Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems

Dr.R.Anandalakshmi
Department of Chemical Engineering
Indian Institute of Technology, Guwahati

Module No # 07
Lecture No # 32
Turbine Terms, types and theories: Part I

Hi everyone good morning so welcome back to renewable energy engineering solar wind and biomass energy systems. Hope you had the essence of solar and biomass energy systems in the previous weeks. Now we are ready to start wind energy systems this is the first week of wind energy systems in today's lecture we will review the basics of wind energy systems what is the source of wind energy? Wind turbine terms basic concepts and how to extract power from wind energy?

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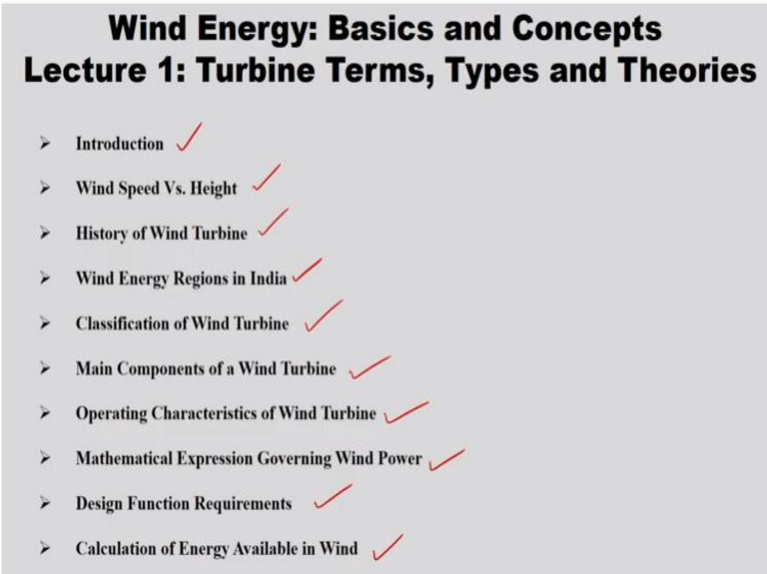

The today's lecture is about introduction wind speed versus height history of wind turbine wind energy regions in India. Classification of wind turbine; main components of wind turbine, operating characteristics and mathematical expression governing wind power design function requirements and then calculation of energy available in wind. So before going into this lecture we will review whatever we left with.

In solar energy in the third lecture we had these wind energy basics. What is the source of wind energy? So we will first review that because in between you had biomass energy systems. So we will review that and then slowly we will go to wind turbine terms, types and theories.

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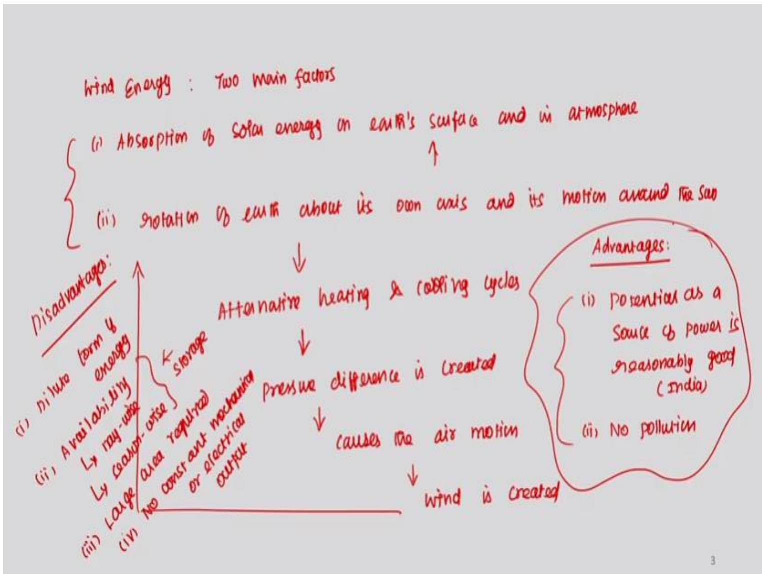

For wind energy the main factors are 2 main factors one is absorption of solar energy, on earth surface and in atmosphere. So, this is what we have discussed how land is getting heated? How the lake side is getting heated? The factor is nothing but the rotation of earth about its own axis and its motion around the sun. So due to these 2 main factors so what we get is alternative heating and cooling cycles so due to which the pressure difference created.

So this pressure difference causes the air motion that is the way wind is created. So if you see what is the ultimate source for wind energy? This is nothing but a solar energy so that is what we discussed probably in last lecture of solar energy utilization. So then we should also know about its disadvantages and advantages. First we will see about its advantage side so one is the potential as a source of power is reasonably good especially in India.

So the second one is no pollution because the ultimate source is solar energy so we have these 2 advantages but what is the disadvantage? The disadvantage is whatever we have discussed in the solar energy one is diluted form of energy the second one is availability. So this various day wise as well as season wise only particular season you get the required wind energy. So this availability in terms of storage and also the third one is we need large area to capture the large area is required.

And if you go in depth no constant mechanical or electrical output so this already we told the availability it is a, intermittent energy. So whatever is applicable for solar it is applicable for wind also. Aim is how to overcome this advantages this how to maximum this as an advantage to draw power from wind energy. That is the main aim to extract power from the wind energy.

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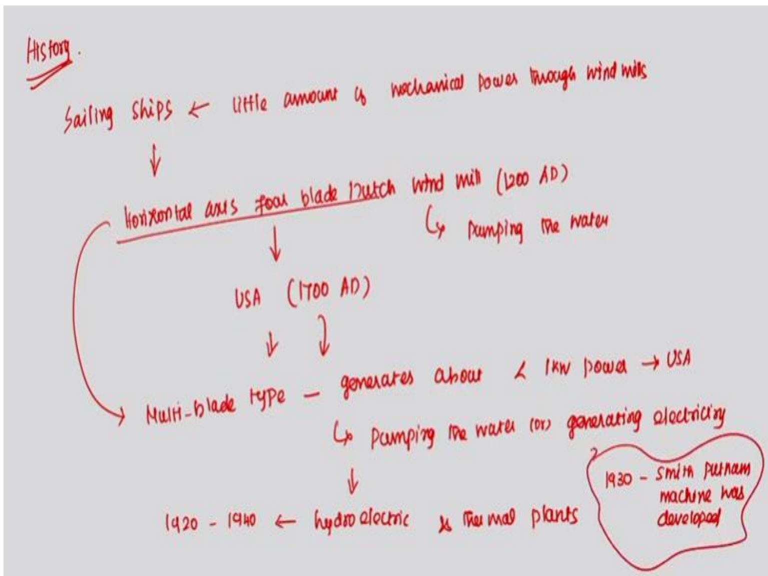

If you see the history right how or when this power extraction from wind energy was started? In ancient times for sailing ship this wind energy was used so almost kind of little amount of mechanical power through wind mills was used. And then first horizontal axis 4 blade Dutch wind mill so this was probably the one with started in 1200 AD. So this was mainly used for pumping the water so then Dutch is they introduced the same thing in USA in around 1700 AD.

So then with 4 blade system the improved version of multi blade type which generates about less than 1 kilowatt power was developed in USA. So this improvement version so this also used for pumping the water as well as for generating electricity. And after that what happens in 19 century around 1922 to 1940 what happened is then other water plant of hydroelectric and thermal power plants they took the front seat.

So this spending research and development on wind energy extraction took the back seat the again around 1930 there is something called Smith Putnam machine was developed so this is major breakthrough.

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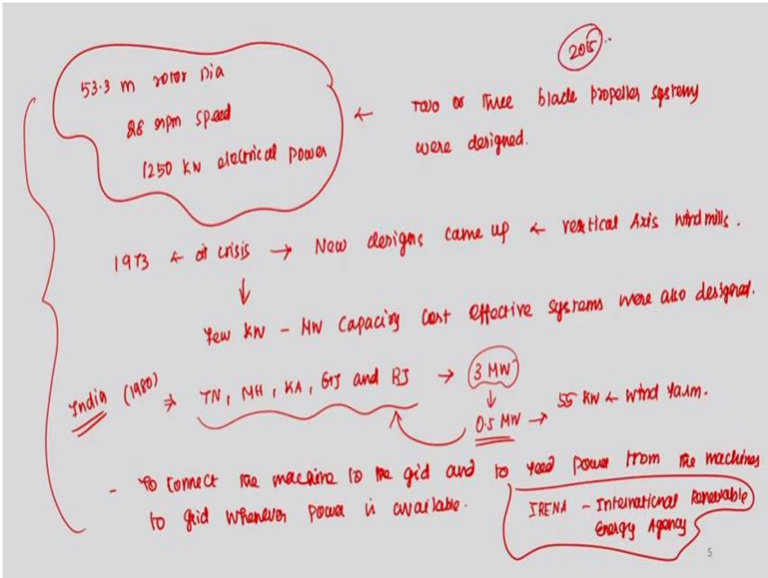

So this was about 53.3 meter rotor dia and 28 rpm seat it drove about 1250 kilowatt electrical power. So during this time there were many improvements in the design of the wind turbine. So here 2 or 3 blade propeller systems were designed so there lot of improvement there is one such kind of improvement is this one. And again what happened is? In 1973 so the major oil crisis so then, the downhill of the wind energy picked up again.

