Non-conventional Energy Resources
Prof. Prathap Haridoss
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Madras

Lecture – 24
Wind Energy Design considerations

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Hello, today we continue our discussion on wind energy and in fact, we will wind up our discussion on wind energy we will sort of wrap things up with today's class. And in the last few classes we have looked at the whole wind energy concept and the area, from a wide range of different perspectives. So, we looked at economic aspects, we looked at geographical aspects, we looked at environmental aspects, scientific aspects associated with it and technological aspects. So, you really have to look at all these aspects to get how you know much more complete you know feel for the feel field, when you make a decision long term decision on any particular technology.

So, I for example, I also told you know this long term is a very important thing and the idea of you know looking at a technology from it's starting point to it's finishing point, it is also another very important aspect when whenever you are discussing any kind of technology, which you want to put out as a mass market application technology.

So, for example, we discussed specifically about the blades for the windmills, and the fact that they are presently being made out of composite materials; and so, it is very important that the composite material have a pathway for you know eventual reuse or recycling, that is you know somewhat reasonable, that you can do without creating a situation where the amount of chemicals being used and you know maybe perhaps wasted or released into the environment, during just the manufacture of the windmill being so high that it destroys the purpose of putting a windmill up therefore for clean energy.

So, this kind of what they refer to as cradle to grave kind of analysis has to be done with any technology; not just windmills just any any technology because often the first thing that we see about the technology, often looks very promising and it that may also be a good thing to notice, but then we have to do this kind of analysis to understand if there is any other aspect of the technology where you need to tighten up. And it may just be quite possible that once you identify that problem you can solve it, and then after that the technology right from the beginning the cradle stage to the you know till it is finished off and has to go for recycling, that entire lifecycle of that technology is a clean life cycle and then you really have made a big difference.

So, that's the kind of point of view we have to take. So, with respect to wind energy as we said you know, it's clean because it is just wind it is already there you are not really burning anything to create this energy or any such thing it was already there, and in many ways it is a it's a variation of the solar energy because the solar energy heats the atmosphere, and then you get these various you know densities at various locations of the atmosphere, and then you will have a weather pattern that develops. And based on that and location of you know planes, location of hills, mountains etcetera you have pathways for wind and so, accordingly you can know tap the wind energy. We saw how it the amount of power in the wind depends on the cube of the velocity and therefore, high velocities are very nice. And we also saw these issues like I said about the how the blades are manufactured, how the tower is manufactured and that you know the various materials are being looked at for all of these things, the idea that you can use permanent magnets, but then you need to have a lot more of neodymium, which may not be easy to get. So, all these issues have to be looked at as a totality to completely utilize that technology to be aware of what is the weak point so that you can simultaneously keep addressing that weak point, because it is also true that you may never find a technology which has absolutely no weak points.

So, you will have some weak point, you have to be aware of it, and keep addressing it as you go along so that, it is no longer a show stopping weak point. It may still be something that is not the best that you are expecting it to be, but it will not be something that people who look at some years down the line and say you should never even have taken this path right. So, that is something that we have to be aware of. So, as I said if are going to put out hundreds of thousands or millions of windmills out there, then it is important to know what is the path for recycling those blades.

Because if you put out a win a million windmills and if they are all three bladed windmills, you have three million you know wind blades that are out there that you have to do something about once they complete their life cycle. And these are very long blades these are you know 60 meter blades maybe 70 meter blades eventually will come. So, these are long objects these are not some small things that you can pack and you know hide it away somewhere, you have to deal with them you have to do something about it. So, that’s an aspect that you have to look at.

So, in today’s class we will actually as I said you know sort of wind up this discussion on wind energy in particular we will look at some things associated with some overall design considerations. Overall design considerations for the windmill and see what sort of thought process is involved there, what kind of you know options are there maybe we are not fully aware of all those options. So, that kind of an discussion we will have little broad based discussion, which puts some perspective on the technology as a whole ok.

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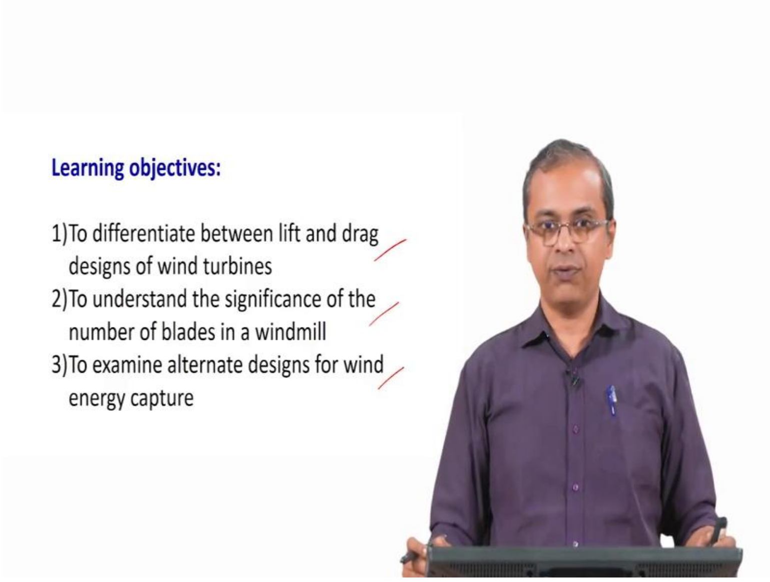

So, our learning objectives for today's class are to differentiate between lift and drag designs of windmill. So, this is something that we have briefly discussed actually in in in one of our earlier classes, that first of all that there are these variations in the design.

So, although you see a windmill and you just see something moving as a result of the wind that is blowing. There is large amount of difference that exists between one type of windmill and another type of windmill, in terms of the ability of that windmill to effectively capture the energy available in the wind. So, all of them will capture some energy, it's not that they were not going to capture some energy there as long as there is something that is you know stable and has a you know predictable or a consistent way in which it moves, we can always attach a generator to it and then tap that energy and that's basically what is being done. But for various considerations they may have done one design versus the other, but each design has some specific advantages and disadvantages and in that context there is a difference between water considered as lift based designs versus drag designs. So, we will look at that.

