Power Plant Engineering
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Lecture – 32
Wind Energy

Hello, I welcome you all in this course on Power Plant Engineering. Today, we will discuss another nonconventional of energy source that Wind Energy.

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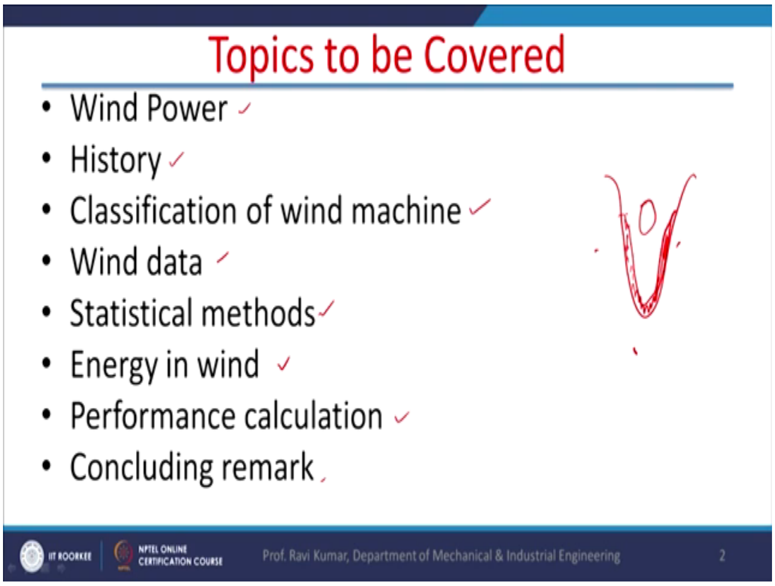

In wind energy, we will start with the Wind Power; what is wind power; then history of wind energy has very interesting history; classification of wind machine; wind data; wind data are very typical in a statistical method of generating wind data; energy in wind performance calculation and concluding remark about the wind energy.

In India, the wind energy has limited sources because it is a India subcontinent or the India country as a country three sites it is it has ocean. So, near the this ocean boundary here. We can have the wind power in somewhere in the central India also, there is a possibility of the wind power. So, possibility of wind power are limited in our country, but it is another non conventional energy source.

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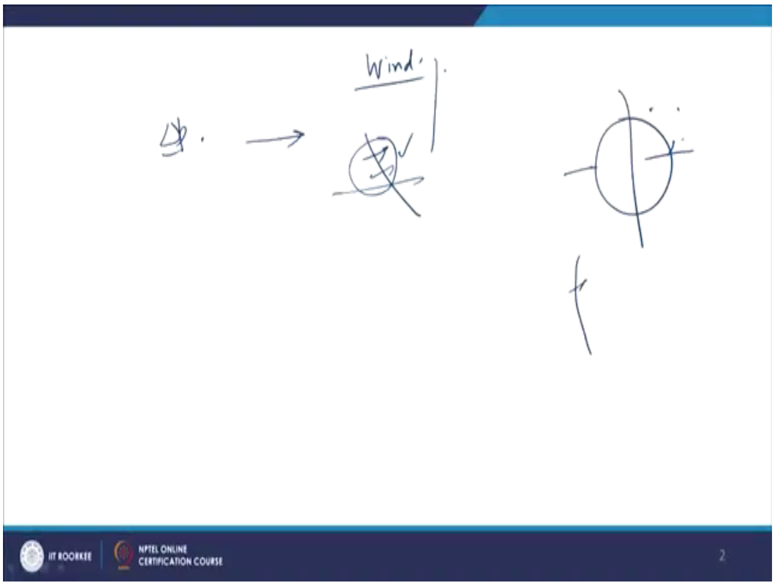

Now, the wind how the wind is caused first of all?Let us understand the mechanics of the wind; how the winds are generated.

Now, winds are generated because the solar radiation is not uniform on the earth surface right. So, and in the night in one part of this earth, there is night, there is no solar radiation and other part of the earth, there are solar radiation. And these radiations, they keep on changing with time and with date. So, this causes difference in density of the fluid or the density of the air or pressure difference and this pressure difference drives the wind.

Now, this moment of the wind is also not very predictable. This moment of the wind keeps on changing. It it's like solar radiations throughout the day, we will have different wind velocities and throughout the year also we will have different velocities. But if you go by the probabilistic model, there is a probability of predicting the solar radiation is I mean very close to the real; the real world if you compare with the probability of wind.

So, wind is if you compare the predictability of the wind and the solar, the wind is more unpredictable right. So, these are the factors, these are the I mean riders which restricted the use of the wind power. Wind is a diluted power right and it is more diluted than the solar power. So, that is why if you look at the wind power plants; wind power plants, they are huge in size; they are huge in size so that there is a continuous supply of the power right.

There normally the fan or the wings, they normally move in let us say the rotor which normally moves with the 30 rpm, 28 rpm, 40 rpm, 45 rpm; so rpm are less. So, that is where the plant has to be big bulk of the fluid has to be handled in order to generate the power.