So then after that new designs came up one another major breakthrough is vertical axis wind mills. And after these improvements there were many few kilowatts to megawatt capacity and cost effective system as well alright. So economically viable systems were also designed so this is a brief history of wind energy anyway we will see in depth there are few other breakthrough as well that we will see in depth.

So this is about worldwide and what happened in India so in India the major breakthrough was 1980's. So there are 5 states of India were identified the coastal regions of 5 states of India were identified as the potential source of wind energy. So which are Tamilnadu, Maharashtra, Karnataka, Gujarat and Rajasthan alright so in these 5 states the total capacity of 3 megawatt windmills were came for operation and this 3 megawatt again splited into around 0.5 megawatt in each coastal region.

So this 0.5 megawatt also it is not a single machine so it is the kind of 55 kilowatt capacity machines altogether as a wind farm. And how it is operated what practices being followed to draw the power from these wind mills or to connect the machine to the grid. And to feed power from the machines to grid whenever is available because it is intermittent whenever power is available.

So now then what is the scenario in India? Right now we already told for current installed capacity as well as the current generation capacity for solar energy from the arena. So it is international renewable energy agency so from this side you would get all the information what is the current installed capacity of the wind energy. And what is the generation capacity of the electrical power from wind energy system all the data’s you would be able to get. And we will also see till 2015 what, is the development in the subsequent slides?

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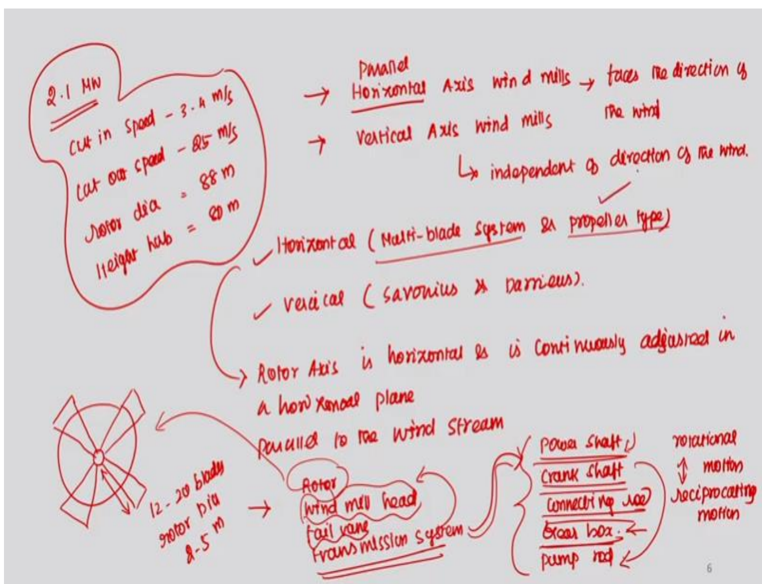

So the one major breakthrough is of about 2.1 megawatt alright so this one was having Cut-in and Cut-out speed this terminology you would see in this particular lecture. So here we are discussing about the introduction of wind energy and whatever we discussed some 3 weeks before. So what, are all the sources of wind energy etc., so the Cut-out speed is something about 25 meter per second and rotor dia of about 88 meter and the height of the hub.

So these terminologies you would get to know in this particular lecture so this is another big wind machine which was used to draw the electrical power alright it during the development of wind mills for power generation. So then we come to the wind mills what are the types of wind mills available. So as we discussed so one is horizontal axis wind mills second one is vertical axis alright.

Sometimes this is called parallel axis as well why it is so? So here it faces the direction of the wind but unlike parallel axis windmills vertical axis machines are independent of direction of the wind. So in the horizontal again we may have different types one is multi blade system so by now you knew multi blade system and propeller type. So the second is vertical so the famous designs are Savonius and Darneus type.

So in the horizontal axis windmills the rotor axis is horizontal based on that only it is called as horizontal axis windmills. And also it is continuously adjusted in a horizontal plane also in terms, of wind direction if you see it is parallel to the wind direction wind stream. So that is what it is called as parallel axis machines as well again we told there are 2 types one is multi blade system and propeller type. So multi blade systems are something like this so you have a inner rim and outer rim.

So in this your blades are attached I just draw 4 but it is multi blade system that is what it is? So if you see the width the blade is increased from inner end to outer end and inner end is fixed with one circular rim. The same way the outer end also fixed with outer circular ring so it is mostly containing 12 to 20 blades rotor dia is about 2 to 5 meter. And also if you see the major components of this particular multi blade horizontal axis wind machines.

So it is the rotor components, which consists of blades and then wind mill head tail vane and then transmission system so what is this transmission system? This again consists of power shaft and then it may also have crank shaft and then connecting rod and then gear box and then pump rod. It is especially what we are seeing here is the rotor system it is consists of this blade system. So then it has to be kept in the rotor is connected with the wind mill casing when we call it as a wind mill head.

And you will have one tail one and rear side of the wind mill and then transmission system. So this transmission system mostly kept in this particular casing so this has power shaft and then crank shaft and connecting rod and gear box. So this gear box mainly used to reduce the speed so there are 2 kind of motion one is rotation motion and reciprocating motion. So this gear box here for example here the multi blade horizontal axis wind machine is used for pumping the water.

If that is the application then you might have this kind of transmission system. One is for power shaft and another is crank shaft and connecting rod. So which converts the rotational moment and the reciprocating moment so that is connected to the pump rod. So which; delivers this reciprocating motion for pumping the water. So from this gear; box when you convert the rotational motion into reciprocating motion.

So if you want to reduce the speed to 3 to 4 times this gear box mechanism can be used because we are not going to discuss anything in depth on the machine system because that is not our cup of tea to discuss in that. So here I am just telling that what are all it may contain and other than; the multi blade system so you will have propeller system as well in the horizontal axis wind machines. So how does it look like?

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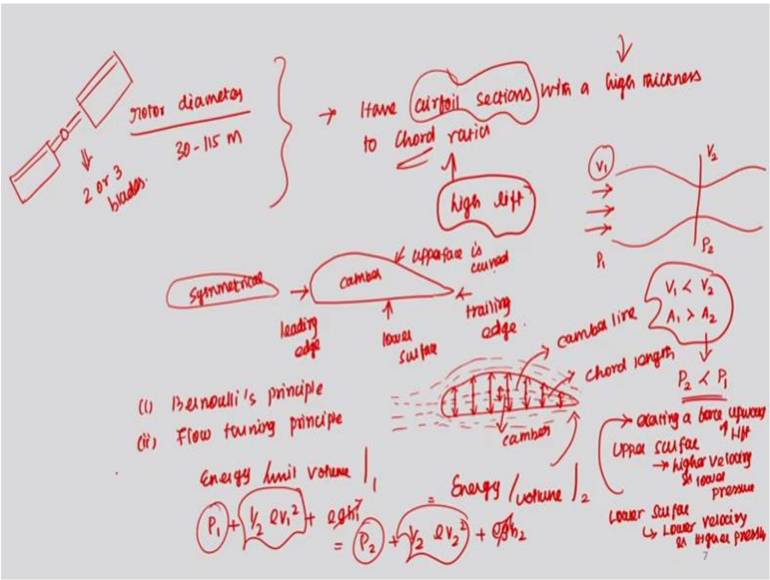

It looks like something of this kind so this is propeller type so here rotor dia is higher than what we had seen in multi blade system. So rotor diameters are about 30 to 115 meter you can get so normally it may have 2 or 3 blades not like multi blade systems. So the, another important concepts we might need to be comfortable is the air foil section. Because these all blades have air foil sections with the high thickness to chord ratio so why it is?