The other thing that maybe sometimes we think about, but maybe we don't really look at in any great detail is to understand the significance of the number of blades that are present in a windmill. So, and we traditionally tend to see three bladed windmill designs, but what are the options there and why do people you know why most of them are setting a three blade design. So, is there some great significance to it or is there no significance to it, is it simply a matter of symmetry things like that; we we just need to get a sense of what is involved here in terms of the significance of the number of blades. And also alternate designs for wind energy capture. So, there may be lot of interesting other designs that people are looking at. So, we will at least consider one which is you know significantly different than what we have discussed in the class so far, in some ways it is significantly different it is actually fundamentally there is something similar.

So, I will highlight that to you, but in some ways it looks significantly different. So, we will see that as well. So, we will look at differentiating between lift and drag, we will understand the significance of the number of blades that are present, and we will also examine alternate designs for the wind energy capture. So, these are the learning objectives for the class we will just see them as we go along ok.

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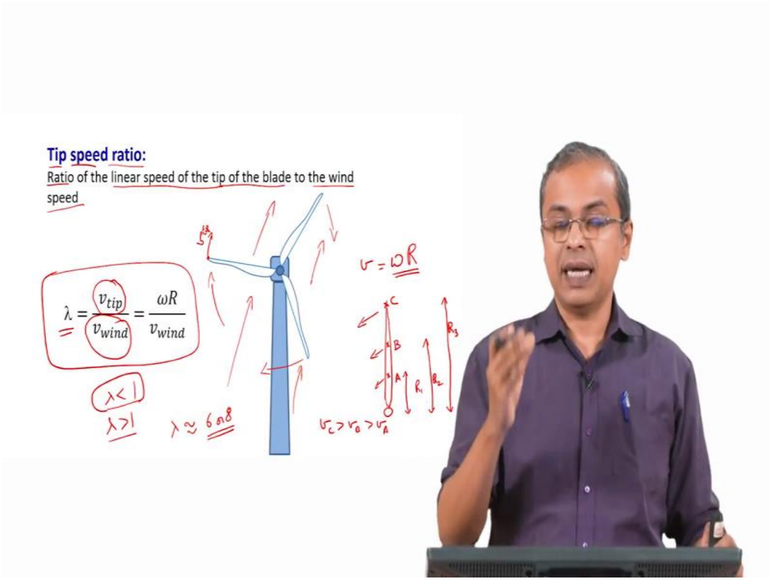

So, in this context there is a term that I actually defined a while earlier, but we didn't discuss it in detail. So, I will highlight that here it's called the tip speed ratio tip speed ratio. It is something that is reasonably significant in the context of windmills or wind turbines and we should at least get a sense of what it is, and maybe how it can be used to consider possibilities with respect to a wind turbine. So, it is in in terms of description and mathematics, it is relatively straightforward we are basically looking at the ratio of the linear speed of the tip of the blade ok.

So, linear speed of the tip of the blade to the wind speed. So, it’s a ratio of two speeds; the speed of the tip of the blade of the windmill to the ratio to the speed of the wind itself okay. So, what do we mean here? So, for example, you see a schematic here of a windmill right. So, you see a schematic of a windmill. So, let’s say based on how the breeze is blowing, let’s say it is rotating that way okay. So, let’s say it is rotating this way.

So, if you take if this is the way in which it is rotating, if you take the tip, this tip, tip of this blade the specific blade and that will be true for all the other blades, there will be a certain velocity with which it is moving. So, there is a certain. So, that velocity we are referring to as v tip, v subscript tip that is the velocity with which the tip of the blade is moving and why is it moving? It is moving because there is wind coming from the front and moving backwards right. So, wind is moving from the front of this windmill and moving backwards.

So, going past the windmill and going backwards, and we will assume that the wind is coming horizontal. So, the wind is windmill is standing there and then the wind is just blowing this way. So, blowing past the windmill and then going continuing further. So, there is a velocity with which this wind is coming towards the windmill, and because of that this windmill is rotating right. So, this windmill is rotating. So, we want to know as it rotates. So, for example, if these are the windmill blades if they are rotating, we want to know what is the velocity of the tip of this blade.

So, what is the velocity of the tip of this blade is something that we want to calculate, and then having calculated the velocity of the tip of that blade we divide that by the velocity of the wind that is coming and that is referred to as this tip speed ratio. So, that’s basically what we have put here represented by lambda it is the ratio of the tip velocity, which is the v tip that I have up here and the numerator divided by v wind okay. So, this is what we have, and if you know, if you look at angular velocity versus the you know if you look at rpm of something that is rotating you look at how many you know radians per second it is you know going through this angular motion.

Then the linear velocity of that of any any point based on this due to this as a result of this angular velocity is simply v equals omega R, where omega is the angular velocity and R is the radius of the point; of that point for which we want to know what's the linear velocity right.

So, if you have a longish blade and it is rotating, you can look consider various points here, you can consider the point here, you can consider point here, you can consider point here. So, I will just say this is A, this is B and this is C. So, even though omega is the same if they, if the whole blade is rotating round and round and round and omega is the same. So, many radians per second you will have the angular velocity, the linear velocity of each of these is going to be different. So, if you look at this formula omega R, v equals omega R clearly the R is more. So, this is I will just say this is R 1 this is R 2 up to here let's say this is the center R 1, R 2. So, let's clear this.

That would be R 1, this would be R 2 and this would be R 3. So, clearly the linear velocity of C is higher than the linear velocity of B is higher than the linear velocity of A. So, v C is greater than v B is greater than v A. And that's simply got to do with the fact that to travel the same angular you know movement to make the same angular moment the A has to had to travel a less distance, B had to travel longer distance, C had to travel even longer distance.

So, and the as a result and that has happened in the same amount of time. As a result the linear velocity of A is less than the linear velocity of B is less than the linear velocity of C even though or they all have the same angular velocity right. So, so this is v equals omega R and so, if you want know the velocity of the tip, once you know the rpm of that windmill you just have to sit there and what is the rpm of the windmill, then you will know how many radians per second it is revolving at. So, full 360 degrees would be 2 pi radians. So, based on that how many you know how many rpm it does that, when you rpm into 2 pi radians it would have covered in 60 seconds.

