Sustainable Energy PPTs on Unit 2

- **<u>Wind Energy :</u>**Solar energy heats up air from the equator, and this low density heated air is buoyed up.– to poles – convective circulation

Wind Energy is the most mature and developed renewable energy. It generates electricity through wind, by using the kinetic energy produced by the effect of air currents. It is a source of clean and renewable energy, which reduces the emission of greenhouse effect gases and preserves the environment.
Wind energy is a type of energy used to make electricity, like fossil fuels or nuclear power. Wind energy harvests energy from the wind and

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vanes or blades (rotational

erator =aerogenerator

km/hr. Low maintenance

Ir eration

from the wind and
converts it into electrical
power. Wind is created by
temperature changes in
the atmosphere. As warm
air rises, cool air moves
into the area, and the
movement creates what
we know as wind. The

- 20000 MW – 8 MW from Wind power; likely to increase to 25 MW
- Basic principles of Wind Energy Conv ersion:
- Nature of Wind: counter clockwise & clockwise circulation in Northern & Southern hemisphere. Wind speed increase with height
- **Factors influencing speed:** Speed & direction by :1)Pressure Gradient Force (Center of high pressure to centre of low pressure. High Pressure decreases with height. Low pressure increases with height. Pressure gradient: (High – Low)/ Distance – But flow not direct. There are more factors
- 2)Coriolis Force – Causes wind to curve right in NH & left in SH. Force is zero at equator & increases with latitude & wind speed. Produces wind parallel to isobars.
- 3)Friction- Rough surface, hills mountains, buildings . Max below 1500 meter of atmospheric layer. Slows wind, reduces impact of Coriolis force
- Result: Clockwise & outward around high pressure area & counter clockwise & inward in low pressure area

Power in the wind

- Factors to extract energy from wind (i) Wind Speed (ii) Cross Section of the wind swept by rotor (iii) Overall conversion efficiency of rotor, transmission system & generator or pump
- 100% efficient aero generators convert 60% of wind energy. (70% max. but losses in gearbox, transmission system & generator or pump)
- Power (Pa) = Wind KE = (1/2)mV^2; m=ρAV; V=Wind velocity, A = Area of air cross section = π(D^2)/4; ρ= air density
- Pa=(1/8)πρD^2.V^3 (Basically m is m dot). ……… (1)
- Wind transfers energy to rotor. Speed minimum during rotor wake (downstream wind velocity deficit region surrounded by increase rings of turbulence). Again regains energy
- Power extracted by rotor = Vr (wind speed before rotor) *Δ p (pressure first increases, then decreases) - pressure is maximum for certain V- so there exist a maximum of rotor power

Power in the wind

- Cp(Power Coefficient) = Power (extracted by) of wind rotor (Pt)/ Power available in the wind (PA) = 16/27 = 0.593 (max). ……(2)
- Cp is also maximum or ideal theoretical efficiency
- Coefficient of aero generator= electric power generated/available power wind (at rotor) is about 35% after losses
- Eq.(1); V=V(t) i.e. function of time; So averaging over Pa = Pa(t): $Pa(t)_{avg} = (1/2)\rho\ A\ *[V(t)^3]_{avg}$ ….(3)
- <u>Maximum wind turbine output power</u>
- Wind turbine (horizontal axis propeller-type windmill) power output can vary.
- P = (1/4g)*ρA(Vi+Ve)* [Vi^2-Ve^2) (Derive); Vi=incident wind velocity, Ve=Exit velocity; g=1 (const.). For Ve=0, it will become equation (1). But Ve can't be =0 (wind accumula-tion).

Power in the wind continued

- Optimum Ve for which P is Pmax: dP/dVe = 0 or Ve=Vi/3
- So Pmax = Pt = (16/27) * Ptotal= 0.594*Ptotal; Ptotal= PA – leads to eqn. (2)
- Forces on Blades (1) Circumferential force or Torque (T) = Pt/ω =Pt/πDN (Newton N); w= angular velocity of turbine wheel; N= Wheel revolutions per unit time(s^-1) (Pt is P_{max})
- T = (ηρDv$_i$^3)/(8gN); ηis the efficiency = 16/27
- (2)Axial force along wind direction provides axial thrust; balanced by mechanical design : Fx = ρA(Vi^2-Ve^2)/2g ---- max. for Ve = Vi/3 -- (4ρAVi^2)/9g --- proportional to D^2 – this limits turbine wheel diameter of large size

Thrust

- Before we go further, we will comment on
- **Thrust :**Torque is a force that causes an object to rotate about axis. Thrust is the component of force acting perpendicular to a surface. A thrust is a force, but not every force can be counted as thrust.
- Higher torque, higher thrust
- In case of a propulsion device, let V0, P0 & (mdot)0 be the incident velocity of air, free (incident) stream pressure & incident mass flow rate (mdot = mass flow rate = mass/time). Let corresponding values for the exit air are Ve, Pe, (mdot)e respectively
- Then Thrust = Force = (mdot)e * Ve – (mdot)0 * Vo +(Pe-P0).Ae
- Where Ae is the exit cross section area
- To increase thrust : (i) Ve > V0 ----- propeller aircraft
- (ii)Ve >> V0 ----- Turbo jets

WECS (Wind Energy Conversion System)

- Windmill – Lift water, irrigation, drainage, watering cattle. WECS – Electricity, heat.
- Back-up for electricity during insufficient wind
- (1)battery storage (2)local electricity generation system (3) Stand by generator of liquid/ gas fuels)
- Small generators: Rotational rate = frequency of mains supply. Output is DC or variable AC
- Without grid – heavy duty batteries or convert into heat store (hot water)
- Large & medium size wind generators – depending on size of local distribution grid. (1)Induction generators Used if Significant other generating capacity, providing reactive power; minimal control. Example : Squirrel Cage, Doubly fed, Wound rotor (2)Synchronous generators If Limited local generating capacity; high degree of autonomous control, complex, expensive. Example wound rotor, permanent magnet) Disadvantage– When turbine blades speed up due to gust of wind, the synchronous generator which is locked up to the speed of power grid, can't speed up.
- Forces on Turbine : Drag, Lift, Centrifugal & Gravitational forces. When wind flows across blade (airfoil of helicopter) air-pressure on one side of blade decreases. Difference in air pressure on two sides causes lift & drag.