It is to bring high left so if you remember our introduction video so we told that the drawing wind power mainly depends on 2 forces one is lift force and another one is drag force. So to elevate this lift force into higher value so, this all blades may have air foil sections. So air foil section what you see in the normal flight there are again many types so normally this is something we call it as symmetrical air foil section.

So you will have lower surface symmetrical and upper surface no difference so there is another type called camber air fall section. So in the camber air fall section the upper face is curved so this is leading edge this is trailing edge so this is lower surface alright. So then what is this terminology chord ratio that chord is nothing but for example. So if you have this air fall section with upper curved surface so this if you connect the trailing end with the leading end.

So this is called chord length and thickness is nothing but the distance between upper surfaces and the lower surface. So, this all are called thickness at particular point or particular length from the leading edge. So if you connect the midpoint of all these thicknesses so if you draw a line that line is called camber line. So the distance between; camber line and the chord length is called camber.

So that is what it is said that if you have a high thickness to chord ratio then your lift force may be high. So here the concept is like we have 2 theories based on which you will get this lift force which is the upward force so one is based on Bernoulli’s principle the second one is flow turning principle. So the Bernoulli’s principle which says that the energy per unit volume before and energy per unit volume after are say what is this before after?

So this is particular section so this is the common diagram which is used in the Bernoulli’s principle. So you will have the fluid which is entering with the V 1 velocity and pressure is P 1 so this is the second 2 where you could get velocity V 2 and P 2 so this is one is section one before is section 1 we can put it as 1 after is 2. So the energy conservation principle basically so if you see area so probably V 1 is less than V 2 the same way A 1 is greater than A 2 because the area is reduced.

So if this is happening then based on this principle so then your pressure at 2 should be less than pressure at 1. So this is what is called Bernoulli's principle normally they equate the pressure energy and kinetic energy per unit volume this is off rho V1 square + rho g h1 which is nothing but a potential energy per unit volume which is equivalent to pressure energy at point 2 + kinetic energy at point 2 + rho g h2 which is nothing but potential energy per unit volume at point 2.

So if both are same then so whatever is happening with velocity so increase or decrease that has to be compensated with the pressure increment or decrement? So that is what basically happening here so how do I relate this to air fall section. So if you see the air is coming here with the free stream velocity so it has to see this stagnation point and take a round shape of the air fall section. And some of them go to lower surface as well. So this is the way it happens.

So the upper surface takes longer time because it has to travel the larger surface so it may take high speed because the 1 and 2 has to be matched the section 1 and section 2 has to be matched in the sense energy per unit volume at 1 and 2 has to be matched. So because of this larger surface area it has to travel in faster speed. So if the velocity is increased so automatically pressure has to decrease.

So that is the way the upper surface of the air foil so that has upper surface has higher velocity and lower pressure. So the opposite is true for this is lower velocity this comparatively it is not lower velocity in the sense not much lower and higher pressure. So this pressure difference is exerting a force upward so that is called left force. So this is the basic principle involved in the rotation of the blade and how the lift force is created. There is another principle we told it is nothing but flow turning principle.

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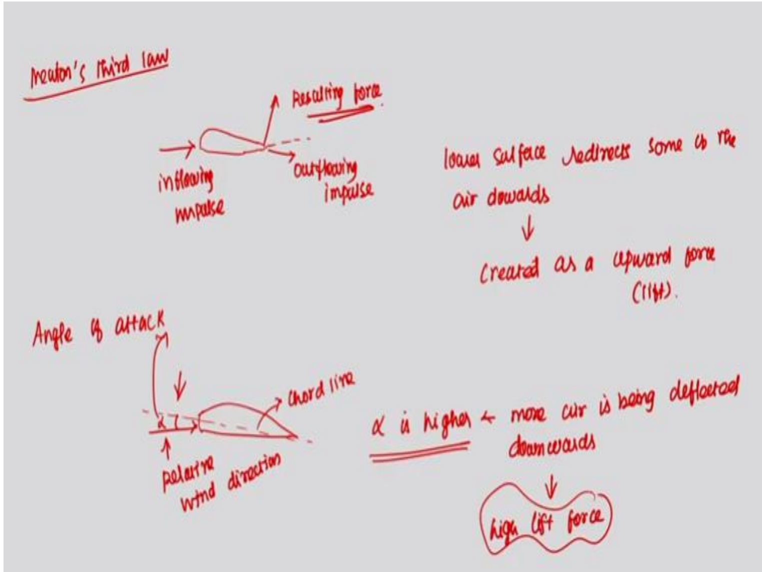

So that is based on Newton’s third law so this is something like so whatever we seen over there so this is inflowing impulse. So if you see this figure it has to take a downward when it sees this stagnation point so some of the air is travelling upward surface and part of that is also going downwards. So this is inflowing impulse and if you have air fall section of this way so if it is a outflowing impulse.

So this is so you are resulting force acting in this direction so it is basically the lower surface redirects sum of the air downwards. So based on Newton’s third law so it has equal and opposite reaction so that opposite force is created as a upward force called lift. So based on third law so if you are asking me why is, it not the upper surface is also contributing to lift? Yes of course, so this also responsible for directing some of the air to downwards.

So totally it is just that opposite force is created upward which is called lift. And there is another terminology also being used in the wind design which is nothing angle of attack. So remember whatever we are doing here we are learning the basic concepts involved in a; wind energy so we are not going to in depth here so we are learning terminology. So if it is a course exclusively for wind power extraction then we might have discussed in depth about all this things.

So some of you if you are working in mechanical or chemical engineering so, you might have learnt the course called fluid mechanics so in that you might have learnt in depth about all these things. But here the, who are, not part of these basic departments who did not flow about fluid mechanics. I am just briefing about that terminology so this is angle of attack so what is this?

So here you have a relative wind in particular direction and you have your air foil section of something like this. So this chord line is this one so this is relative wind direction so this angle is called angle of attack. So the convention is that if alpha is higher more air is being deflected downwards. So more and more air is deflected downwards then you will get equal and opposite lift force.

So that is way also you get a high lift so high lift force. So that is something like the basic calculation if we alpha is higher or positive then you would also get high lift force. So; why we discussed all those things because of this particular terminology when we are discussing about the propeller type horizontal wind mills. So that is something called thickness to chord ratio so if you get that particular ratio is high then you get high lift force.

So how the lift force is being created that is what we discussed based on Bernoulli's principle and flow turning principle. So coming back to here, what we were discussing so we discussed about the horizontal axis wind mill and we supposed to discuss about the vertical axis wind mills.

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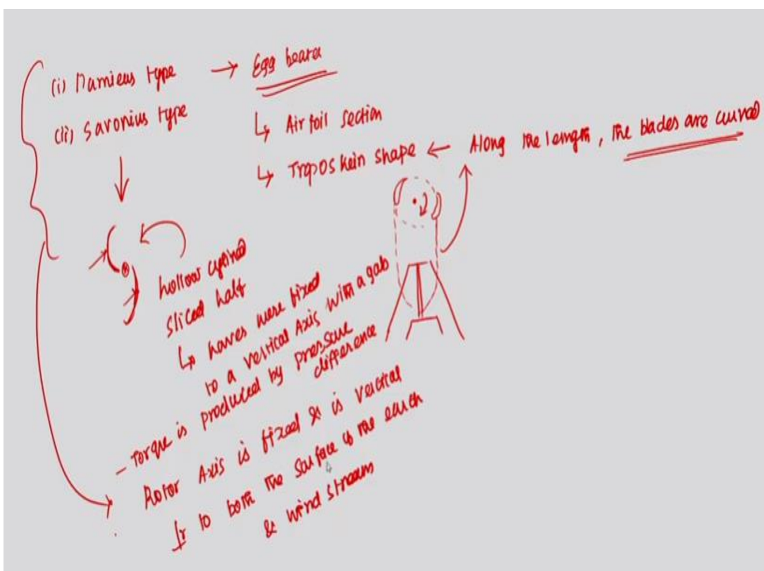

So as we said earlier there are again 2 types one is Darnieus type second one is Savonius type. So what is Darnieus type so it is a kind of professor Sukhatme says it looks like a Egg beater so imagine how it looks like so it also has air foil section to create a high lift force. And also this shape is something called Troposkein shape the blades so what is this particular shape so this is something like along the length the blades are curved.

So I am not good at drawing so till we have this figure but still we are discussing about introducing all, the machine so here we will see also. So here if you see this is something called air fall section. So this is nothing but rotation so this blade is when it comes so it is curved. So this also curved this way so this is something called rotation so it rotates about. So this particular shape is called Troposkien shape because the blades are curved along the air length.