So, you get the angular velocity and once you get the angular velocity you do v equals omega R and then you get the linear velocity. So, if you do that you will get this lambda which is the tip speed ratio omega R by v wind. Just to give you an idea in and we are going to see some values as we go along. We are looking at lambda values which could be lambda could be less than 1 in some cases, based on the design of the windmill it could be less than 1. Lambda could also be greater than 1 it can of course, also be equal to 1. So, it can be less than 1 greater than 1 etcetera. So, you are looking at a range of values and usually I mean maybe towards the higher end of the spectrum we are looking at something like lambda could be approximately say maybe 6 or 8 okay or maybe even 10. So, some something like that is what we are looking at as the value of lambda in the normal set of circumstances, that you are going to see a windmill in and for a set of types of windmill that you are going to consider ok.

So, that is the tip speed ratio which means what? I mean do we need to understand what it means by 6 or 8 or what what is the significance of saying lambda is less than 1 or lambda is greater than 1. If lambda is less than 1 it means that the tip is moving at a speed linear velocity, which is less than this velocity of the wind okay.

So, please remember in with respect to the chi type of windmill that I have shown you on this plot, which is this three bladed windmill; the wind is actually flowing perpendicular to the blades right it is flowing perpendicular to the blades. So, the tip of the blade is moving in a direction perpendicular to the direction of the movement of the wind okay. So, they are not in the same direction, they are in perpendicular directions. So, that is something that you have to keep in mind. So, they are moving perpendicular directions what we are saying is when lambda is less than 1, the blade the tip of the blade moves with a velocity that is less than the velocity of the wind that is crossing that blade ok.

So, if the velocity of the wind crossing the blade is let's say 10 kilometers an hour or let us say we want at least 10 to 16 before this thing starts moving, let's say it is moving at 20 kilometers an hour. So, if I were moving at 20 kilometers an hour, the tip of the windmill is perhaps moving at 15 kilometers an hour okay. So, in that case you will have 15 by 20. So, 0.75 right. So, that is that would be the ratio if you had something like that. If the tip we are moving at if and so, we will assume 20 kilometers an hour breeze and then relative to that we will think about it. Supposing you had 20 kilometers an hour breeze whereas, the tip was moving at 30 kilometers an hour, then you would have 1.5. So, 1.5 would be the lambda value or tip speed ratio, and if you have would something like you know when I say 6 to 8.

So, what does it mean when it's at 6 it means the wind is flowing at 20 kilometers an hour, the tip is moving in a direction perpendicular to the wind. Please remember that it's the direction perpendicular to the wind at 120 kilometers an hour okay. So, that is the point that we have to remember. So, you may wonder how come you know that velocity is higher than this velocity, but that's got to do with the fact that the phenomenon that is occurring is different and that is the reason there are some designs where it is where exactly what you are thinking is going to hold true, and which is the case where lambda is less than or equal to 1. As long as lambda is less than or equal to 1, it is it is consistent with our you know intuitive process that with that says wind is flowing at some speed, the blade cannot go faster than that speed or something like that right. But what other designs the movement is different and as a result the process is different as a result you are able to create the situation where the tip speed is different. In all cases energy is conserved. So, it's not. So, that is I think the more fundamental aspect that you have to remember, you should not worry so much about the velocity, you should and you know be stuck on this idea that how can that velocity be higher than this velocity, that's not the defining characteristic in this case in many of these windmill designs.

What is more important is the energy is conserved. So, what the in terms of the movement of the windmill, whatever energy it has picked up is going to be less than or equal to the energy that the wind that. In fact, it is going to be less than the energy of the wind that arrived at the windmill, it is never going to be even equal to that energy right. So, so it is going to be less than that energy. As a result that is the characteristic that we should feel satisfied has been met in this situation, and as long as that characteristic is met whatever is the velocity that ends up being there in the windmill is fine I mean. So, we need not worry you that you know that velocity is not matching this velocity etcetera, that that's not how it works the energy conservation is the more fundamental defining idea right. So, that's the way you should think about it ok.

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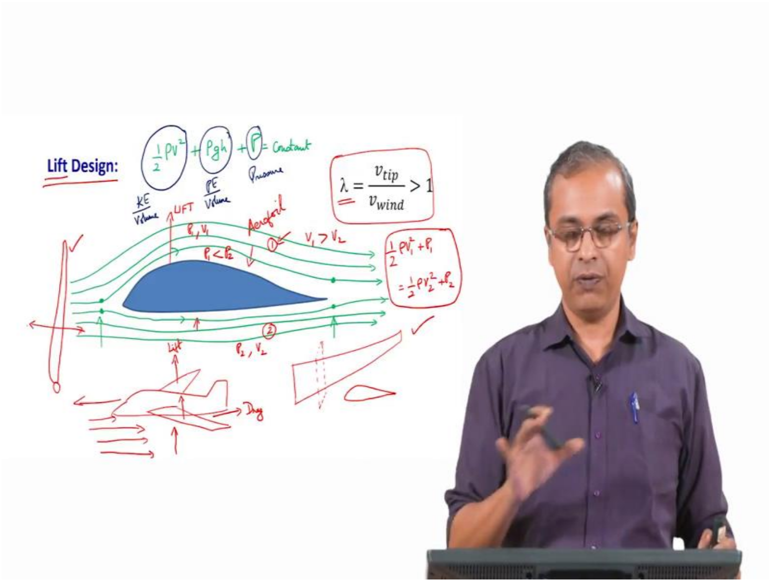

So, we spoke, I spoke in the just now about the idea that you know you have different designs of windmills and based on the design you may actually have this tip speed ratio which is greater than 1 right. So, that is the idea that I am pointing out here. So, there are certain types of design of movement based on flow. So, here we have flow of wind, and based on that you have movement of the windmill blades.

So, some of these movement of windmill blades happens, I mean again this is based on the design of the windmill. Based on the design of the windmill you can design the windmill such that the movement of the blade occurs due to a phenomenon referred to as lift okay so it occurs dues to a phenomenon called lift. This is the same lift concept that is there when a aircraft is trying to take off or even when it’s flying right. So, as it is flying it is the same concept that exists, there is a lift process which pushes the aircraft up and that is how the aircraft takes off and then stays in the air.