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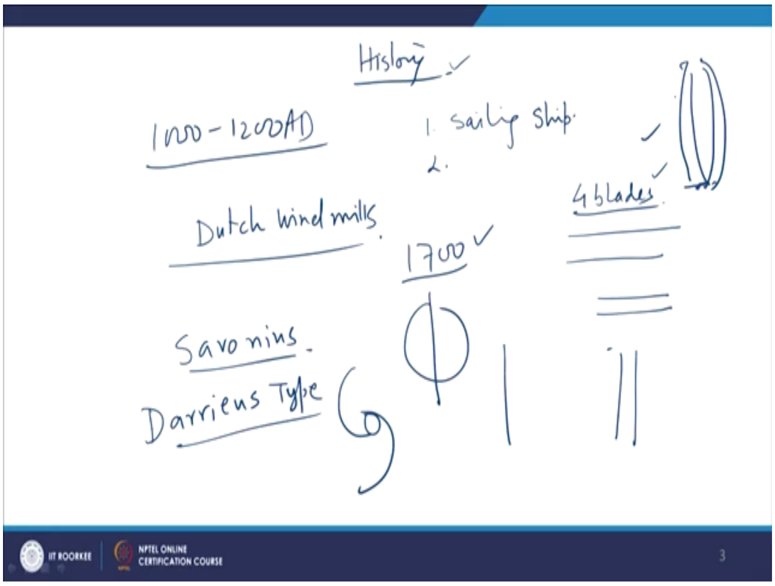

Now, wind has wind power has a very interesting history. Wind power in old days maybe 1000 to 1200AD, during this period, it was not used for power generation, but wind power was definitely used for some other purpose mainly for sailing the ships; that is where the one of the major application of wind power was sailing the ship. Sailing ships or pumping water, crushing some material for this purpose windmills were used and the earliest wind will mills for Dutch windmills. Dutch windmills, they have typical windmills with a horizontal shaft has 4 blades.

Now, these wind mills when in the Dutch they started spreading their business and it is throughout the world and it came to us in around 1700 and after that enormous development took place in this technology of solar; solar wind power generation. These solar power sorry not solar power, wind power generation. So, the wind turbines, they are horizontal; rotor, they have with vertical rotor also. There are two typical geometries. So, one is type of blade arrangement.

It is nothing but two cylinders if you take, a cylinder cut into two pieces and you fix those pieces over a shaft. So, this type of arrangement is known as Savonius type of arrangement another is Darrien's type. In Darrien's type of arrangement, it is the blades like eggbeater you know the omelet, we use beater for the for making omelet out of the eggs, so it is of that shape beater shape. And this is also if one of the configuration which is used for wind power generation.

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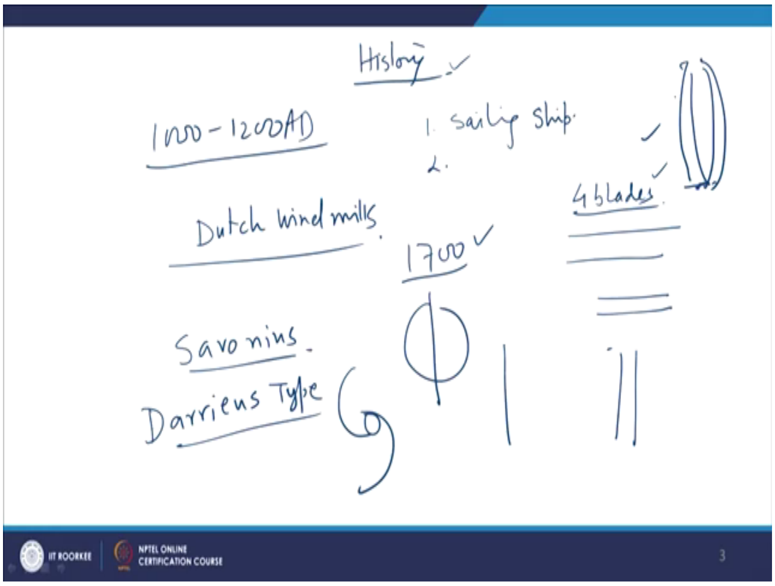

The benefit of the wind power is does not pollute the atmosphere, not pollute right fuel is not required; no fuel right. Of course, it is renewable. Say as long as the earth survives wind will be there. Sun will survive approximately 10 to power 11 years. So, we do not have to bother whether it is a solar energy or the wind energy, we do not have to bother about the source.

Small scale, if you go for small scale it is cheap, but if you go for the large scale it is comparable with the convention power plants. The drawback; the major drawback of this is effective fluctuations; it is fluctuating because the wind velocity does not remain same. So, it keeps on fluctuating that is the major drawback.

Storage device is beaded in the form in a battery or some other device which is which can be used for the storage of the energy and wind it because you say it is a gaseous fluid. So, it makes a lot of noise. Not lot of noise, but noise considerable noise is there. So, I am mean the if you go near the windmills, you will find there is a noise. We can call it a noise pollution also.

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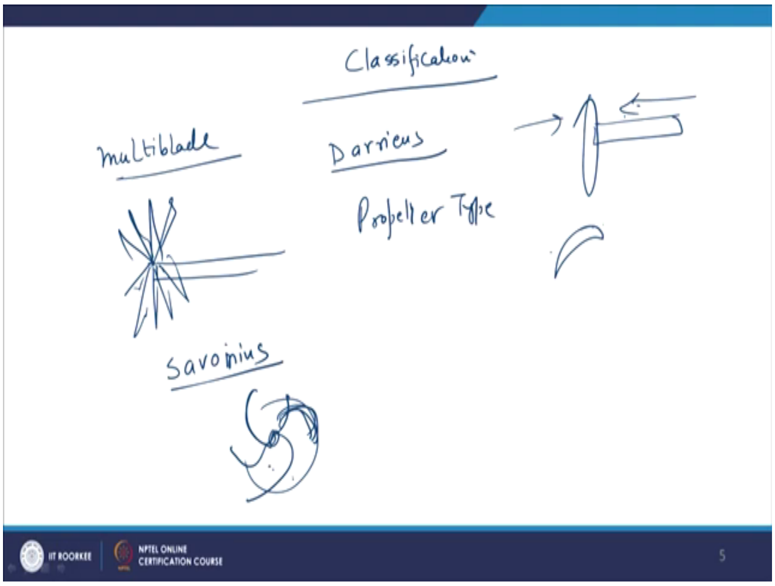