Lift & Drag

- Lift – Force act on high pressure side & move to low pressure side of lifting surface (airfoil) – perpendicular to air stream; Lift = 30 * drag (parallel to air flow)
- Lift decrease, drag increase during wake (stalling – sudden turbulence). This happens when increasing angle of attack becomes such that angle of air flow on low pressure side is excess.
- Other mechanism for creating lift: 1) Magnus effect – spinning cylinder in air stream slows down air speed when moving into wind, increase on other side. 2) Thwaits Slot- Blowing air through slots of a narrow cylinder
- Forces on blade: Vr – resultant velocity of free wind & velocity of air foil. FL=Lift force; FD = drag force

Wind data & Energy Estimation

- Wind fluctuate by factor of 2, power by factor of 8.
- Latitude/ altitude/ topography/ scale of hour, month, year – all affect nature of wind
- {V/Vg} = [h/hg]^n; Vg, hg, n depends on nature of terrain (lake, desert, land, shores, towns, suburbs, city centers, break of large trees etc.)
- Spell of low wind speed/ gusts (to safeguard against damage) are important.
- Wind speed at any height known ---- at any other height can be calculated.
- Surface wind data as : 1) Isovents – contours of constant average wind velocity; Good/ bad wind velocity regions
- 2) Isodynes – contours of constant wind power (area perpendicular to wind flow – watts/m^2)

Wind Surveys

- 1)Instrumentation – 3-cup anemometer wind direction sensors (height - 10 m to 45m)
- 2)Data recording systems (Strip chart /Magnetic tape)
- 3)Type of data – Wind speed & directional-hourly averages
- 4)Data reporting: Wind frequency curves – daily, monthly, yearly
- Energy Estimation – for wind energy potential : (i) Velocity duration curve (Mean wind velocity Vs Hours) (ii) power duration curve; for energy output – frequency (= no. of hours mean wind velocity available) duration curve
- **Ideal Plant** : We find annual load factor. Power output & velocities are plotted on two Y-axis. Velocities involved are:
- V_d ------ Design Speed – for which rotor is designed
- V_f -------Furling speed at which rotor is turned away from facing wind or stopped to protect the windmill
- V_c ------- Cut in speed – Speed below which windmill doesn't operate
- V_{rat} ---- Velocity at which plant output is maximum

Ideal Plant Contd.

- C_p (output power coefficient) is maximum at designed speed V_d, but is lower at other velocities. That is varies as a function of velocity
- Site Selection Consideration Require strong, persistent wind. Monthly & Annual winds remain const. over years against variable daily wind
- Suitable for wind turbines – Known moderately high or high. Choosing poor site – sub optimal output – High capital cost
- **WECS - Considerations**
- 1)High annual avg. wind speed- Data survey/ contour maps/ visiting potential sites to find best sites/ Choosing optimal site

WECS Considerations Contd.

- 2)Availability of anemometry data –for precise spot – accurate, linearity, location on the support tower
- 3)Availability of wind velocity curve at the proposed site
- 4)Wind structure at proposed site – Ideal : V(t) should be flat – smooth steady wind. Departure from homogeneous flow is structure of the wind
- 5)Altitudes of proposed site- higher velocity at higher altitudes
- 6)Terrain & its aerodynamic- aero-turbine should be perpendicular to actual wind flow
- 7)Local Ecology – higher hub heights in case of trees, grass or vegetation which destructure winds – more cost
- 8)Distance to roads or transport
- 9)Nearness of site to local centers/ users
- 10)Nature of ground – stable ground condition – no Erosion

WECS Considerations Contd.

- 11)Favourable land cost
- 12) Other conditions icing (air containing droplets of super-cooled liquid water) problem, salt spray, blowing dust should be absent
- <u>Useful guidelines for height of 20m</u>
- 1)Best Sites: Offshore & Sea-coast: Avg. value on coast - 2400 kWh/m^2 per year
- 2)Second best - mountains -2400 kWh/m^2 per year
- 3)Plains – 750 …
- Climate: 1)Humid equatorial – no wind (whether sea-coast or mountains) 2) daytime /hot/cold climates – fair or good
- 3)Frequency of cyclones (Japan, Caribbean) wind energy not usable
- Contours/ rough surface/ building trees/ obstacles can cause shear (lowers wind speed) & compression.) Best height – 7 to 10m
- <u>Characteristics of good wind power site</u>
- 1)Site with high annual wind speed 2) No tall obstruction up to 3 km radius 3) Good – open plain or open shore line 4)Mountain Gap (wind funneling) 5) Top of smooth, well rounded hill with gentle slope – on flat plain/ on island in a lake or sea

WECS – Basic Components

- Basic Components of WECS
- 1)Aeroturbine – Wind energy – mechanical energy (pitch control which controls rotation speed/ Yaw control for horizontal axis machine) – Electrical generator (using Step up Gearing to enhance rotational speed of turbines & Coupling) – to load or utility grid
- 2)Yaw Control – Yaw fixed (swept area perp. To wind direction) or Yaw active (wind direction changes, motor/ tail vane/ servomechanism to rotate turbines slowly about vertical axis)
- Sub Components of windmill: Wind turbine (Blade, Hub, Pitch Change, mounting) ; Then Wind mill Head, Transmission & control (Speed increaser, driver shaft bearing brake clutch & coupling) & Electrical (Generator control & indicators as ground level), Supporting structure

Subcomponents of Windmill Contd.

- **ROTORS** 1)Horizontal axis rotor 2)Vertical axis rotor (Advantage - operate in all direction & so need no yaw adjustment. Easy to maintain)
- Windmill head – rotors/ rotor bearing/ controls/ pitch/ tail vane
- Transmission : Pitch of blade – 40-50 rpm; Generator requires 1800 rpm. Transmission options: fixed ratio gear, belts & chains etc.
- Generators: 1)Constant speed – synchronous induction & permanent magnetic type 2) variable Speed – Expensive
- Controls: orientation of rotor/ start up & cut in/ power control by varying blade pitch/ generator output monitoring/ shut down/ cut out/ protection/ emergency power/ maintenance mode
- Components of control system: sensor, decision elements (relay, logic modules, analog circuit, microprocessor), actuators (motion with help of energy - hydraulic, electric etc.)
- Towers: concrete / pole/ built up shell-tube/ truss tower (most popular for low cost)

Subcomponents of Windmill Contd.