So, lift is very critical it is a phenomenon, a very important fundamental phenomenon that exists in the context of aerodynamics and this is the same concept that is being used in certain windmill designs. So, what it is, is something that we are just going to briefly look at. What you see here on your screen is an aerofoil. So, based on which part of the world you are looking at some places they will simply refer to it as air foil, but more specifically we call it aerofoil. So, you can see this shape this is a shape that I have drawn here. So, schematic of a shape, this shape is the cross section of a surface of a object and if the object has this kind of cross section, and it is interacts with wind it tends to create this lift okay. So so, for example, aircraft wings, if you look at aircraft wings and take a cross section of the aircraft wing. So, if you have an aircraft wing that looks like that right. So, you have this aircraft wind wing and you take a cross section of it. So, you cut the aircraft wing there right you cut the aircraft wing there and you take a cross section of it, then it will have this shape this exact shape that I am showing you here something of that nature.

So, it will have a shape that looks like that. So, some shape like that is what the cross section of that aircraft wing will look like. Similarly we have this windmill blades. So, you have a blade like that, and you have a blade that looks like that, I mean that's the hub and then you have a blade if you cut this here. So, we just cut it out here and you take the cross section and then you look at the cross section then this is what you will see okay. So, this shape is referred to as the aerofoil shape. So, what happens? So so, the point is in this kind of a circumstance and similarly with the wink of a plate, what you are seeing is if you see the aircraft. So, I just draw a schematic of some aircraft here, and then you have the wing right. So, you have something there. Now you must remember that the breeze as the aircraft moves forward, the wind is actually coming in this direction ok.

So, this is the direction in which the wind is coming because the aircraft is moving in this direction. So, even if it is on a stationary day, you the engines of the aircraft switch on and then the aircraft moves forward okay. So, it moves forward gains speed on the runway it is picking up a lot of speed, and it let's say it crosses some 300, 400 kilometers in are something like that. It is picking up some pretty good amount of speed.

So, at that point relative to the aircraft the wind is coming backwards right. So, wind is coming backwards. So, what happens the aircraft lifts off the ground right. So, the lift happens in this direction. So, the wings are helping the aircraft to move in that direction okay. So, that is the lift. On the other hand the wind is also rubbing against this aircraft and that sort of like you know you can think of it as friction, which is holding the aircraft back. So, there is a force in this direction that is called drag, this is called lift ok.

So, this is upward direction what is happening is lift what is pushing the aircraft back is a drag okay. Now the point you must notice here is that the wind is flowing in this direction the lift is happening in a perpendicular direction. So, the, that is an important thing that you have to remember. The lift is not happening in the direction of the wind, the lift is happening in a direction perpendicular to the wind. So, that's a very important thing to keep in mind. So, now, if you keep that in mind and that is exactly what is happening in on an aircraft wing which I have shown here, that is also happening on the blade of a windmill of the design that I will just shown you those three blade windmill designs that I just showed you, which is a horizontal axis windmill. So, in those designs the breeze is moving horizontal to the ground with respect to the ground, the blade is moving in a direction perpendicular to the breeze right.

So, exactly the same in terms of directional orientation, that is consistent with what I am just showing you for an aircraft. So, what is happening? So, what is so special about the shape? So, there is this thing called the aerofoil shape and that is what you are seeing here. So, what happens is you have a lot of let me just take some other color here. So, it is easier for you to follow. So, we have some color here. So, you have you know let's say you have breeze coming. So, this stream line will go off this way that will go that way ok.

So, you will have lot of breeze that is doing this. So, now, generally what is happening here is that, the path traveled by the air molecules on top of the aerofoil is longer than the path traveled by the air molecules at the bottom be below this aerofoil. Now there is some analysis that people do and you know there are different approaches to looking at this. So, one approach basically says that let's say you have two molecules here, one molecule here and one molecule here.

So, then they look at what is that path traveled by that molecule on top to arrive here and the molecule at the bottom to arrive here. And so, one sort of assumption or assumption that is made is that they travel they are both arrived here and they both start at the same point, and the arrive at the same point at the same time okay. So, the starting point is similar and the finishing point is similar and one assumption is that they all arrive at the same point to ensure continuity.

So, if that is the case then the path traveled on top is a longer than the path traveled at the bottom. So, therefore, the velocity of the wind above this aerofoil is higher than the velocity of the wind below this aerofoil okay. So, that is one approach although some people are suggesting that actually the velocity in fact, these particles on top in may even be coming faster than that. So, that is another angle you can think of, but that simply adds to this process not subtracts from this process, but the general assumption is they are all arriving at the same time, even when they are arriving at the same time you were going to see some difference. So, the idea is that the velocity on top is higher than the velocity at the bottom of the wind.

So, now if you look at fluid flow and you look at the idea that energy is conserved okay. So, that is the again the underlying phenomenon that I said, you know that's the phenomenon that we should I know tie ourselves up to and within the context of that phenomenon whatever happens. So, we looked at Bernoulli's principle.

So, in Bernoulli's principle we say half rho V square plus rho gh plus P equals a constant right. So, in this context we basically said that we basically said that you know this is the kinetic energy per unit volume. So, this is KE per unit volume, this is potential energy per unit volume and this is of course, pressure. I showed you that the dimensions of kinetic energy per unit volume or and potential energy per unit volume which is basically energy per unit volume it's the same as pressure. So, therefore, this equation is appropriate and correct as per dimensions and this says that this is the constant.

So, if you look at situations where let's say you are basically you know not worried about the change in height, because the you know the breeze is flowing at the same height let's say between the starting I mean compare the starting point and the end point there is no great variation in the height, they are essentially the same location. So, we can forget about or we can neglect potential energy per unit volume because that's the same both of the starting point and the end point. So, we basically have only two terms here half rho V square and so, let's say this is path 1, which is coming on top and path 2 which is coming at the bottom. So, half rho V 1 square plus P 1 should equal half rho V 2 square plus P 2.

So, this is a P 2 comma V 2, where v is the velocity here not volume, velocity here and then on top you have P 1 and V 1 which is the velocity on top. So, if you have created a situation. So, given that you know this has to be conserved, you have this equation here that has to hold as part of energy conservation of this fluid flowing around this airfoil. If this equation has to hold, then whenever the velocity goes up in any one location correspondingly the pressure goes down okay.