And the next one is Savonius type so it is of this shape S shape that 2 haves of the hallow cylinders. So this hallow cylinder sliced half and hall haves were fixed to a vertical axis so remember here in the vertical axis machine the rotor axis is for both type the rotor axis is fixed and its vertical. And also it is perpendicular to both the surface of the earth as well as the winds stream unlike horizontal axis machine.

So with the gap so that is how it looks like as a kind of S shape so the torque is same way for both vertical and horizontal machine that torque is produced by pressure difference how it is created? Then we have already seen in depth so this pressure difference is created between the half so this way and this way which half facing the wind. So this is what about the basic concepts and terminologies and what is the source of wind?

So etc., we discussed and now we will go and discuss in depth about whatever we discussed in brief.

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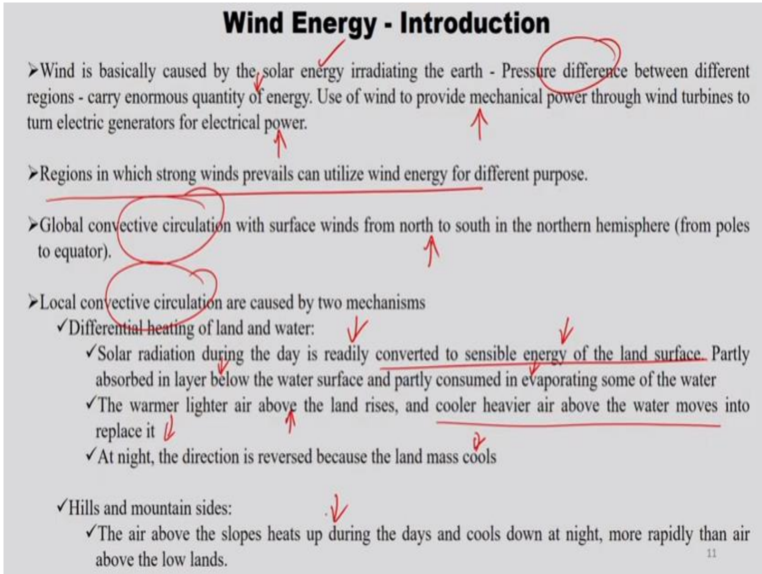

So wind is basically caused by the solar energy irridiating the earth so the main reason is pressure difference between different regions wind carry enormous quantity of energy. So this wind is used to provide mechanical power through wind turbine to turn electrical generators for electrical power. So the regions in which; strong wind prevails and utilize the wind energy for a different purposes. So there are 2 ways it can be created the wind energy can be created in 2 way.

One is global convective circulation other one is local convective circulation this also we have seen in the solar energy utilization method. Global convective circulation is winds from the north to south in the northern hemisphere from poles to equator. In local convective circulation the differential heating between the land and water so the solar radiation during the day is converted to sensible energy of the land surface.

So this is happening in the land so when it receives the solar energy so it receives amount of sensible energy but what happens in the water partly absorbed in the layer below the water surface one is absorption and another is whatever the absorbed energy partly consumed in cooperating some of the water. So because of that the temperature at the land side would be higher compared to water side.

So the warmer lighter air above the land raises the cooler heavier air this cooler and hotter it is comparative between land and water. And heavier air above the water moves into replace it because of this pressure difference so the wind is created because of air motion. At night this cycle reverse and hills and mountains also contribute wind energy because the air above the slopes heats up during the day and cools down at night more rapidly than air above the low lands.

So these 2 are local convective circulation and global convective circulation from poles to equator. So because of these 2 convective circulations wind energy is being created.

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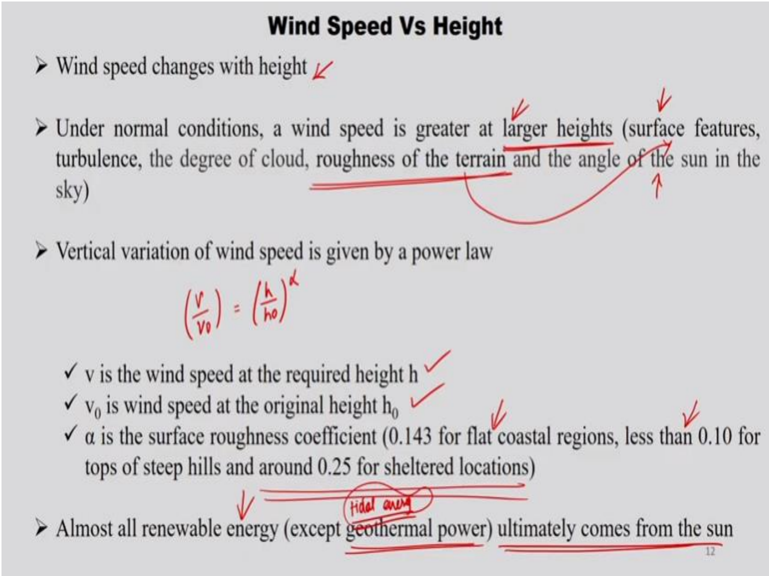

And wind speed changes with height and at normal condition wind speed is greater at larger heights. This is again we can say wind speed greater at larger heights but whether it is same no? Because it is also depend on the surface feature turbulence of the air and degree of the cloud and roughness of the terrain and this is again related to surface features only. And the angle of the sun and the sky so this we have discussed the motion of the earth about its axis and then sun.

So this all contributed this relation wind speed versus height but in general wind speed is higher at larger heights. For example surface features so when we talk about that so there may be good sites bad sites and can be improved there are sites can be improved. If we follow certain design procedure that we will see probably in depth.

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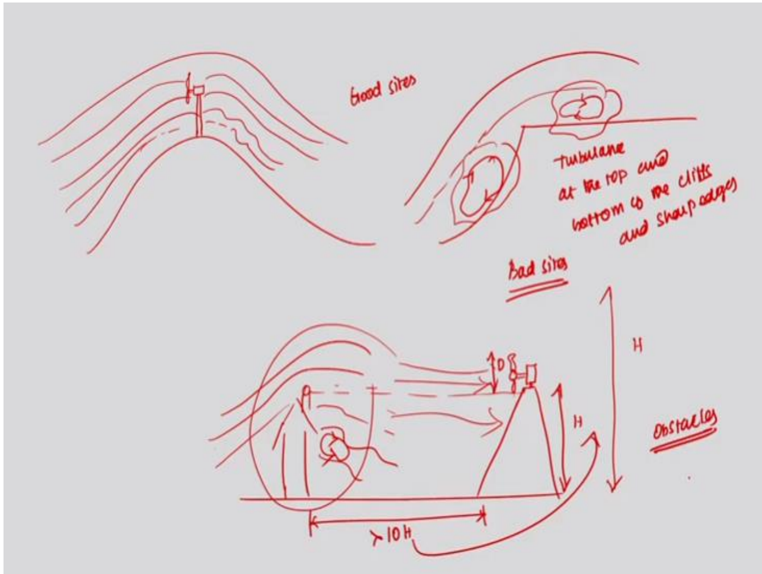

So for example if you have smooth face like this so here if you construct your wind mills so then your air also something because it is considered as obstacle. So you may probably getting, waves here so here so it will be something like smooth. So this kind of sites we call it as a, good sites and there are sites which has sharp edges. So such kind of faces you can expect turbulence at the top and bottom of the cliffs and sharp edges.

So there may be a wave formation or here so it goes something like this so there here, also you may get because of these sharp edges so a lot of energy, being wasted in such kind of wake formation instead of converting into useful power. So this we call it as bad sites which cannot be improved probably naturally it is like that and there are sites which can be improved. So for example you have industry kind of thing so there also you have chimneys or something.

So when the air hits so here also you have kind of wake formation for example here you have a wind mills. So if you have a wind mills here so this is almost equivalent to the tower height so this is height of the tower so this is the diameter of the rotor. So you would get such kind of obstacles when before air reaches to these rotors. So here the general rule is that the distance between the obstacles and your wind mill.

So that should be 10 types of height of this tower plus in the sense greater than so the distance between obstacles any such kind of obstacles with the wind mills it should be greater than 10 h is nothing but the height of the wind mill. And apart from that to avoid this kind of obstacles here you need to provide taller tower whether you need to increase the h or increase the distance between the wind mill and then the obstacles.