Now, it is sort of a noise pollution also. Classification of machines; first of all horizontal and vertical. So, when the machine is horizontal, there can be two arrangements. This side there are blades; air is entering from this side and the air is coming from this side; there can be two arrangements. There is a multi blade type of system; in multi blade on a rotor, there are blades and they are multi number of blades which are fixed on the rotor. This is known as multi blade type of system right.

Savonius, I have already explained; there are the two cylinders cut in half pieces, we can have 4 also, but it is a half-circle of a cylinder. They are fixed on the shaft and the wind is blown and its shaft is vertical. When the wind is blown, this these cylinders because pressure difference is developed between the leading and the tailing edge and that is that causes the movement of the cylinder in rotational direction.

There other type is Darrien's; Darrien's also I explained you earlier and propeller type. So, propeller type, it has air foil type of shape of the blade and the number of the blade it varies from 3 to 4 to 5, they can go up to 6 to 8 also. So, there are different type of machines based on the basically based on the configuration of the blades.

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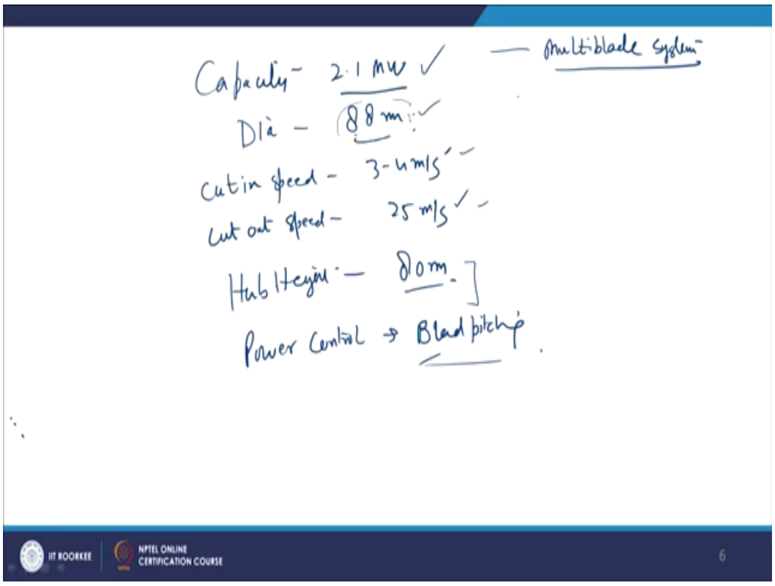

Now, if you take a multi blade type of machine; typical multi blade I will give you an idea suppose the capacity is 2 mega Watt; 2.1 mega Watt, it is multi blade type of system. In a multi blade out the system, where capacity is 2.1 mega Watt that will have a dia of 88 meters. It is very common in windmills the diameter of the order of 175 feets or 200 feets.

So, it is dia this is 88 meters cut in wind speed, cut in speed. This is wind speed that is 3 to 4 meters per second. Another is cut out, 25 meters per second. It means if the speed of the wind is less than 3 meters per second, the turbine will not generate power and when the cut out speed with the speed is 25 more than 25 meters per second that may damage the turbine. So, turbine will not generate the power right.

Hub height? Is 80 meters; height of the singular storage houses approximately 3 meters; 3 to 4 meters. So, 20-25 meter, it is the height maybe up to 20-25 is storage building right and now, power control. It is by blade pitching right. So, you can imagine the size of a multi blade turbine where the capacity which is generating 2 big or 2.1 mega Watt. The diameter of the blade I mean is 88 meters, cut in speed cut out speed and how are it is its a it is a quite huge structure for generating such power. Now, what happens in a wind energy that is major restriction is a variation in the wind velocity.

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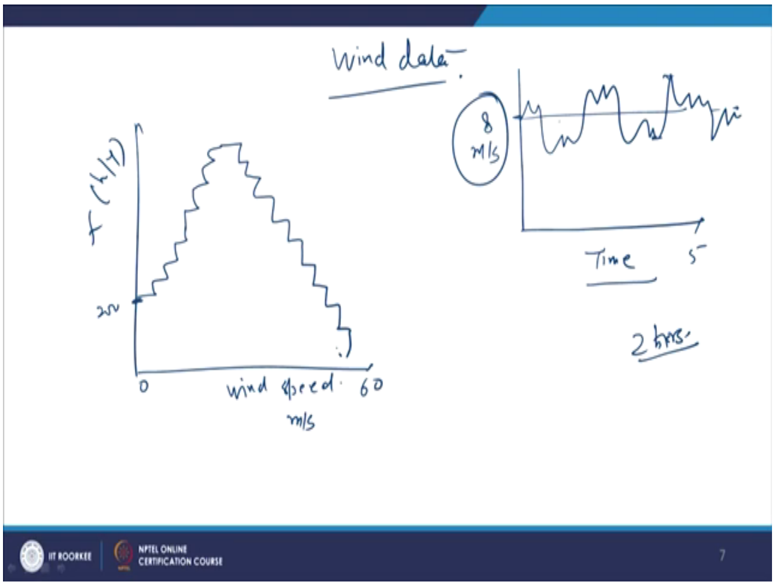

So, wind data are very important right. If you take for example, if you collect the data for a duration of 5 hours and normally the speed is 8 meters per second. So, you will not find a constant speed, the speed will keep on changing and you will have to take average of this speed and you will have to take account into account the range of this speed also right.