- Towers must withstand wind load during gusts; mounted above level of turbulence. Minimum height-10m; max. – 60m
- Upwind of Tower – Wind encounters tower behind vertical tower – tower vibrates. Blades are in front of tower. Complex yaw control
- Downwind – Less tower vibrations (so preferred), but blades can be subjected to severe alternating forces during tower wake. Blades behind (i.e. downwind) the tower. No yaw control needed
- Repowering Concepts Replace old power stations with newer ones with higher efficiency; can be from small to big; from switches or boilers to entire systems
- Innovations in power technology –Benefits - Higher capacity, increased production, lower installation costs, better power quality, increased revenue, employment opportunities
- Germany, Denmark, California in US (365 MW) made advances
- Obsolete coal fired power plants (old coal boiler) are retired – Gas-fired turbine (GT) & heat recovery steam generators (HRSG) used

Design consideration of Horizontal Axis Machines

- Rotor Can have any no. of blades – wooden /metals/ composite of glass & plastics / carbon fiber (light weight, strong)
- Connected to generators/ mechanical device like water pump or heat generator
- Taller tower, better wind speed
- Lift or Drag devices – Lift devices provide higher rotational speed & higher output power to weight ratio . Or lower cost to power output ratio. Use slender blades (Width << height). Often uses tapered &/or twisted blades to reduce bending strains on the roots of the blades – Optimum angle of incidence is obtained at all radii, when the machine runs at designed speed. So, high speed machine blades are set at finer pitch than low speed one

Design consideration of Horizontal Axis Machines

- Speed: Small rotors – 400-500 r.p.m.; blade tip speed Several Hundred Km/Hr = 8/10 times wind speed
- Very large airfoil rotors – slower- 20-40 r.p.m.; but comparable blade tip speed : 250-400 Km/hr
- Drag devices – slower; Generates high torques (twisting forces) & ideal for water pumping; But not suitable for electric generation; Power ratio lift/drag = 3:1

Design consideration of Horizontal Axis Machines Contd.

- Slender airfoils need external source of power for start-up.
- Define Solidity (S) = Area of rotor projected on plane perp. to axis of rotation/ Swept area of rotor (S=0.7 for American farm windmill; = 0.1 to 0.01 for high speed lift type propellers)
- Define Angle of Attack : **A** = angle between reference line on the body & the incoming flow; **I** = Angle of Incidence Maximum efficiency in horizontal-axis rotors is achieved when I approaches A; i.e. at l/d maximum. Blades are twisted for optimum A. Too steep A , lift stops (stall)
- Tip Speed Ratio (TSR) = Vtip (Speed of rotor tip)/ V (free wind speed)