So these sites may be it is due to obstacles but if you carefully design your wind mills then it can be avoided. So these are all comes as the surface features or roughness of the terrain and surface features etc., also coming to play when we talk about speed versus height. Apart from that you have obviously the wind turbine design which takes part in this wind power extraction but we are discussing here the physical factors probably the sites what are all good sites what are; all bad sites.

So the vertical variation of wind side is given by the power law V upon V naught equal to h upon h naught power alpha V is wind speed at the required height h. And V naught is the wind speed at the original height h naught alpha is the surface roughness coefficient. So this is given as 0.143 for flat coastal regions, and less, than 0.10 for tops of steep hills and around 0.25 for sheltered locations.

And there are many locations for which the alpha is given already by fitting the data's so that one can get in some standard book that are given in this particular lecture. So almost all renewable energy except geothermal power ultimately comes from the sun this we discussed many a times. And here also some of them say tidel energy as well we do not include because we know this is tidel energy is based on rise and fall of that heights but which is due to moon but the thing is ultimately if you go in depth that is also created due to sun power only.

So we do not take that as a exceptional things but geothermal is obviously coming from the ground so we do not include them. In tidel energy also some of them say them say that it is not direct radiation of sun so it can be also included in the exceptional cases.

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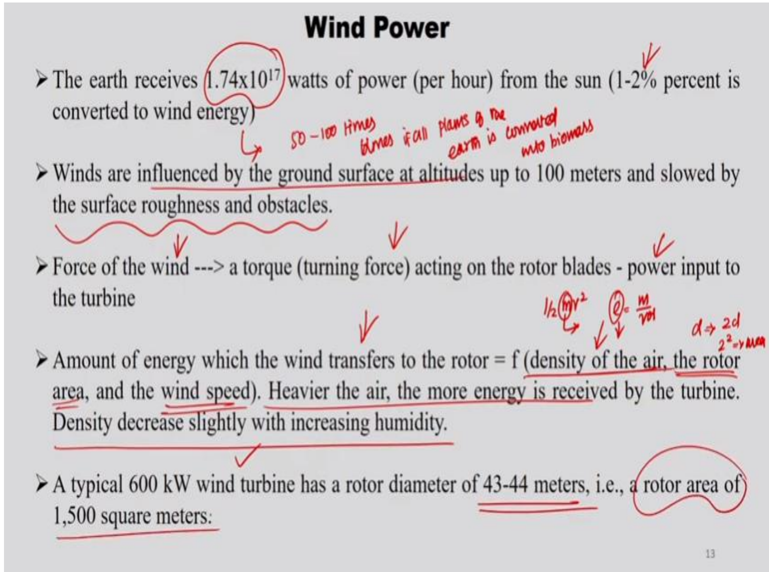

And then earth received around 1.74 into 10 to the power of 17 watts of power per hour in that 1 to 2% is converted into wind energy. But if you compare with biomass it is almost 50 to 100 times greater if all plants of the earth are converted into biomass the comparison between the biomass and wind energy. So winds are influenced by ground surface at altitudes up to 100 meters and slowed by surface roughness and obstacles this we already have seen.

So surface roughness and obstacles are slow down the earth but beyond the 100 meter you probably get a lower turbulence and get good wind speed and the force of wind is converted into torque which is acting on the rotor blades which is again the power input to the turbine. The amount of energy which the wind transfers to the rotor so this is again the function of density of the earth the rotor area and wind speed.

So if you talk about density so, we have already told that the kinetic energy converted into electrical energy ultimately. So the kinetic energy if you see half m v square so this is mass is related to the density mass of the volume. And also remember that density of the air it also various with the temperature. So it is told that air density decrease slightly with increasing humidity also density decreases with increase in temperature.

So the convention is that heavier the air more energy is received by the turbine so in that case you should have higher humidity or higher temperature. So that is nothing but the function of density of the air routed area and wind speed. And rotor area also if diameter is doubled so instead of d if you get 2 d then it is twice 2, power 2 is your area. So if area is increased your amount of energy wind transfer also increases.

A typical 600 kilowatt wind turbine as a rotor diameter of 43 to 44 meters so which comes around rotor area of 1500 square meters.

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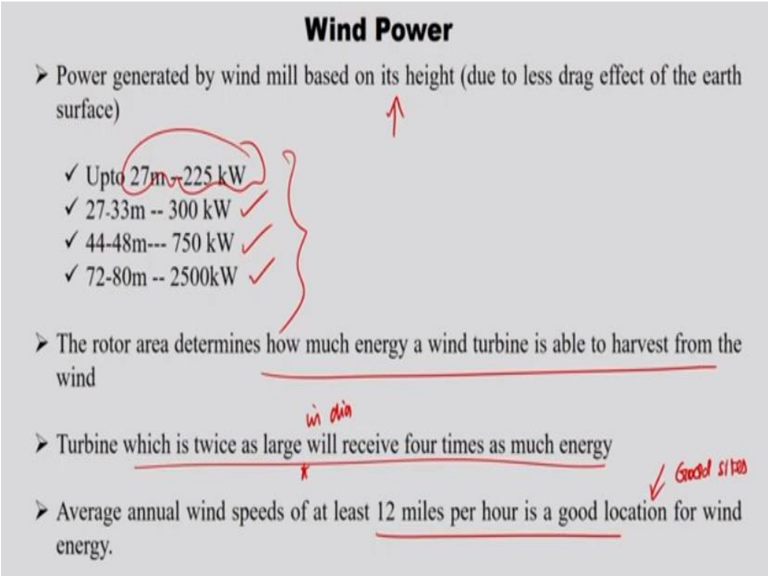

And power generated by the wind mill is based on the height we already told because up to 27 meter you would get very low power why it is because of obstacle and surface reference. So when you go 27 to 33 it is about 300 kilowatt 44 to 48 meter it is about 750 kilowatt and 70 to 80 meter if you go you would get around 2500 kilowatt it is all are approximate values. A rotor area determines how much energy a wind turbine is able to harvest from the wind this I already told.

If the turbine which; is twice as large in dia will receive 4 times much energy because it d square. The average annual wind speed of at least 12 miles per hour is a good location for the wind energy. So this is what we call it as a, good sites along with the surface features.

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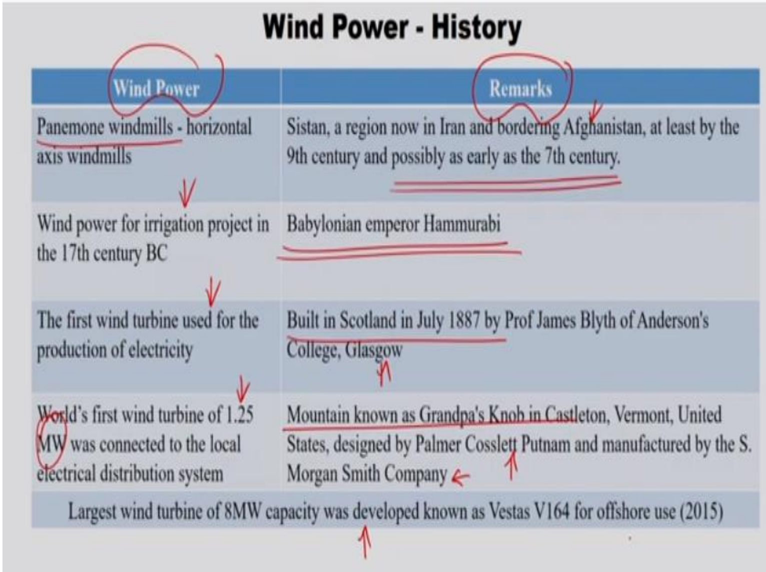

This history we have already discussed but still there are 7 BC century back. So the major one is Panemone windmills which are nothing but horizontal axis windmills so this was developed in Sistan a region now in Iran and bordering Afghanistan at least by the ninth century and possibly as early as seventh century. So we have to discuss recent one and this is back history much more back so and wind power per irrigation project in seventeenth century was developed by Babylonian emperor Hammurabi.

And first wind turbine used for the production of electricity was built in Scotland in July 1887 by Professor James Blyth of Anderson's College, Glasgow. And world's first turbine of 1.25 megawatt this is notable was connected to the local electrical distribution system. So this is an mountain known as Grandpa's Knoh in Castleon, Vermont, US designed by Palmer Cosslett Putnam and manufactured by the Morgan Smith Company.

So this I probably discussed 1.2 megawatt capacity Smith Putnam machine. And largest wind turbine of 8 megawatt capacity was developed known Vestas V164 for offshore use this is around an, 2015.