So, we have generated data speed versus time in minutes. So, 5 minutes we have taken the what is the variation in wind speed. Normally, what we do? We take average of 2 hours.

Average of 2 hour is done and frequency, a graph is plotted in frequency right that is and wind speed hour per year, frequency hour per year and wind speed on this side.

So, wind speed let us go up let us assume it goes up to 60 meters per second which is rare right and it is starts from 0. So, let us say for 200 hours it remain 0; for 200 hours it remains 0 and there is then 2-2 hours, we can have a graph like this frequency graph. Because now what we are doing, we are trying to represent the wind data in a scientific manner, so that some useful information can be drawn which can be used for generating the wind power. Now, with this 2-hour average, we can draw the cumulative frequency curve.

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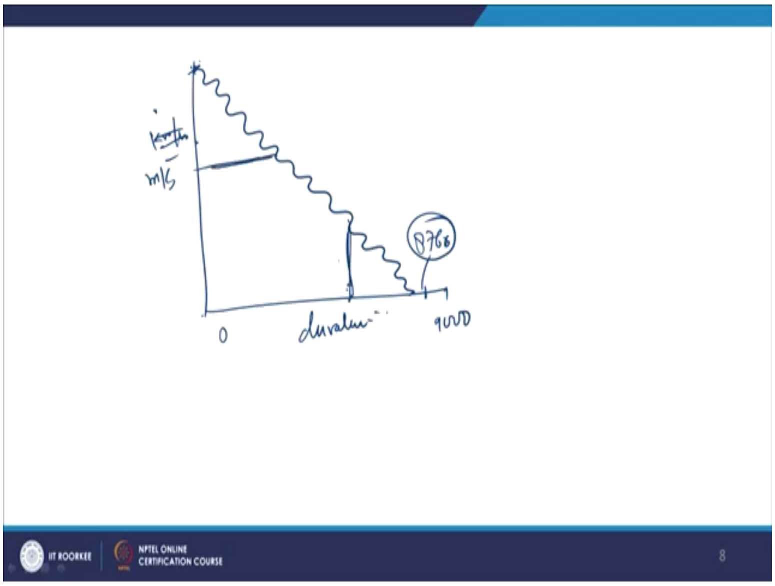

So, if you draw the cumulative frequency curve, it is going to be like this 0 to it is 8760, 9000 right. So, cumulative frequency curve is going to be like this. It is not a straight line, it may be a curve also right kilometers per hour; soduration. So, for this high suppose it is meter per second, let us say meter per second; this high meter per second, the duration is 0 right.

And then, the speed is reducing and for 0 meter per second, there has to be some it. So, it is a cumulative type of frequency we are getting here and because in a year there are 8760 hours right. So, for 8760 hours, we will get a cumulative frequency curve and now, this curve can decide in which part of the curve, we have to design our turbine. So, this is cut in and this is cut out. We will discuss this later on right.

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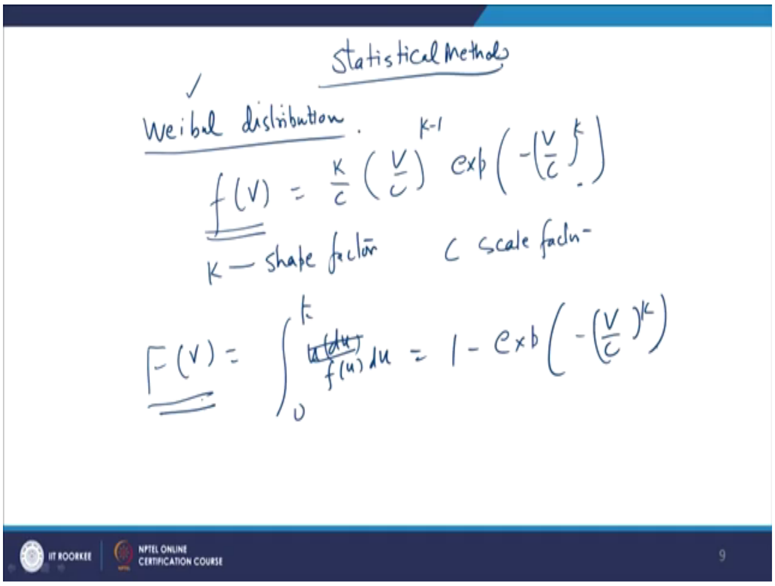

Let us switch to this statistical methods or they are certain statistical method because we cannot have wind data everywhere for every place. So, there has to be some statistical methods to have idea about the profile of the wind. So, there is a distribution, this is known as Weibull distribution. Now, the distribution of the wind pattern or distribution pattern of the wind velocity is normally very close to the prediction of the Weibull distribution and that says function of velocity is equal to K by C V by C K minus 1 exponential minus V by C raised to power K.

So, this is a probability density function K is the shape factor. C is the scale factor right. Now, if I want to have cumulative distribution that is going to be f v 0 to f u d u sorry this is f u d u is equal to it will be 1 minus exp raise to power K. So, this is cumulative a frequency distribution. If you compare the pattern of the wind, wind pattern it matches very closely matches with this distribution.