Airfoil Nomenclature

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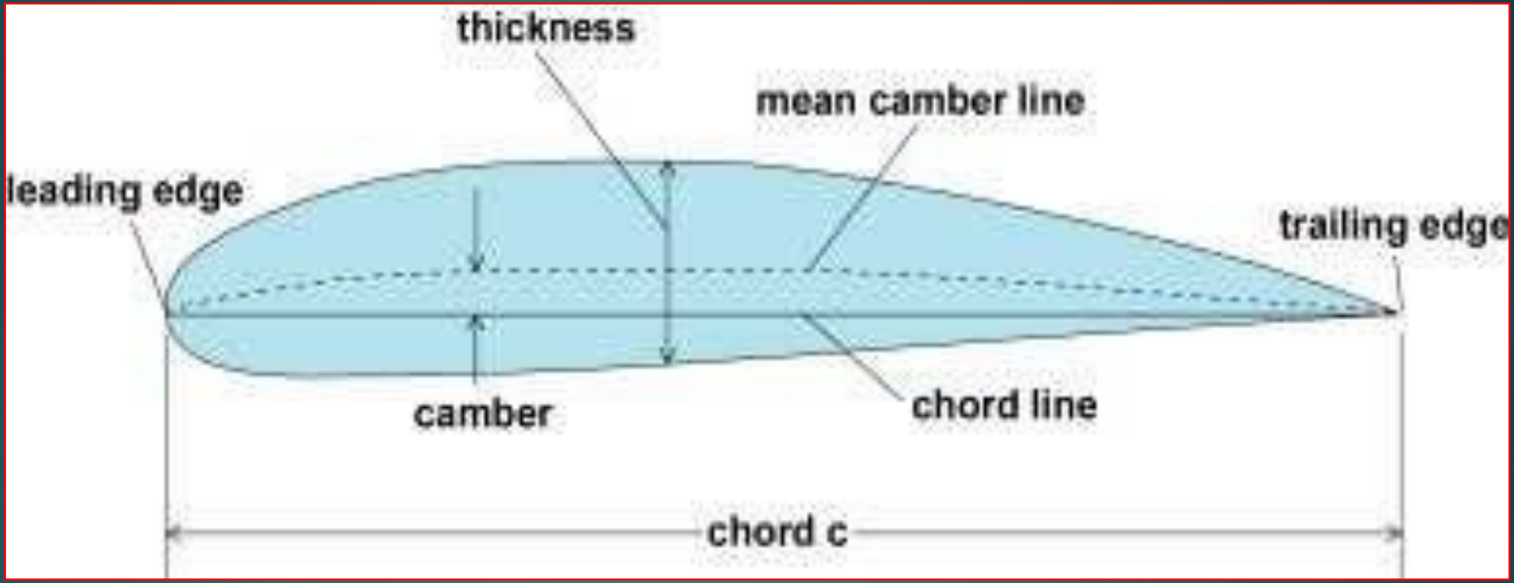
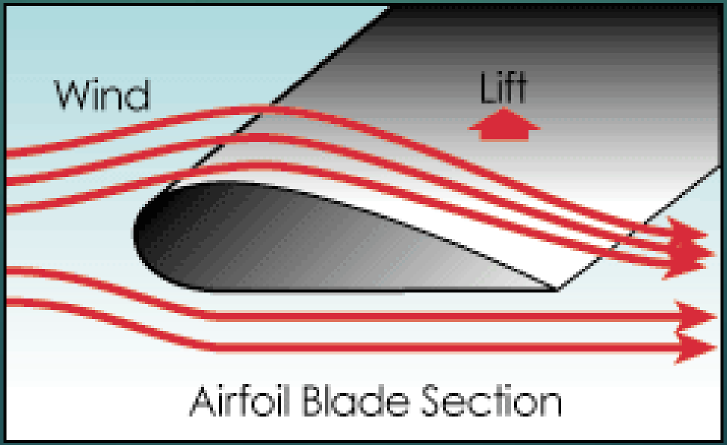
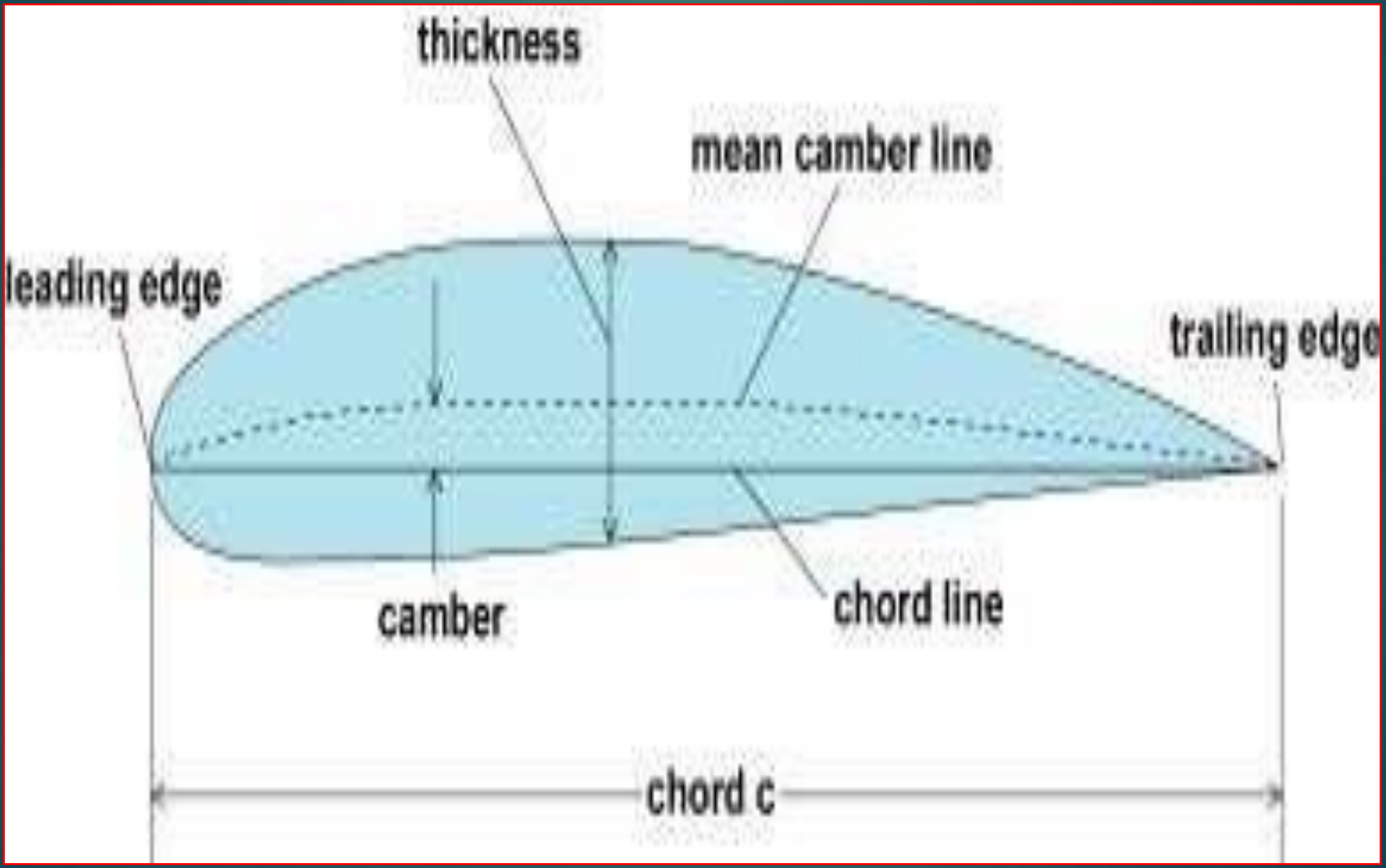
Wind turbines use the same aerodynamic principals as aircraft