So, to the extent that we find that in pathway 1 in pathway 1 because the distances traveled have to be are longer and it turns out that you know if you actually do the proper calculations and you understand all the dynamics that's happening there, the velocity in that path 1 for the molecules happens to be much higher than the velocity in path 2. Therefore, we find that you know because of the shape and how it is interacting with the breeze a V 1 happens to be greater than V 2 and how much greater it is will depend on exactly what assumptions you make and how correct those assumptions are. So, usually the assumption made in most places where we discuss this is to say that the molecules start off at the same point and they end up later also at the same point and therefore, they simply look at the path travel that one travels a longer path in the same duration of time, the other travels a shorter path in the same duration of point time and therefore, the velocity of 1 is greater than the velocity of 2.

But like I said you know some people actually say that the there is some analysis which suggests that it may even be the difference maybe even more than that not just simply based on what is there when you when they both meet up there. So, in any case the velocity is higher, there is you know there is no two opinions that the velocity is higher because the velocity is higher the pressure is lower. So, if pressure on top is less than the pressure at the bottom.

So, if P 1 is less than P 2 then what happens? Pressure below that aerofoil is more than the pressure above the aerofoil right. So, velocity 1 is greater than velocity 2 and as a result pressure 1 is less than pressure 2, pressure 2 is below the aerofoil, pressure 1 is above the aerofoil and since you have low pressure on top and higher pressure below, it pushes that wing up. It pushes the wing up because you have this difference in pressure right. So, that is how the lift is generated, and that is the process by which you get the situation where breeze is flowing in one direction the movement is happening in a perpendicular direction ok.

So, that is the point in in with this design right. So, with this design breeze is flowing in one direction or wind is flowing in one direction movement happens in a direction perpendicular to it. And that is the way in which this aerofoil as a result of the pressure difference between the bottom and the top, because more pressure is at the bottom less pressure is in the top it gets a lift. So, you get lift.

Okay so, this is the idea and whenever this movement is based on lift and you have this windmill where this movement is based on lift, then you don't have to worry about this exact relationship between the two velocities you end up having a situation where the tip of that windmill is actually having a velocity higher than the breeze that is flowing perpendicular to it and of course, energy conservation takes care of all other issues associated with it and you get values of lambda that are greater than 1, and like I said it could even be 4, 5, 6 etcetera which can be significantly greater than 1 ok.

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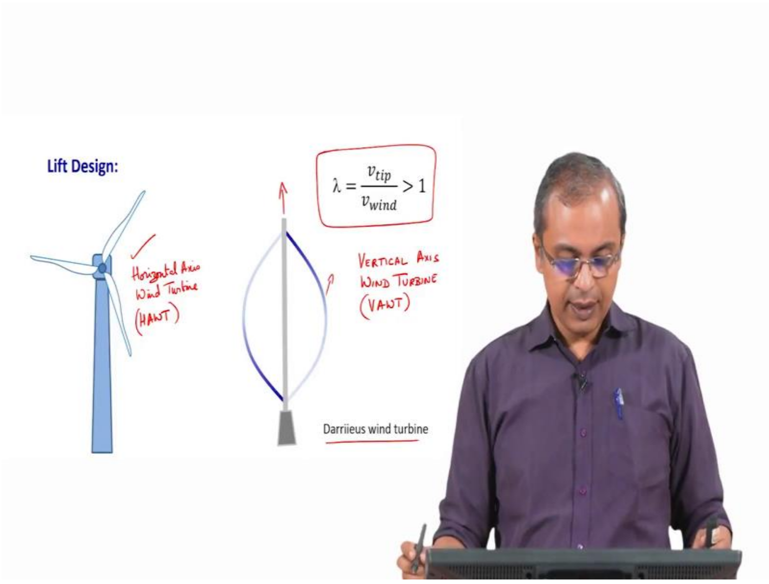

So, this is lift based design and most of these three blade windmills that you see you know when which you see along many places in India at least these days you see it, those are all consistent with this kind of thought process and analysis. So, lift based design for example, would be this, this is a standard design that I think we are all familiar with which we see in many places.

There is now also, but this is horizontal axis wind turbine. Horizontal axis wind turbine so, sometimes they write it in you know as an abbreviation HAWT horizontal axis wind turbine. What you have here is another wind turbine which is referred to as the Darrius wind turbine, and it is vertical axis wind turbine. So, that is also I mean okay. So, that is VAWT. In this particular example even this is vertical axis. So, the axis is in this direction the blades are moving in this direction, but in this case also the blades are designed such that the movement occurs due to this lift phenomenon ok.

So, it is not occurring due to another phenomenon which are just going to discuss in our immediate next slide which is the drag design, this is still based on lift okay. So, lift based design is what you are seeing here also and it is a slightly twisted kind of blade that's why you see this difference in shading as you go from the top to the bottom. So, it rotates this way, and it is also still based on lift and. So, for this also the lambda can be greater than 1 okay. So, this is what we are looking at.

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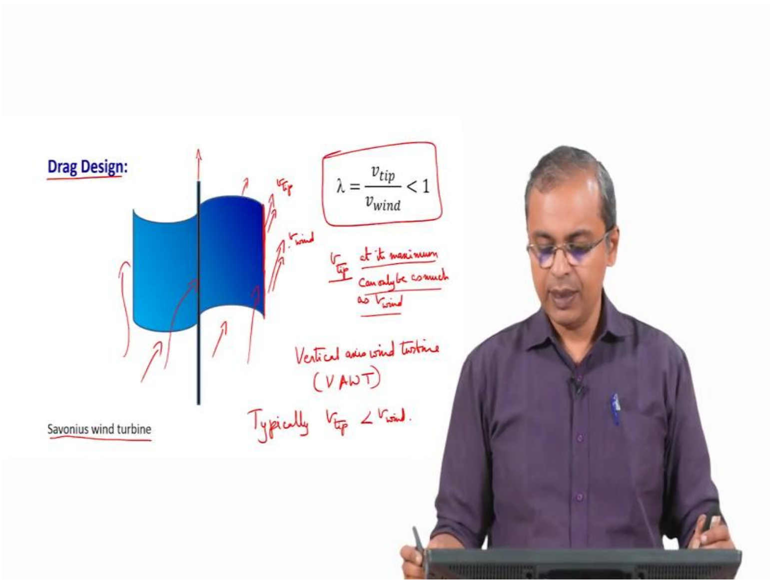

Now the other design that I told you which is perhaps the older style of windmill design, some of the early windmills had this design that they looked at which is called the drag design. And the Savonius wind turbine is a particular style of the drag design, which is what you see here. So, again this is also a vertical axis wind turbine okay, but there is a big difference here. So, here the wind is flowing this in this direction. So, in you know in both places it is flowing this direction, but when it comes to this surface it just slides past the surface and also still you know gathers up here.