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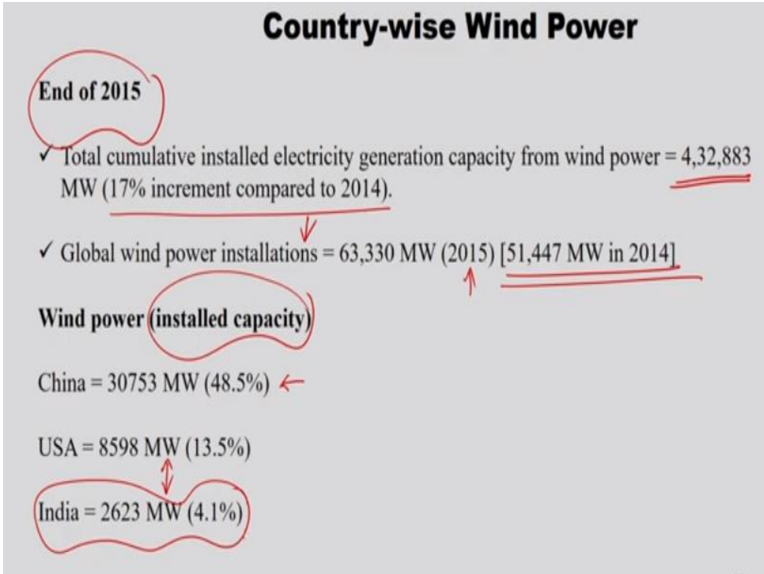

So at the end of 2015 the total cumulative installed electricity generation capacity from wind is around 4,32,883 megawatt which is 17% increment compare to the year 2014. And global wind power installations are equal to 63,330 megawatt this is also at the end to 2015. But at the end of 2014 it was about 51,447 megawatt and wind power installed capacity in terms of countries at the end of 2015 and China it is 30,753 megawatt 48.5% leading.

And USA next one 8,598 megawatt 13.5% then there are many in between but we are interested in our country India which is about 2,623 megawatt which is about 4.1%. Recent statistics you can refer to arena.

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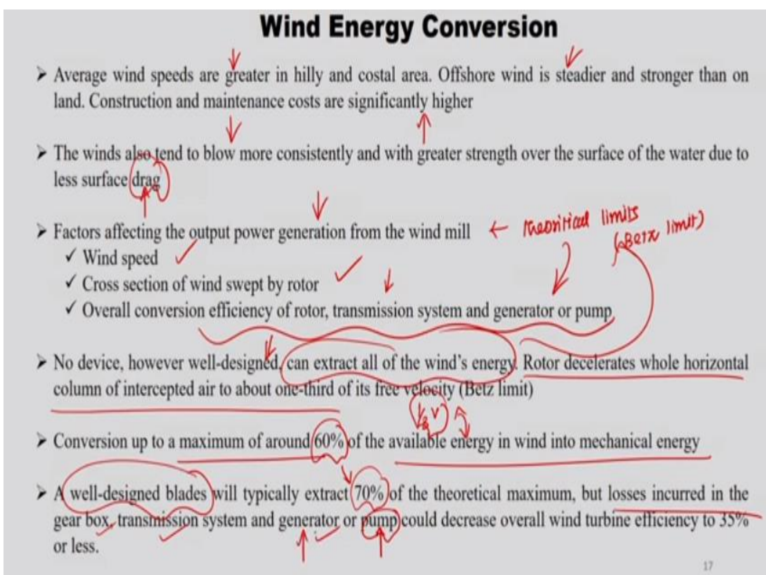

And wind energy conversion is nothing but the average speeds are higher in hilly and coastal area this we discussed multiple times. Offshore wind is steadier and stronger than on land construction and maintenance cost are slightly higher if you want to go for off shore. The winds also tend to blow more consistently and with greatest strength over the surface of the water due to less surface drag.

This is important and the fact is affecting output power generation from the wind mill or wind speed cross section of the wind swept by the rotor this we call it as the rotor area. And then overall conversion efficiency it is not there are theatrical limits further efficiency that we are going to discuss in detail called Betz limit. So out of this theoretical limit again when it goes for practical installation then you will have rotor transmission system and generator or pump. Their conversion efficiency and their losses also included in the theoretical limit.

No device however designed can exactly all of the wind energy because what we said this we are converting kinetic energy into electrical power. So what is that kinetic energy is nothing but the velocity mass into velocity square of half m v square. So if you want to convert or extract all the wind energy then you supposed to stop the wind at the rotor’s phase. But it will not happen if you stop the air over there the velocity becomes 0 and you will not have any more input air to (()) (56:49) power protection.

So because of that reason you cannot extract all of the wind energy so there is some theoretical limit. Rotor decelerates whole horizontal column of the interceptor air to about one third of its free velocity not full velocity becomes 0 it is 1 one third of the velocity so that is called Betz limit. And conversion of maximum of around 60% of the available energy in the wind into mechanical energy that is what this limit are called Betz limit and well-designed blades will typically extract 70% of the theoretical maximum.

Already theoretical maximum is 60% in that, 60% a, well-designed blades there is no losses from the blade then they can extract 70% of the theoretical maximum. But losses are incurred in the gear box transmission system generator or pump as I already said could decrease overall wind turbine efficiency to 35% or loss. So what is the generator or pump so if you want to use your wind power to pump the water then the pump losses or if you want to convert them into electrical power than generator losses that is why it is given generator or pump.

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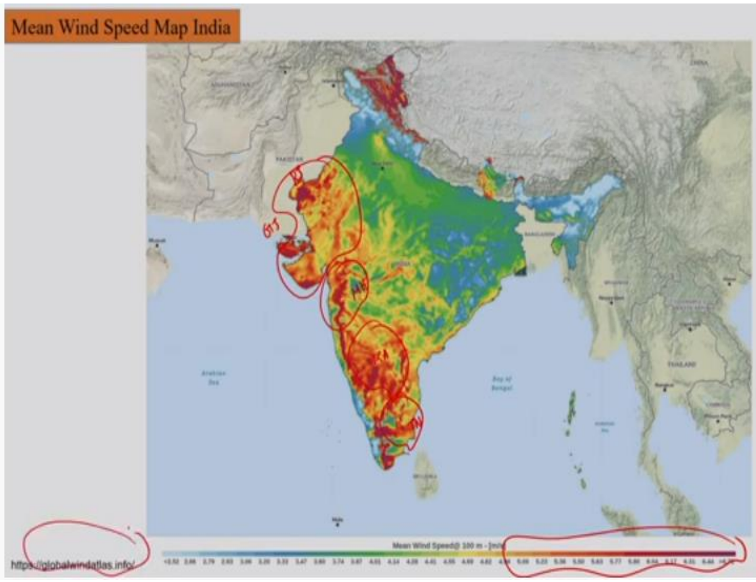

So this is mean wind speed map of India so if you see this is the large capacity so as we discussed in brief introduction. So GJ Gujarat as well as Rajasthan side and here it is Maharashtra side and here Karnataka side and TamilNadu down south. So this is having the maximum capacity for wind power protection so this is taken from global wind atlas dot info.

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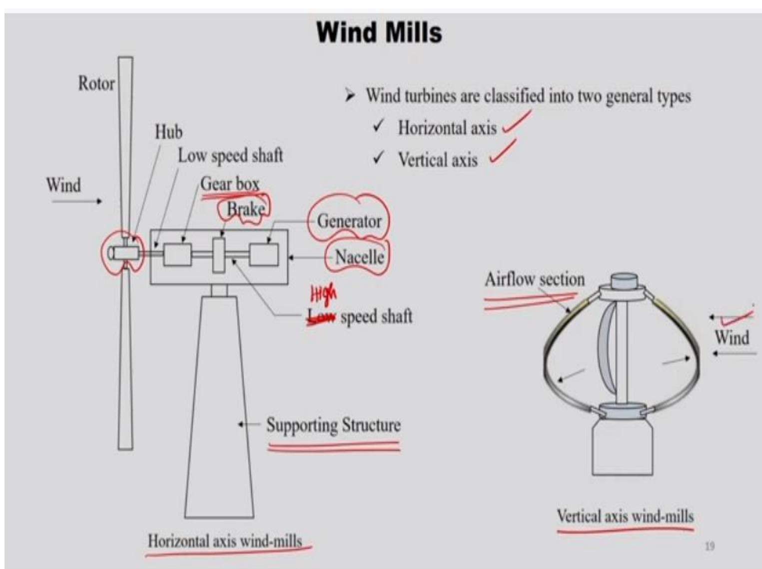

And we have already discussed in that about horizontal axis and vertical axis this is what is the system look like by now you know this are blades rotor blades are propeller. So this nothing but hub which connects the shaft the horizontal axis with the blade systems and then the next one is lower speed shaft and this probably not speed shaft this is high speed shaft. So this is high speed shaft and this is gear box so to multiple or increase or decrease the speed.