Air foil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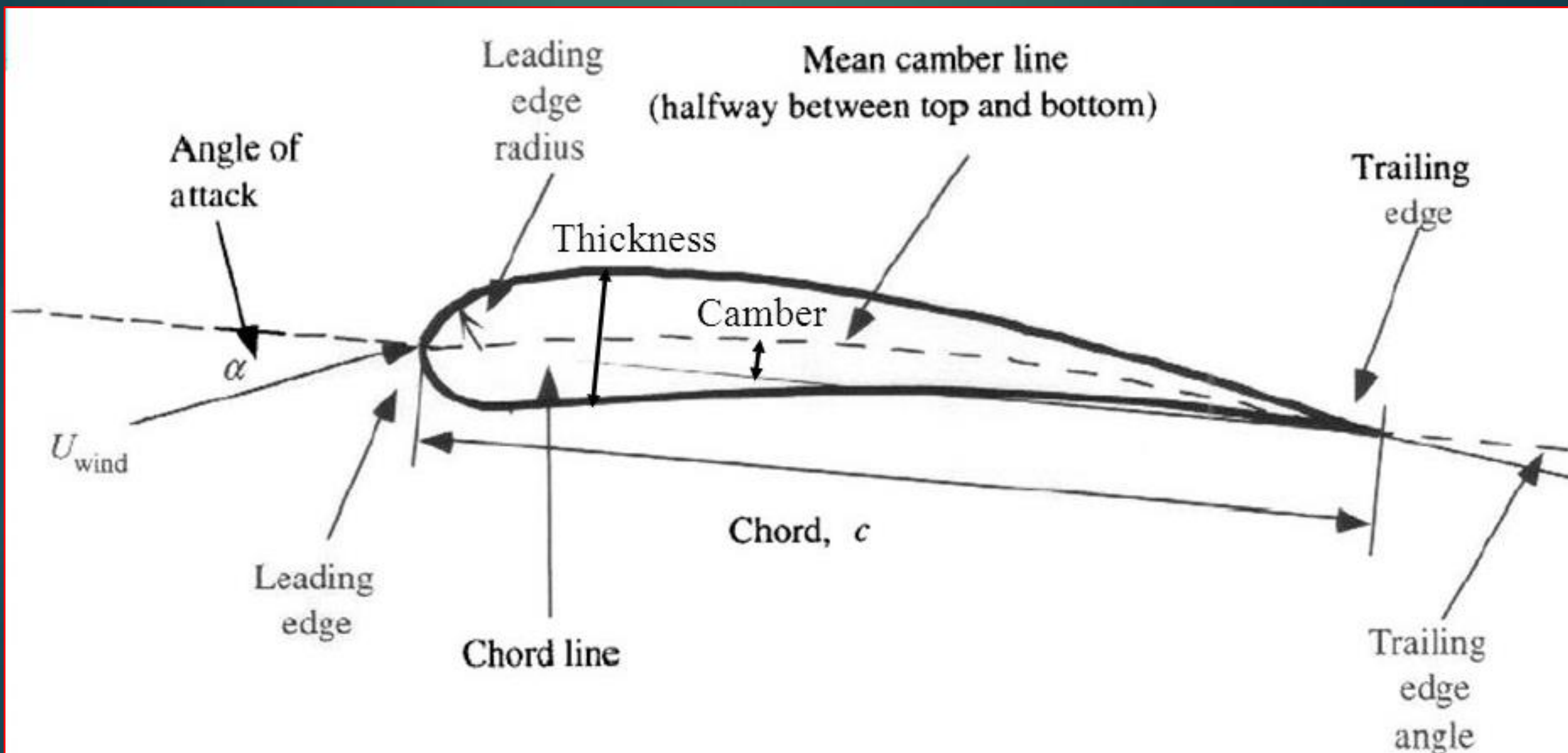
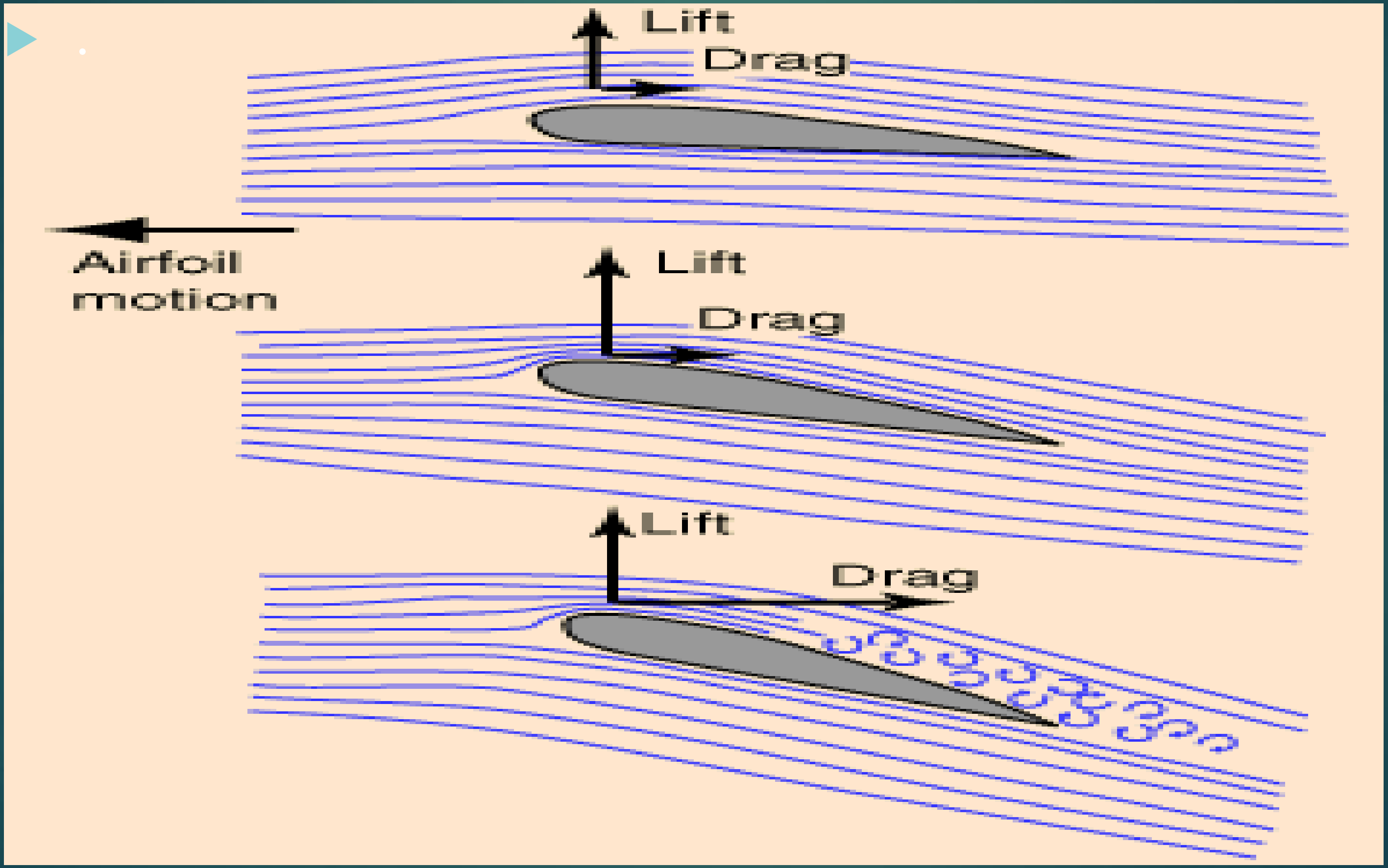
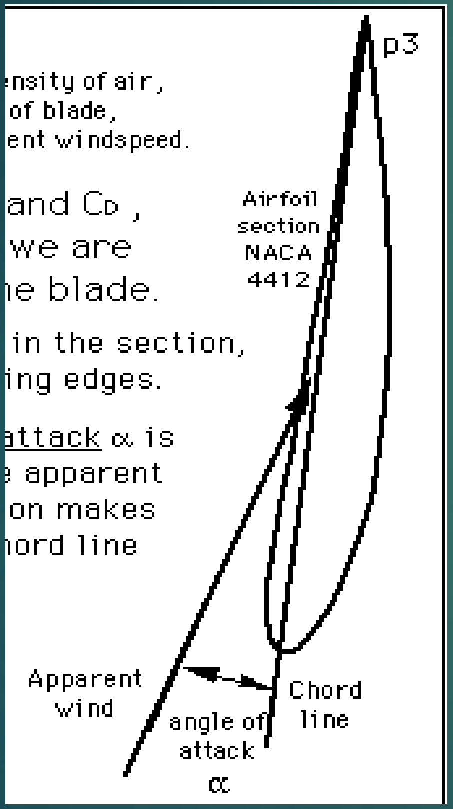
Basic Airfoil Terminology