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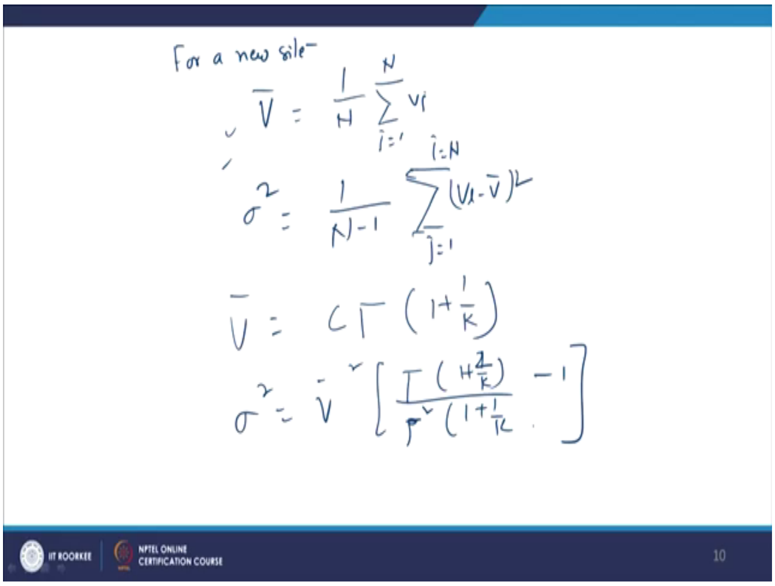

Now, for example, for a new site; average velocity is going to be equal to 1 by N V i; i is equal to 1 to N. Then, N can be hours or days and there are two things. In any statistical distribution, there are two things; one is average, another is standard deviation is going to be N minus 1 sigma V minus V average whole square i is equal to 1, i is equal to N.

If I mean these are the two values; if these twos values are with us, we can easily find the distribution of the wind pattern. Now, V bar is equal to C lambda 1 plus 1 by K and this is equal to V bar square gamma function 1 plus 1 by K divided by gamma function square 1 plus 1 by K. This is 2 by K minus 1 right. So, these are certain statistical distribution which can be used for predicting the wind pattern in any locality.

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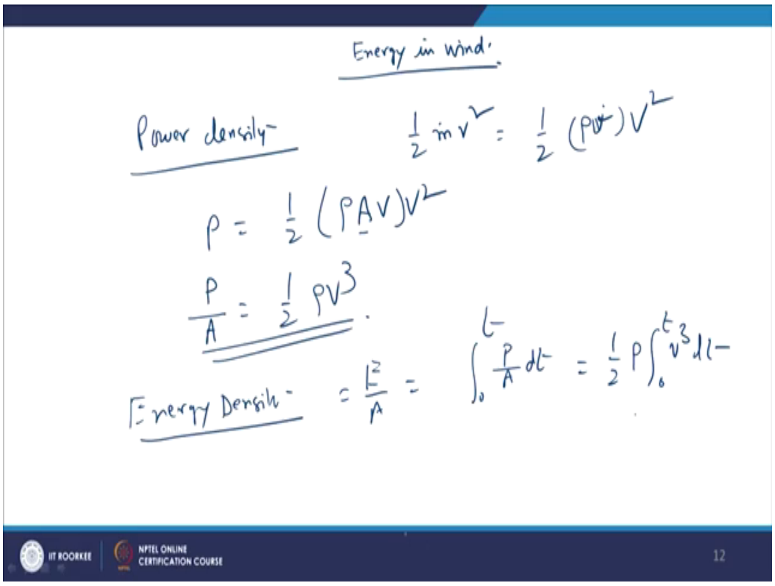

Now, energy in the wind, now energy in the wind, the one term is power density; power density. So, wind has kinetic energy that is half mv square and m dot is the mass flow rate. Now, if we take the mass flow rate, then half mass flow rate is the density into volumetric flow rate; volumetric flow rate V square v is the velocity; small v is the volume.

So, power is equal to half rho A V into V square. Now, power by area is equal to half rho V cube right. This is known as power density power per unit area. Now, similarly there is energy density. Energy density is energy per unit area. So, we will integrate 0 to t P by A dt is equal to half rho 0 to t v cube dt.

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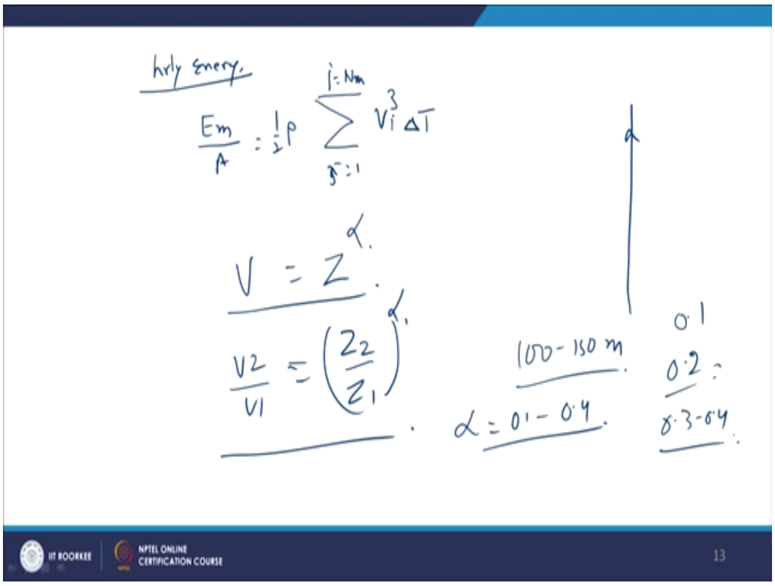

Now, hourly energy; hourly energy contains. So, E m divided by A is equal to half rho; i is equal to 1 and i is equal to hour is equal to v i cube delta t. So, this is hourly and if you want to do monthly, we simply take monthly data right. There is a power law also if we move to a height, the velocity will change right and there is a power law that is velocity is equal to Z raised to power alpha.

