distribution essentially depicts the number of hours for which the wind blows at different speeds during a given period of time.

• The wind speed distribution at a site is determined by measuring wind speeds with equipment that records the number of hours for which the wind speed lies within each given 1 m/s wide speed band. For eg. 1 m/s, 2 m/s, 3 m/s etc.

- It is preferable to record wind speed and direction as close as possible to the proposed site for at least a year.
- However, this will only give information for a particular time period and weather pattern changes.



Source: (Researchgate, 2022)

- To ascertain the wind speed characteristics for a longer period of time, co-relation is done between the measured data of the site with the data available in the nearby meteorological stations or other wind recording sites.
- Then by statistical analysis and extrapolation, the estimate of the longer-term wind speed characteristics at the site can be made.

WIND ESTIMATION TECHNIQUES

- Using wind speed measurements from a nearby location
- Using wind speed maps and atlases
- Wind flow simulation computer models

WIND ESTIMATION TECHNIQUES

Using wind speed measurements from a nearby location

Makes use of existing wind speed measurements from nearby site and the using the data to derive the data for proposed site either by interpolation of extrapolation

Using wind speed maps and atlases

In many countries maps are available which gives estimates of the mean wind speeds either for specific purpose of wind energy or for any other purpose. Such maps/database can also be used.

WIND ESTIMATION TECHNIQUES

Wind flow simulation computer models

Many computer models have been developed that aim to predict the effects of topography on wind speed. For many such models, data of wind from the nearby site and topographic description of the sites are required. CFD (computational fluid dynamics) is increasingly being used to model the wind flows in complex terrain, over and around forests and for designing wind farms.

ENVIRONMENTAL IMPACT OF WIND ENERGY

- Generation of energy by wind turbine doesn't involve the release of carbon dioxide or pollutants. Large scale implementation of wind energy is one of the most economic and rapid means of reducing CO2 emissions
- Negative Impacts:
 - Noise
 - Mechanical Noise:
 - produced by mechanical or electrical component
 - Can be negated easily by using quieter gears, using acoustic enclosers or by eliminating the use of gearbox

ENVIRONMENTAL IMPACT OF WIND ENERGY

Aerodynamic Noise:

- produced by interaction of air flow with the blade
- Can be described as "swishing sound"
- Affected by the shape of the blades, interaction of the airflow with the blades and the tower, wind conditions, shape of blade trailing edges
- Aerodynamic noise increases with increase in blade speed, hence at lower wind speeds, the turbine are designed to operate at low speed.

ENVIRONMENTAL IMPACT OF WIND ENERGY

Electromagnetic interference

• When a wind turbine is positioned between a radio, television or microwave transmitter and receiver, it can sometimes reflect some of the electromagnetic radiation in such a way that the reflected wave interferes with the original signal as it arrives at the receiver. This can cause the signal to be distorted significantl

Wild life

 Birds could be killed by flying into the rotating blades along with other hazards that birds face such as potential disturbances, barriers and potential habitat loss (Boyle, 2013).

ADVANTAGES OF WIND POWER GENERATION

- It is renewable source of energy and will not be depleted
- Is available in abundance in most part of the world
- Does not pollute environment unlike other fossil fuels
- Cost is competitive compared to conventional power plants
- In most parts of the word, number of days when the wind blow is high
- Villages and rural remote area can use the wind energy for electricity production
- The land area occupied by wind turbines can be used for other purposes as well such as tourist park, vehicle testing ground etc (S. Hasan & Sharma, 2009).

DISADVANTAGES OF WIND POWER GENERATION

- It is non-steady and unreliable as there are wide variations in the speed and direction of winds.
- Large wind farms requires flat, vacant and very large land area free from forests
- There is fluctuation in power depending on the wind speed
- Some negative impacts are noise, bird hits, land erosion and impact on wild life (S. Hasan & Sharma, 2009)

REFERENCES

- (2022). Retrieved November 2, 2022, from Researchgate: https://www.researchgate.net/figure/Schematicdiagram-of-a-typical-run-of-river-hydropower-system-4_fig6_258404306
- AEPC . (2022). *Guidelines For The Study of Solar Mini Grid Projects*. Nepal: Alternative Energy Promotion Centre, The Government of Nepal, Ministry of Energy, Water Resources and Irrigation.
- Boyle, G. (2013). *Renewable Energy Power For A Sustainable Future* (Vol. Third Edition). Oxford: Oxford University Press.
- IEA. (2022). Retrieved October 9, 2022, from https://www.iea.org/reports/offshore-wind-outlook-2019
- *Researchgate*. (2022, November 3). Retrieved from https://www.researchgate.net/figure/Histogram-of-wind-speed-frequencies-modeled-by-the-distribution-of-Weibull-Calculations_fig1_311260271
- S. Hasan, S., & Sharma, D. (2009). Non-Conventional Energy Resources. Delhi: S. K. Kataria and Sons.
- Singal, R. (2011). Non-Conventional Energy Resources (Vol. Third Edition). Delhi: S. K. Kataria and Sons.