So, you end up getting more push on the right side of this wind turbine less push on the left side of the wind turbine. So, but the point is it is based on a pushing action. So, the wind is physically pushing the blade that is directly ahead of us. So, the blade basically moves in fact, in the direction of the of the wind. So, it is first getting pushed in the direction of the wind, and then because it is stuck on a you know on an axis it rotates away. But fundamentally the action is being pushed okay. So, now, and or rather that and that is why this term drag is used push or drag that is pushing the the wind turbine away as it physically pushes it away. Now the important point you have to remember here is that the tip here the tip of this wind turbine as it starts moving, when it is getting it's maximum thrust it is moving in the exact same direction as the wind. So, the tip this is v tip and this is v wind.

So, that's the direction of the wind and that is also the direction of the tip okay. So, now, the air molecules are physically pushing the the wind turbine in the direction that they are moving. Now clearly the only source of energy there is the, you know velocity with which that the kinetic energy of those wind molecules that have come there and so, this they are coming with some velocity and they with that velocity they are pushing this surface that is ahead of them. So, clearly that surface cannot move faster than the rate at which those molecules are coming and pushing them pushing that surface right. So, in this design this flat surface or this curved surface in this case, cannot move at the tip of that curved surface cannot move at a velocity faster than the velocity with which this wind is flowing because this wind is is directly pushing this surface, there is no lift involved here this pushing action that is involved here.

So, in this case if it attempts to go faster then there it's no longer getting any thrust from the wind, then it lose the ability. So, even for a moment if it were to go faster than the wind, it will pretty much there will be no further push it will slow down till the wind catches up and wind will keep pushing it. So, even if you hypothetically consider that situation. So, you put it in the wind and you turn it faster than the wind, it will slow down. It will slow down and it will go only at the wind velocity.

So, you would you use your hand and you rotate it much faster than what the wind can do, and you just leave it there in a few seconds it will line up with the wind velocity, it will not be able to go faster than the wind velocity. So, in this case the tip a V tip can only be ns equal atmost maximum either it can be at it is maximum can only be as much as V wind okay and that's because they are both moving in the same direction. So, that's the big difference when you had the lift design they were not moving in the same direction and so, the relationship was very different and Bernoulli's principle defined what could be done there.

Even here there will be energy conservation etcetera. So, that it is not that this is in violation of energy conservation, this is also associated with energy conservation, but there are additional restrictions because of the fact that there is a push design involved, it is not a lift design and as a result the v tip at most at it is maximum can only be as much as v wind. So, typically V tip is less than V wind. So, therefore, you have this tip speed ratio being less than 1 okay. So, now, this is the idea that we have to keep in mind, and this is important sort of in the context of the windmill designs.

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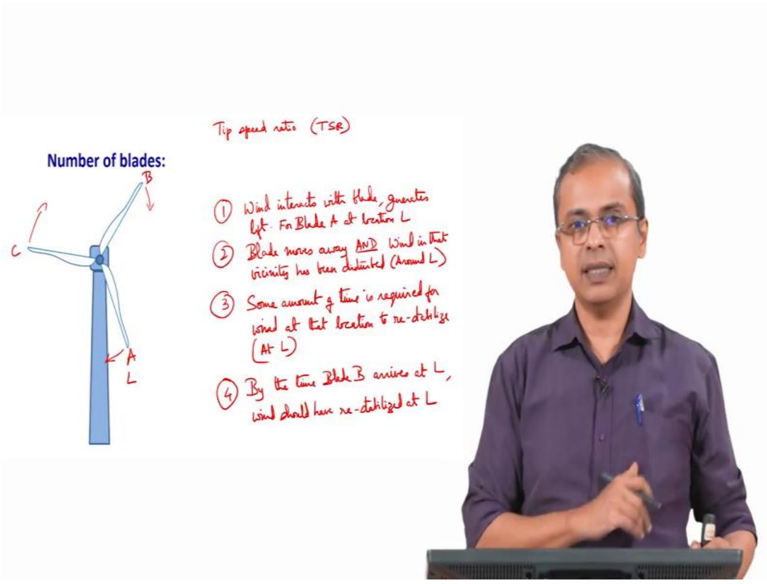

So, now that’s a concept we will keep in mind we will use it as we find necessary in the design discussion.

So, let’s look at number of blades and let’s say to what degree this tip speed ratio or TSR we will call it tip speed ratio we will call that as TSR. Let’s just see to what degree this TSR is of any consequence to us. So, typically we have three blades and it is rotating our most common application is power generation. So, that is why it’s also being referred to as a wind turbine as opposed to simply calling it a windmill. Now the point we have to remember is that as the blade rotates. So, let’s say it is rotating that way okay. So, wind strikes a blade and as a result of wind going past the blade due to a lift action the wind the blade moves away.

Now, as the blade moves away it has locally disturbed the wind right. So, there has been an interaction between the wind and the blade and that has resulted in some disturbed wind. So, some turbulent wind is there. So, you had some smooth wind going you had some turbulent wind. Now if you have the next blade of the turbine arrive at that spot before this turbulence goes away, then the next blade cannot completely benefit from the flowing wind okay. So, what to just restate the wind interacts we just say wind interacts with blade, generates lift okay. So, that’s the first thing that happens. So, what happens? Blade moves away and at the same time wind has been disturbed; wind in that vicinity in the location of that blade where the blade where that interaction happened you know in that vicinity that region of that near that region you know even in that vicinity has been disturbed, and at that point it is not smooth it is kind of turbulent because it had that interaction and. So, it has been disturbed.