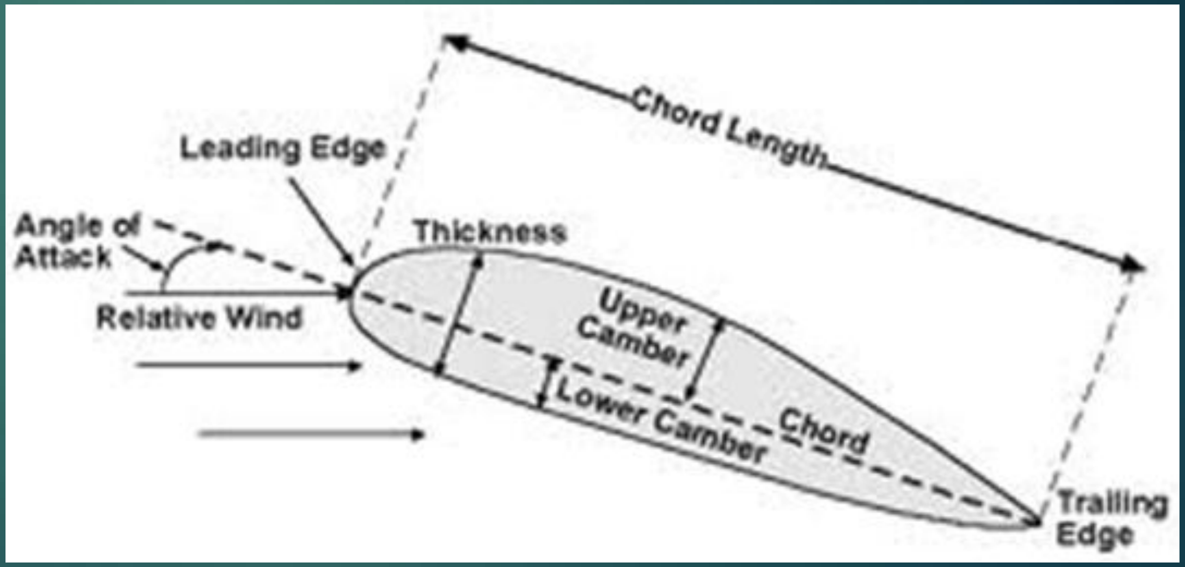


Lift & Drag



Angle between the chord line of airfoil & the flight direction is called the Angle of Attack (Blade Angle) It has got a large effect on the lift generated by the airfoil. Typically it is between 1 to 15 degrees.





TSR

- TSR is characteristics of rotor. There exist an optimum TSR at which efficiency is maximum
- Higher rotor speed, higher TSR, lesser 'S'- needs less material required (relatively slender blades can be used). But it requires higher l/d ratio
- Higher l/d means (higher TSR), it needs good quality airfoils (good surface finish & structural integrity to withstand high rotational speed. This raises cost
- Low TSR windmills – require solid blades or sails so that wind energy is not lost through the gap between them. Needs coarser pitch setting as l/d is less critical (lift is stronger in plane of rotation & drag is weaker)
- As TSR increases, the number of blades decreases.

TSR

TSR	No. of Blades
1	6-20
2	4-12
3	3-8
4	3-5
5-8	2-4
8-15	1-2

- Efficiency increases 6% for number of blades going from 1 to2 & additional 3% when no. goes from 2 to3. Minimal improvements with higher no. but sacrifices in blade stiffness as blades become thinner.
- More blades – more torque, but slower speed. Even no. of blades – Stability problems- uneven forces on rotor shaft & rotor blade
- Alternate definition for S = NC/πD ; where N is the number of blades, C is the average breadth of the blade. D is the diameter of circle described by blade. So we can see as TSR increases, N decreases & so 'S' decreases
- Curve of efficiency (or power coefficient) Cp is compared with TSR. Their curve characterize wind rotor

TSR Contd.