So, V 2 by V 1 is propositional to. So, V 2 by V 1 is propositional to Z 2 by Z 1 raised to the power alpha. This is varied up to the height of 100 to 150 meters, not more than that and the value of alpha is 0.12, 0.4. So, normally if you go to the field, it is smooth field is smooth, it is 0.1 right. If there is a rough (Refer Time: 21:17) and there is a jungle right, it would it can be up to 0.2. If you come to the cities, in cities it can be 0.3 to 0.4 right. So, this is the power law for the height.

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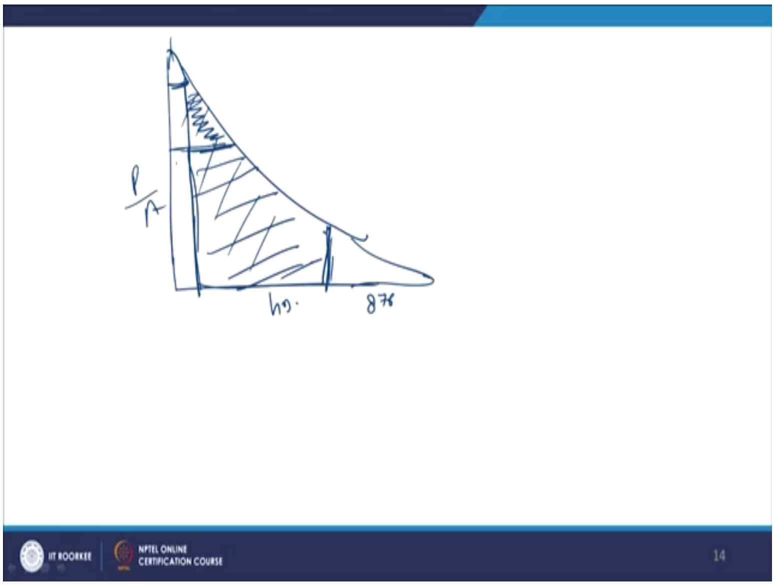

Now, let us go back to the design of a wind turbine because wind every power generating system has to be designed for a particular rpm and it is effective in a particular range only. So, if you take the cumulative frequency like this power density, power divided by density and this is hours and 8760 right.

So, this is cut in speed and this is cut out speed right. This is suppose this is cut in speed and this is cut out speed. So, this much is available is still because we want to have less fluctuations we will sacrifice this part also. So, effectively this is the part which is available with us for the design of a typical machine or the typical wind turbine right.

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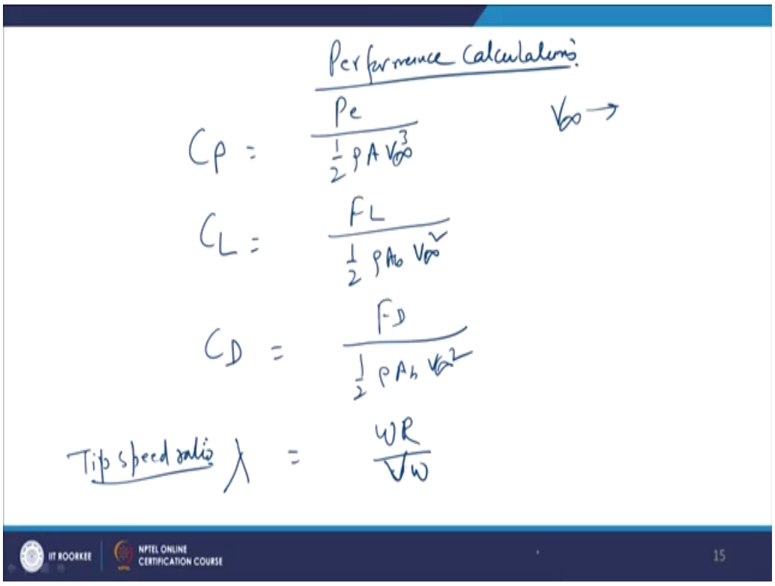

Now, for judging the performance of a wind turbine performance calculation. There is a performance coefficient because normally the performances are judged through the coefficients. So, performance coefficient that is the electrical power generated divided by half rho A V infinite cube. V infinite is the normal velocity of the wind which is passing through the turbine and there is a lift coefficient CL. It is equal to lift force divided by half rho Ab, this is v infinity square.

There is a drag force CD; it is F D half rho A b V infinity square and tip speed ratio that is lambda omega R by V w that is known as Tip speed ratio or normally, we call it a speed ratio.