So, blade moves away, but it will take a maybe a few seconds some amount of time is required for wind at that location to re stabilize. Why it re stabilizes? Because wind is coming fresh wind is coming then wind is coming from a long distance right. So, it has some stable properties, some velocity some smooth flow that is happening that is coming with which it is coming. So, now, you had a blade, that blade interacted with the wind it got pushed away, but in the process it sort of messed up the wind there, but if you give it a few seconds this messed up wind will go away fresh wind will arrive here, which would be the same as whatever the original wind that interacted with the blade. So, you need a few seconds before this blade moves away and this fresh wind arrives at that location okay. So, some amount of time is required. So, it is a finite amount of time usually a matter of seconds maybe fractions of seconds to a second or a few seconds before the wind will re stabilize at that region.

So, if I call this region A. So and let me call this blade B call this as a blade C. So, this blade A will move away, but this particular location let me call this location as L okay. So, a blade A is at L because of the interaction it moves away. Now blade B is also going to come to the same location L. By the time the bay blade B arrives at L, we want the wind to be stabilized at the location L. So so, we say wind interacts with blade generates lift for blade A at location L okay, blade moves away and wind in the vicinity has been disturbed in that vicinity has been disturbed near around L. Some amount of time is required for wind at that location to re stabilized at L. So, this restabilization we want at L. So, then four by the time blade B arrives at L wind should be stable there okay. So, this is this is the kind of thought process that is here by the time the blade B arrives at L the wind should have restabilized at that location L.

Now, the point is if the wind has not restabilized it does not mean that your windmill will stop operating or that it will stop generating energy, it is just that that process will not be efficient. You will actually lose energy you are not capturing all the energy in the wind, a wind has much more energy you are capturing disturbed energy only some part of that energy you will capture from the wind you are not capturing all the energy that is there the free flowing wind. So, the better design is such that you want to set it up such that the tip speed ratio is such that, by the time that blade comes to that location vacated by the previous blade the wind has restabilized okay so, that is how we do this calculation.

So, if you want to extract the maximum power out of that is available in the wind, we need to consider the tip speed ratio of this windmill and based on that only we decide how many blades are possible okay. So, if the tip speed ratio is high then you can use less number of blades ok.

If you use less number of blades then is just let’s say. So, you have less number of blades. So, for example, let’s just look at this we will look at possibilities here.

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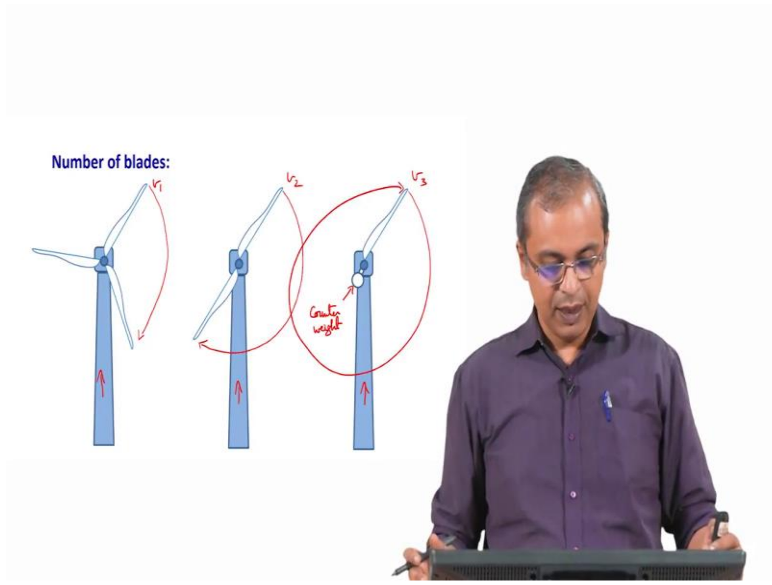

So, we could have two blade design, we could even have a one blade design we will just talk about this. So, we have a two blade, three blade design, two blade design, one blade design. So, supposing the tip speed ratio is some value v 1 in this case and v 2 in this case and v 3 in this case these are tip speed ratios. So, if the tip speed ratio is some value v 1 which is medium, you want it such that in that at that velocity by the time it comes here this the wind has stabilised here. If the steep speed ratio is higher than you need the blades to be further separated, so 2 blade system would work. So, this tip would work travel this entire distance before it comes here, and by the time that wind would have stabilized and of course, in this case this travel the full circle and come right back here right. So, that is the full circle that it is going to do, to come right back to that starting point.

So, the higher the tip speed ratio you can get away with lesser and lesser number of blades. The lower the tip speed ratio you can if you wish used more and more blades and still capture more and more energy from the windmill. So, in principle you can have a three blade design, two blade design, and one blade design based on tip speed ratios and also you have to keep in mind that if you are using this primarily for generating electricity, then having higher rpm's is what is more useful to us.

Generally the torque requirement is not as high whereas, the rpm requirement is much higher and therefore, high tip speed ratios is important because that decides the rpm the faster the tip is moving you will have a higher rpm right. So, generally these designs are based on that thought process, you should also keep in mind that as the blades move ever. So, often one blade will line up with the tower. So, you have a tower here. So, that blade the instant that it is lined up with that tower it is not going to face the same kind of environment that the other blades are facing. So, usually the blade that is in front of the tower actually has a, you know disturbed kind of behavior relative to the other blades and that affects the stability of this wind turbine or affects the stability of this whole process.

So, if you have only two blades, you have one blade facing a drastically different situation compared to the second the blade that is diametrically opposite to it. Every time the blade is you know one of the blades is lined up with the tower right. So, that's a very unstable situation relatively speaking. So, three blade designs in that sense are considered to be very good because you have two blades which are you know sort of stabilizing the wind turbine, when only one blade is facing this circumstance of that tower okay, of the involvement of the tower.

So, generally three blade designs are preferred; one blade design can also do the job you simply have to have a counterweight here, can also do the job if you are only interested in looking at rpm if torque is not an issue. If torque is not an issue when one blade design can also you know at the end of the day that blade also is about rotating as a result of the interaction with the wind. So, it will also have the same tip speed ratio and or something to that based on that behavior of the wind interacting with that blade.

So, you can get the rpm using one blade also, but generally this is considered very people where ever this has been installed although functionally it works fine, it is considered as something that lot of people object to because it seems to affect them to see this single blade rotating. So, it's actually more psychological reason why people don't use this design. It seems to bother a lot of people to see this single blade repeatedly rotating in the sky there, something about that is very disturbing to a lot of people when they see it in action, it's not something that seems to fit with our you know psychology of what we are expecting in nature and therefore, a lot of people object to this design when it is put up.