- Cp is optimum at maximum l/d ratio. At less than optimum, TSR is low, speed is low, lift & drag both high, so they balance. At higher than optimum, TSR is high, so is speed. Angle I decreases & approaches 0. Lift & drag force balance. No net shaft power & efficiency again approaches 0
- For rotor system performance, torque characteristics are of more interest. Performance require characteristics of load & its torque requirement (i.e. rotor torque speed)
- Torque – a force that causes an object to rotate about axis. Larger diameter- greater torque
- Define Torque Coefficient CT = Shaft Torque (T)/ Tmax torque at maximum efficiency of rotor
- One can show Cp = CT.λ
- Where λ= TSR = Outer blade tip speed (Vt)/ Unperturbed wind speed (Vi) = Rω/Vi ; R is the outer blade radius & ω is the rotational frequency
- Cp & CT are functions of λ, not constants. Ideally C_{Tmax} will be = 0.593/ λ
- Pumps load characteristics: Generally pump needs higher starting torque than running torque (high solidity). But electrical generators needs little starting torque; so can be driven at high speed

Number of Blades

- Typically 2 or 3 propellers blades (built up to 6);
- 3 blades - more vibration than 2 due to turning or yawing of rotor to face it to the wind. Overcome by controlling the yaw rate
- 2 blade- major attention – less cost to fabricate in large sizes & high TSR
- **Blade Design**: Airfoil type cross section & a variable pitch; slightly twisted from the outer tip to root, so that rotor doesn't stall; constant chord length (leading edge to the other end); blades should be narrower at tip (in modern turbines, tip speed is 6 times the wind speed) than at root
- Large 2-bladed turbine – blades are inclined at small angle to vertical (corning angle) – decreases load on roots. This is absent in very large rotors.

Blade Design Contd.

- Aerodynamic is sacrificed for strong rotors. It is constructed it such a way to with stand with forces due to wind turbulence, directional change in wind, speed variation with height, gusts, gravitational force, pressure of tower etc.
- Weight & Size : Dimension increases – mass increases – power per mass decreases– TSR also decreases --- drag forces increases

Practical diameter – 90-110 m, light weight – by woody, Al skin, plastic reinforced with glass fibers (for diameters up to 34m); Aircraft type blade : Al/ Al alloy. Strong rotor blades by steel

- Yaw Control: Yaw fixed, yaw active
- Wind stream variation – rated power at Cut-in wind speed & rated wind speed. Higher wind speed-pitch adjusts rotor speed. Rotor stops at very high wind speed (cut-out or furling speed)

Wind stream variation contd.

- Rotation increases with higher wind speed but changing speed of rotation generally does not provide the optimum conditions for genera-ting ac at constant frequency. Solution : variable speed input --- variable frequency ac --- convert to dc --- rectify to constant frequency ac
- Pitch of blade adjusts rotor speed if it exceeds rated value. Electric power generator output remains constant from rated wind speed to the cut out speed
- Rated wind speed Vrated value should be > Vaverage, but should not be so high that generator start operating below rated power. $V_{rated}/V_{average} = 1.8$ for $V_{average} = 17.5$ kmph. This decreases to 1.5 when $V_{average} = 35$ kmph
- Over-speeding tears the blades by root, small tail vane reduces swept area At very high speed, 'Spoilers' (a device fitted to aircraft or turbine) exert drag on rotor & reduces lift.

Wind stream variation contd.

- Feathered blades – pitch changes automatically in response to the wind. This causes power generation even in gale.
- Small Machine : 'Feathering weights placed on hub responds to centrifugal forces as rotor speed increases. As they lean outwards, automatically alter the pitch of the blades. Large rotors – performance controlled by computer
- Wind turbines must be able to withstand the cyclic variation of gravity due to revolving blades & vibrating winds – otherwise wear, fretting, metal fatigue can occur
- Teetered Hub allows rotor to seesaw back & forth by a few degrees. This reduces stress in large two bladed rotors
- Turbine Tower System – Both upwind & downwind locations used

Stator & rotor in a generator

- The stator is the stationary part of a rotary system.
- It's a coil of wire in a case A magnet on a shaft spins within the stator, creating alternating current.
- Rotors, the rotating part, have permanent magnets that move around the Stator's iron plates to generate an Alternating Current

Squirrel Cage Induction Generator (SCIG)

- Magnetic field created in Stator appears to rotate around rotor. Fixed speed turbine. Maximum efficiency at rated wind speed. Change in wind speed does not alter turbine speed much, but increases electrical output. Two set of windings – one for low wind speed, another for medium & high wind speed
- Capacitor are connected to compensate for reactive power (AC to DC, again to AC)
- Output voltage stepped up by 3-ph step up transformer to suit connection to grid system. Gear Box precedes generator.
- Advantage : Reduces reactive power demand, cheaper, fast transient response, absence of harmonics in current. Disadvantage : Noisy operation, costly power converter, low efficiency, frequent gear box maintenance.

Doubly-fed Induction Generator (DFIG):

- Provides Variable speed to turbine, Input to rotor currents of variable speed. Maximum power output over wide range of wind speed using maximum power point tracking (MPPT) control technique. Generator rotational speed is proportional to wind speed. Wound rotor surrounded by Stator. Two 3-ph windings – one stationary & one rotating are separately connected to equipment outside generator. One winding produces 3-ph AC power at fixed desired grid frequency; other to 3-ph power at variable frequency. Input power is adjusted in frequency & phase to compensate for change in speed of turbine. For adjusting frequency & phase : variable speed input --- variable frequency ac --- convert to dc --- rectify to constant frequency ac. Then to Grid

DFIG

- Multiphase wound rotor, multiphase slip ring assembly with brushes for access to rotor windings
- Principle Stator windings connected to grid, rotor windings (2 to 3 times of stator) to converter via slip ring & ---
- Back to back converter controls both rotor & grid currents
- Rotor frequency can differ from grid frequency
- Controlling (direct torque control or DTC) rotor current using converter, reactive power fed to grid from stator can be adjusted, independently of generator's turning speed.
- Rotor voltage is higher & current is lower. So rated current of converter is lower. Hence lower cost.
- Protection circuit (Crowbar) to protect converter diodes & BJT from high rotor voltage.

DFIG Advantages

- Advantages: 1)Induction generator can both import & export reactive power. This helps machine to support the grid during severe voltage disturbances (Low voltage ride through or LVRT)
- 2) Control of rotor voltage & current enables the induction machine to remain synchronized with the grid, while the wind turbine speed varies. Variable speed wind turbine utilizes available resources more efficiently than fixed one
- 3) Mechanical power fed to grid by converter is only 25-30%. (Rests fed by the stator directly). This make converter cheaper & efficiency higher.