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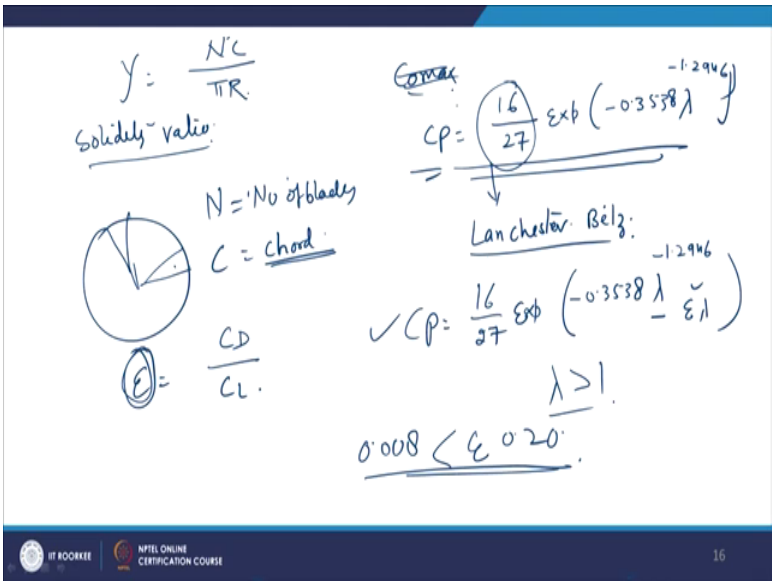

Now, there is a solid ratio also or solidity ratio not solidity ratio and solidity ratio is N C upon pi R. It is the ratio of the blade area, suppose in a turbine part of the circumferences plotted with the blades. So, it is the blade area and total frontal area that is known as a solidity ratio.

If it is the entire day its going to a solid ratio is 1 and N here N is the number of blades and C is the mean chord length; chord length of the blade right and there is a term epsilon, it is lift drag coefficient by lift coefficient. This epsilon is very important parameter in designing a wind turbine. The Co max or we can say the Cp maximum power coefficient can be calculated as 16 by 27 exponential minus 0.3538 lambda raised to power minus 1.2946.

Now, if you take into training this is a simple formula, this formula was proposed by Lanchester Belz; Lanchester Belz. Now here, the drag is not taken into the ground drag because when there is a rotation in the turbine hub, drag will also develops. So, the Cp is going to be coefficient of power is going to be 16 by 27 exp minus 0.3538 lambda raised to the power minus 1.2946 minus epsilon lambda. That is why epsilon is very important in judging the performance of any turbine.

It is valid only for when lambda is greater than 1 and epsilon is in the range of zero-point epsilon is in the range of 0.008 to 0.2. This is valid for that only.

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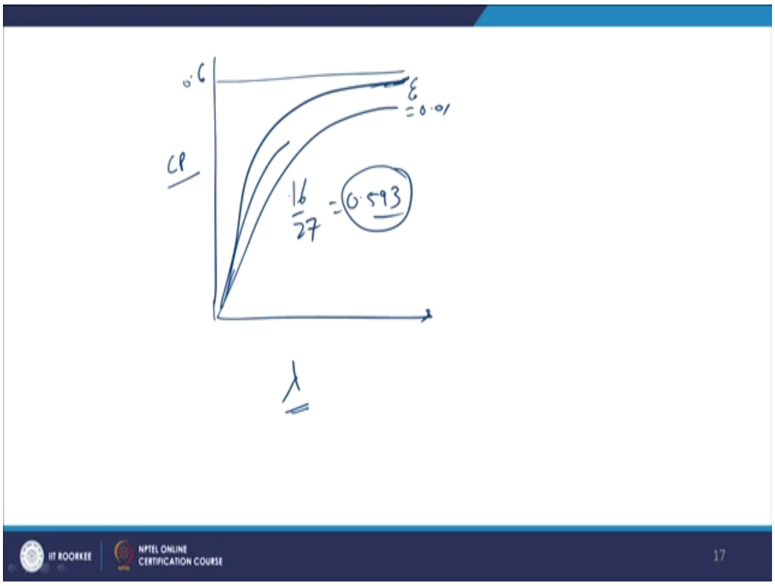

Now, if we take into the account, then and if you draw the graph between C p and tip speed ratio lambda and coefficient of power coefficient Cp; Cp is power coefficient and this is tip velocity ratio and this is 0.6, we get a graph like this. And when the value of drag coefficient epsilon, this is epsilon; now this is epsilon is equal to 0.01 and when epsilon keeps on increasing.

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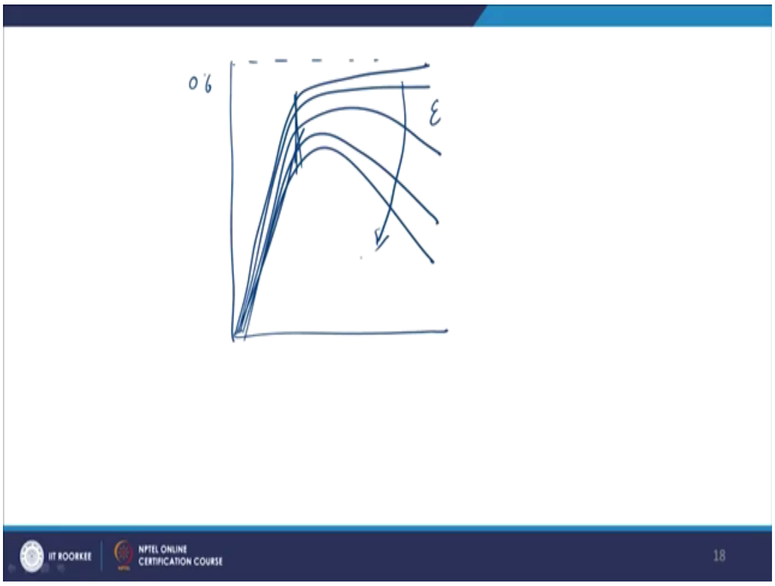

Now, suppose no not like this. Its curves are like this and we are getting maximum here. And for this maximum value, we have used this equation. We can have from if you look at this equation, we can have the maximum value of 16 by 27; 16 by 27 and this 16 by 27; the 16 by 27, it turn out to be 0.593.