So, there is no real objection to two blade designs and three blade designs, in that context the three blade design seems to have a good mix of various factors taken into account, the stability, the you know dynamics of the whole process etcetera seems to come off much better the three blade design. So, that is what is commonly used and like I said if torque is important where you are where you don't mind the speed of the windmill.

But you are more interested in torque. So, rpm is not important, but torque is important then having more blades is useful because you are able to get more energy from the wind that is going through that process and then push that use that to generate that torque. So, the older design windmills which were primarily aimed at you know grinding things or pumping up water, where torque was a critical thing they typically have more blades that are put up. So, while we have discussed all this, I would like to take finish of this class by looking at a completely alternate design for windmills and which is going to be quite surprising for you and that is referred to as a wind tree.

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So, what I want to draw your attention to is the fact that people are looking at totally different designs. So, what you see here it looks nothing like a windmill right. So, one of the objections to the windmill is that you know that you have these huge structures which are blocking up space and are you know blocking up your view I mean you go to a nice beautiful landscape, you look around you what you would like to say you know let's go let's go let's say you go into the sand dunes of Rajasthan or someplace and some lovely place you go you want to see nature in pristine condition.

You see the nature and then ever so, often you see this big windmill that is the parked there which you know is not natural I mean you see this huge manmade object that is parked there, it seems to become you know an eyesore. So, to speak in that landscape and the more you know deploy these windmills you are going to see more and more of them.

So, people have come up with some interesting design where it does not even look like a windmill. So, it just looks like a tree. So, I mean of course, this is colored artificially just to you know give you an idea of what is expected here, but basically what you have here you have a serious of vertical axis small vertical axis windmills, wind turbines. These are all vertical axis wind turbines and clearly you can make you know this is just a schematic, you can make like a tree with several branches that looks very natural and you can dot the you can set it up in streets and whatnot or in some open parking areas that is enough breeze blowing. And so, these windmills are actually rotating this way okay. So, that's how they are rotating, and in that process they are generating electricity. So, instead of having one large wind turbine, you have a lot of small wind turbines which are continuously interacting with the breeze and generating electricity, and they look and the whole thing looks nothing like a you know like a wind turbine, and it actually you know distributes it makes the whole you know deployment process very easy, you don't have to create this huge massive structure that you have to go and put up. In many ways it is not very different than putting up a lamppost.

So, you can put up a lamppost on top of it you can even put up this tree, if you want and you can keep generating electricity. So, this is a very lovely concept and since this is not solar power you can do this during day during night etcetera and it works absolutely fine okay. So, those are the interesting design aspects that I wanted to discuss today as we close our discussion on wind energy.

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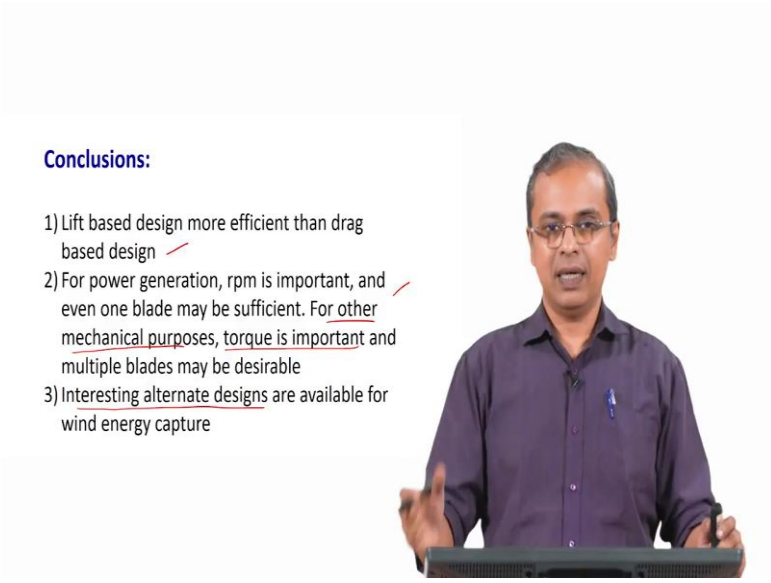

So, in conclusion I just wanted to say that the lift based design is more efficient than the drag based design, indeed is able to have tip speed ratios higher than 1 and is able to capture more energy than the drag based designs. For power generation, rpm is important and even one blade may be sufficient if torque is not important and boundary rpm is important, one blade may be sufficient. For other mechanical purposes torque is very important, and in that case multiple blades may be desired. In any in any case in all these cases you want to check for the tip speed ratio is and then understand that you are you know not overdoing the number of blades that you can actually you are actually effectively using the you know interaction between the blades in the wind.

So, that’s something that you have to look at. And finally, that I just showed you that there are very interesting alternate designs, you can actually check on this in the internet they have lot of videos on this kind of wind trees you can easily just you know search search for it, you will see videos or animations of those wind trees. They look nice they look very similar to trees and maybe you can maybe design one with that looks almost exactly like a tree and then generate twin.

So, that’s alternate designs are there people are looking at all those alternative designs, and so, if you look years down the line if you say certainly wind energy is either everything or a very significant fraction of our you know energy supply, then you may have all these kinds of interesting gadgets distributed across our cities. So, that’s something that we can look forward to. So, in any case with this I would conclude this class, and also our discussion on wind energy in subsequent classes we look at other technologies.

Thank you.

KEYWORDS:

Design considerations for Windmill; Lift Design of Windmill; Drag Design Of Windmill; Three bladed Windmill; Tip Speed Ratio; Lambda; Lift Process; Aerofoil Shape; Bernoulli’s principle; Horizontal Axis Wind Turbine; HAWT; VAWT; Darrius wind turbine; Vertical Axis Wind Turbine; Savonius Wind Turbine; TSR; Two Blade Design; One Blade Design; Wind Tree; Torque; RPM

LECTURE:

Windmill designs like Lift based, drag based and tree like design are explained in detail and compared. The requirement for number of blades is based on application and is used in combination with RPM or Torque. The principle of lambda (Tip speed ratio) being less than one, equal to one or greater than one is evaluated to understand the consequences on windmill speed .