Power converters used in WECS

- Convert DC to DC
- 1) Multiple Boost Converters- parallel structure reduces current rating of equipment to 1/3rd of total input current. Low harmonics. Steps up DC voltage but steps down current
- 2)Matrix Converter: 3 phase source & 3 phase load. 9 switches. Eliminates capacitor. Sinusoidal input/output waveform. Large energy storage element not required. High efficiency. Disadvantage – Low voltage gain & high conducting losses
- 3)PWM Converter- Bidirectional power transmission ability, low harmonic components & good harmonics
- 4)Multi modular converter – Single phase converter is replaced by parallel connected power converters of small ratings. Integrated with PMSG (Permanent Magnet Synchronous Generator), has multiple 3 ph winding set. Power modules with unlimited power output is employed.

Control requirements for WECS converters:

- 1) Maximum generator power operation - MPPT control scheme used Different TSR points are required to be tracked with accuracy for a given wind condition 2)DC-link voltage control 3)Grid current control (active & reactive power)
- Stable active & reactive power flow from generator to the grid , is highly dependent on DC-link voltage stability. DC-link voltage level is directly dependant upon power harvested from the wind speed & stored in DC link capacitor. It is then converted & rejected to the grid and consumer centers. Both stages are controlled by converter modulation strategies : 1) Sinusoidal PWM 2) Cascaded H-Bridge topology (arrangement of series connected unit cells, each with a H-bridge voltage source converter(switches polarity of a blade applied to a load) , with isolated DC sources

Introduction to grid integration of WECS

- Integration of wind power into grid Electricity generated from wind turbines strongly depends on the local weather & geographic conditions that can fluctuate more than hydropower
- Wind power into grid (global power market), can exceed current capability of grids. So grid stability & system security to be addressed. More challenges of grid integration : Controllability, variability, uncertainty
- Thermal management – Robust thermal control system needed (for constant temperature) as environmental temperature vary largely; Dissipation of heat from turbine, cooling for generator, electronic & electric equipment, gearbox etc. needed. Electronics devices must withstand ambient temperature from -40 to +55 degree C
- In cold climate : heating lubrication oil in gear box, blades, hub (to prevent icing), control cabinets
- Integration of wind & other energy sources Wind speed & direction fluctuates. Wind & other complimentary energy should form hybrid power systems for ensuring stability & reliability of power supply
- A) Wind-solar hybrid system – Both produces fluctuating electricity output. Fluctuation can be Periodic (diurnal or annual) or Non-periodic (weather change)

Integration of wind & other energy sources Contd.

- Sunshine intensive during summer/ during day when wind is weaker. Reverse during winter/ night. So wind & solar energy are complimentary
- Zahngbei, China – 300MW of wind power+100MW of solar power (using photovoltaic cell) +75MW of chemical energy power
- B) Wind hydro hybrid system - Complimentary: Winter & Spring (wind power higher; hydro power lower) opposite in wet seasons (summer & fall). Hydropower is dominant source where generators convert water potential energy to electrical energy
- C)Wind-hydrogen system – Hydrogen source – water, fossil fuels, biomass. Wind power, solar power & other renewable energy power generation system can be integrated with electrolysis hydrogen production system to produce hydrogen fuel (high energy density – can be stored, transported & then converted to electricity using fuel cells)

Integration of wind & other energy sources Contd.

- D) Wind-diesel power generation system: Diesel generator can operate periodically to reduce consumption of fuel when wind power varies. 50-80% fuel saving compared to diesel generator alone. Based on proportion of use of wind power in the system; it can be classified as low (presently in use commercially), medium & high penetration wind-diesel systems
- Issues in Grid Integration :Goal Developing efficient ways to deliver variable **renewable** energy (RE) to grid.
- 1)Capacity & Grid expansion & up gradation to access high quality solar & wind resources 2)Increased system flexibility – operational, marketing, forecasting, faster scheduling, grid codes, power purchase agreements, cooperation between authorities, sharing, generation-transmission . 3) Long range demand, interaction among generation & system loads

Challenges

- Challenges: Fluctuation in wind power have negative impact on grid integrity; i.e. power quality, system security, system stability. Higher penetration – more impact on integrity
- 1) Security – Ability to withstand disturbance without causing a break down of power system. Needs voltage & frequency control 2)Power imbalance on the grid – Due to variability & unpredictability of wind. Power may not be available on demand; excess when low demand 3) Reserve management – power balance between the generating plant & load demand. Else frequency will be affected & there will be loss of synchronism 4) Power system voltage control – Nodal voltage decides how much reactive power can be supplied. So nodal voltage distribution must not be less than an acceptable limit. One limitation of wind power integration is that induction generators used in WECS can't inject reactive power to the grid. 5) Power quality – Flickers, deviation from sinusoidal voltage, harmonic distortions, voltage imbalance, voltage dip etc.
- Poor quality power leads to losses in the grid
- Harmonics – caused by power converters, non-linear loads like TV, personal computers etc.. It increases line losses & causes excessive heating of equipment which decreases their lifetime.

Challenges Contd.

- Fixed speed wind turbines produce power pulsation due to tower vibration which causes voltage fluctuations
- Flickers – Periodic voltage frequency variations between 0.5 & 25 Hz that causes annoyance from incandescent bulb Severe at 8.8Hz. Wind generators sometimes produce oscillatory output power, which could cause flickers in power system network.
- Voltage fluctuation by wind turbine have two components : the continuous operation (results from active & reactive power variation due to wind speed fluctuation) & the switching operation (due to fast changes of power from one level to another)
- Effect of flickers is not severe in variable speed wind turbines
- Voltage dip (or voltage sag) : Momentary reduction in rms voltage value beyond a specified threshold for a short duration of time. (Drops below 90% of nominal voltage for less than a minute. Occurs in large load, cause disconnection of wind generators which can cause instability in network.

Challenges on power system stability

- Disturbance can cause disconnection of generators, load, lines, transformer or a fault.
- If the power system goes back to original state of equilibrium (normal operating condition) after disturbance, it is called stable. Stability considering large disturbances is called as transient stability.
- Inductive generators – poor reactive power control. If input torque increases & voltage dip goes beyond threshold limit, it can lead to poor feeder regulation causing voltage collapse as a result of reactive power demand from the grid.
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