And this is the brake system in cut out speed is reached and automatically brakes the power generation. And this is the generator if you want to draw an electrical power from the wind power so this nozzle is nothing but the whole casing. So this is the supporting structure or tower as far as horizontal axis wind mills are concerned. So here only I told if you have this is there 2 blade propeller type or if you have multiple blade system the rotor only would get change.

And same time if you have a generator you draw electrical power and if you want to use this wind mill to pump the water then you will have the gear box that is what I told whether you want to use it as a reciprocating pump or centrifugal pump. If you want to use it for reciprocating pump then you have to convert rotational motion into reciprocating motion using pump rod and then you pump the water using wind mill.

Or if you want to collect the electrical power from wind power then generator is used the next one is vertical axis wind mills. So this I have already discussed the axis is vertical it is fixed and then it is perpendicular to the wind direction and so these are the propeller types.

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So these all are taken from web sources so this is single blade horizontal axis wind turbine this is double blade. This is 3 blade systems and this is half shore wind farms. Wind farms, is nothing but I discussed that 55 kilowatt capacity we combined to produce 0.5 megawatts capacity so this is now wind farm. And this is Darrieus vertical axis wind turbine and this is Gorimill vertical axis wind turbine this is twisted vertical axis wind turbine.

And if you want to see Saviours type then it is of something like this is other side so this is the way air comes and it rotates. So this is something called Savoneus type so these are all available wind will models.

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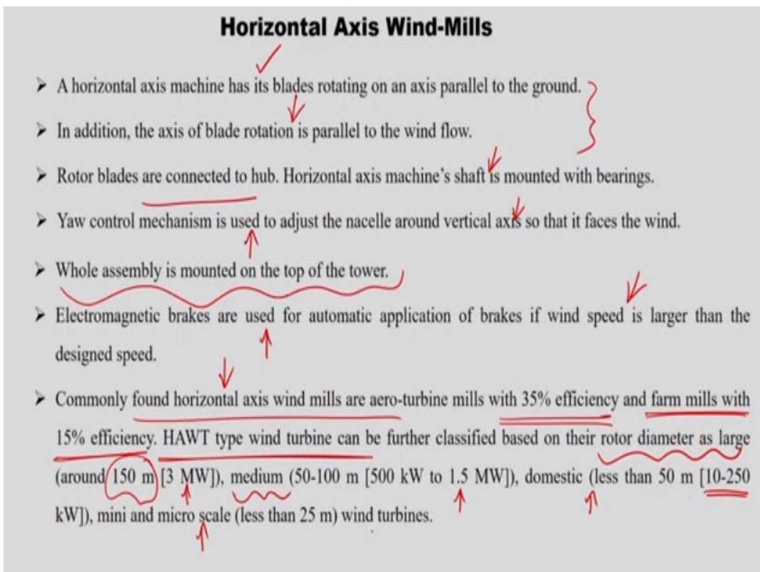

In horizontal axis wind mills this horizontal axis machine as is blades rotating on an axis parallel to the ground. In addition axis of blade of rotation is also parallel to the wind flow these 2 points we have already seen the rotor blades are connected to hub you know what is hub by now. And horizontal axis machine shafted with bearings the yaw control mechanism is used to adjust the nacelle around vertical axis so that it faces the wind.

So this is whole casing this can be adjusted so based on the wind direct not direction so where you get maximum wind power. So yaw control mechanism is used to adjust the nacelle to adjust the vertical axis. So that it faces the wind directly and whole assembly is mounted on the top of the tower this is supporting system. So the main thing is hub which connects the rotor blades then after that you have a whole casing in that all transmission system etc., is there.

And yaw control mechanism is the one which adjust the nacelle around the vertical axis the electro-magnetic brakes are used for automatic applications of brakes, if wind speed is larger than the designed speed that is what we call it as a cut out speed. And commonly found horizontal axis wind mills are aero-turbine mills which has the efficiency of 35% and farm wind mills of having 15% efficiency. Because the horizontal axis wind mills are popular one in terms of efficiency and we will see the advantages and disadvantages.

And horizontal axis wind turbine type can be further classified based on their rotor diameter as large rotor diameter which is about 150 meter which draws 3 megawatt capacity power. And medium rotor which is 50 to 100 meter which draws power of about 500 kilowatt to 1.5 megawatt and domestic one which are less than 50 meter and which draws power about 10 to 250 kilowatt. And then we have mini micro scales as well which are less than 25 meter proto diameter which draws less than at 10 kilowatt power.

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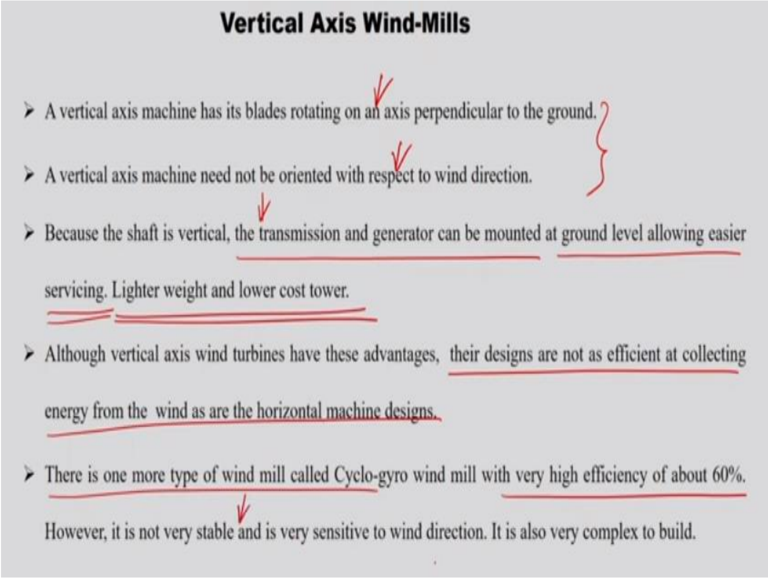

In vertical axis machine they are having their blades rotating on an axis perpendicular to the ground and vertical axis machine need not to be oriented with respect to wind direction. This we have already seen and because the shaft is vertical that transmission and generator can be mounted at the ground level allowing easier servicing. So for horizontal machine you suppose to keep it in the higher height with the supporting structure.

But 1 advantage is because the shaft is vertical you can have transmission system as well as generator in the ground level itself. And lighter weight and lower cost tower but although vertical axis wind turbines have these advantage of the maintenance or servicing or in terms of weight and cost their designs are not as efficient as collecting energy from the wind as are the horizontal machine designs because they are kept in the direction of the wind only.

So efficiency wise horizontal axis winds turbines are good but in terms of maintenance and flexibility one can go for vertical axis wind mills. There is one more type wind mill called a cyclo-gyro wind mill with high efficiency of about 60%. But however it is not very stable and it is very sensitive to the wind direction. It is also very complex to build.

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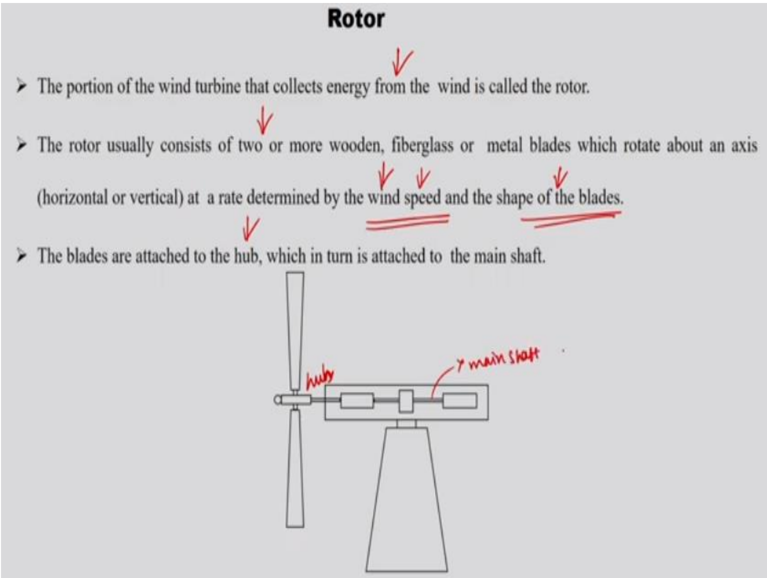

And this is again few points about the various components of the horizontal axis wind machine. So the rotor is the portion of the wind turbine that collects energy from the wind is called rotor. And the rotor usually consist of 2 or more wooden fiber glass or metal blades which rotate about axis horizontal or vertical based on the wind mill at a rate determined by the wind speed and the shape of the blades.