So, this maxima cannot be is more the 0.6 and it will remain 0.593 right; but as the value epsilon will keep on increasing, the value of epsilon keep on increasing, this performance is start going down ok.

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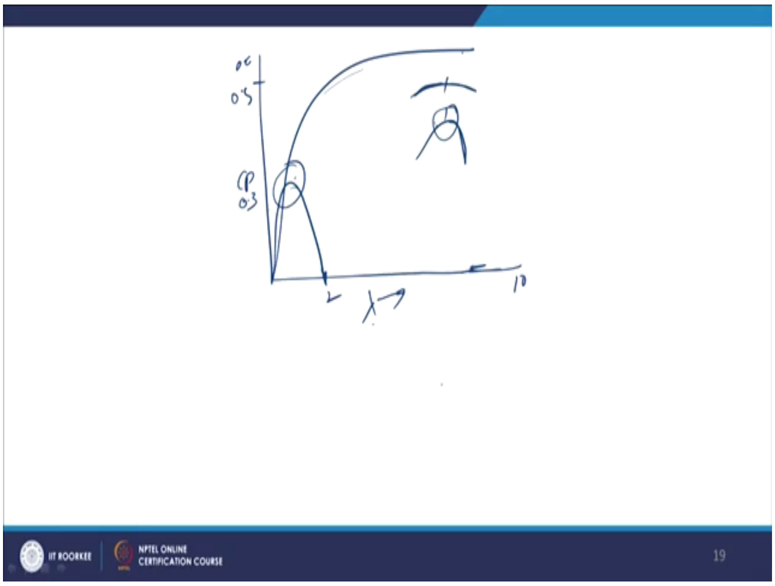

Now, variation of power coefficient Cp with tip speed ratio Cp with tip speed ratio lambda. So, propeller type of turbine it is ok, it goes like this. Savonius this is 0.6, but if you look at the Savonius, it will be something like this. It will go up to 0.3. Now, if you go for the high speed propeller it will be so this is 8, we can go up to 10. So, high speed on this is 0.5; high speed blade will be falling somewhere here; Darrius will be falling somewhere here; Savonius will be falling somewhere here, but the propeller will give you this performance.

So, depending upon the application, we can go for different type of turbines. So, in all the cases power coefficient passes through a maxima. We will getting maximum in all the cases and the propeller type is covering a vast range right and Savonius type of for low lambda and Darrius type of is used for the high value of lambda right.

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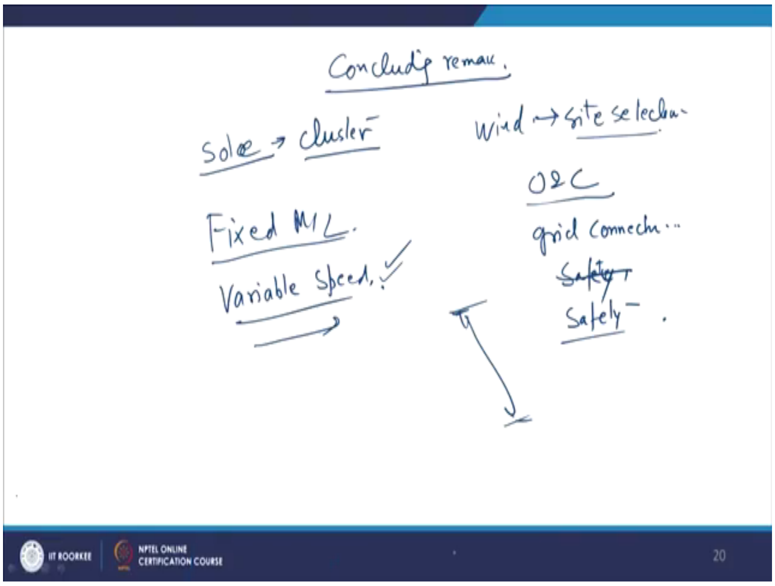

Now, the concluding remark. Now, concluding remark for the wind energy is it can be installed as solo, sole or solo or sole and cluster. They can be installed in a cluster also and you must have seen on the seashores there are there are cluster of windmills, Site selection is very important in case of a wind power; site selection right.

Operation and control; operation and control, grid connection and safety also because they are huge if structures. So, safety is also important. Now, there are two types of machines that is fixed machines and another is variable speed. Nowadays, variable speed are becoming common because if you go for the variable speed, then you can trap energy in greater range of wind energy.

Fixed type of machine, you have to sacrifice certain range of the wind energy. So, variable speed type the control is complicated and they are costly also. But in spite of the fact, nowadays the manufacturers are going for the variable speed type of machines. The another risk is the risk for the birds, these the windmills are their risk for the to birds. Land uses is also because they need a lot of land area. Noise is also an issue with the wind turbine and electromagnetic interference, this is also issue with the wind turbines.

But nowadays, the application of or the use of wind turbines is increasing as it is a nonconventional energy source and it does not require any I mean the recurring cost is low if you compared with the conventional system. The fixed costs may be high, but the recurring cost is definitely low for the wind power systems. That is all for today.

Thank you very much.