This is important wind speed and the shape of the blades that is why we have many designs because wind speed you cannot control it is a natures thing but how to draw maximum power you can do it by using shape of the blades. The blades are attached to the hub this is the hub which is again attached to the main shaft so this is main shaft.

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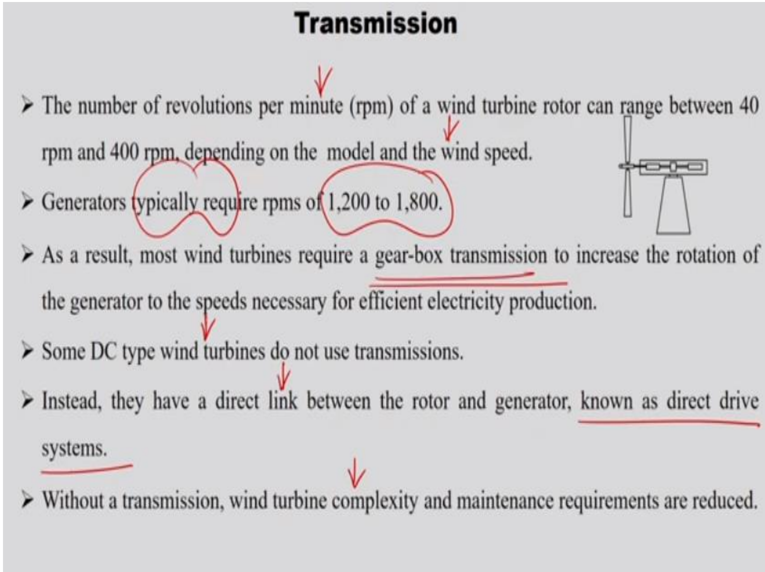

The transmission line the number of revolutions per minute of a wind turbine rotor can range between 40 to 400 rpm depending on the model and the wind speed. But generator typically the require rpms of around 1200 to 800 so which can help us that is nothing but a gear box transmission to increase the rotation of generator to the speed necessary for efficient energy protection.

Some DC type wind turbines also their which do not use transmission boxes instead they have a direct link between the rotor and generator known as direct drive system without transmission wind turbine complexity and maintenance requirements are reduced. In that way the DC type wind turbines are good but the thing is that what power we require is AC probably when there should be convertor as well.

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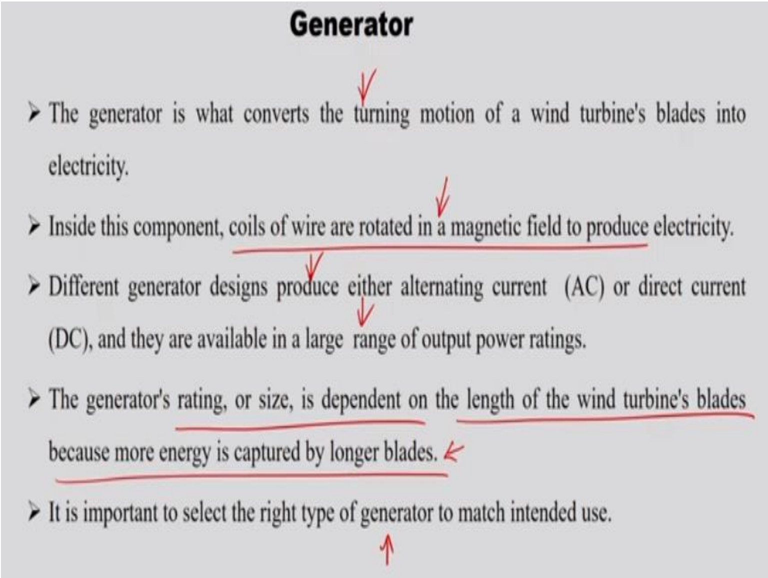

So the generator is what converts the turning motion of a, wind turbine blades into electricity. So instead this component of generator there would be a coils of wire rotated on a magnetic field to produce electricity. This you might have heard all these things in your school level physics we are not going in detail anything about electrical energy protection part of this wind energy system. So the different generated designs produce either alternating current or direct current and they are available in large range of output power rating.

The generator rating are size is depend on the length of the wind turbine blade because more energy is captured by longer blades. If more energy is captured so you need that generator for electrical output. It is important to select the right type of the generator to match the introduced it is based on the designer who designs convert the wind power into electrical power.

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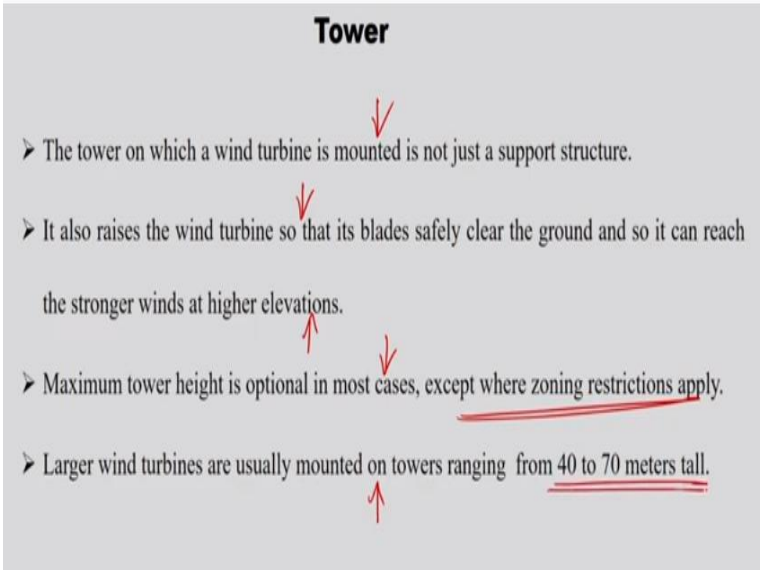

So tower is nothing but on which wind turbine is mounted and is not just a support structure it also raises the wind turbine so that it blades safely clear the ground and so it can reach the stronger wind at the higher elevations. So that is not only support structure it also helps in getting more wind power maximum tower height has optional in most cases except where zoning restrictions apply this also we have seen during the obstacles sections of the zones.

And larger wind turbines are usually mounted of towers ranging from 40 to 70 meters tall. So this normal height so this also we have seen height versus the drawing power so this mathematical expression governing the wind power we will continue in our next class.

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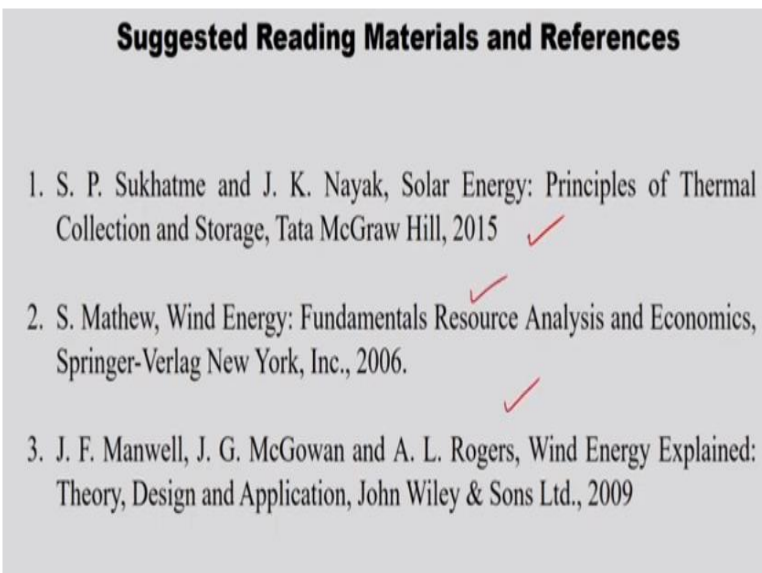

Reference used for this particular lecture is these 3 references Sukhatme and Nayak solar energy principles thermal election and storage and S. Mathew fundamentals resource and analysis and economic and Manwell (()) (1:09:58) wind energy explained theory design and applications thank you.