Wind Energy

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Lecture 39: Aerodynamic of Darrieus and Savonius turbines

Welcome back so, we'll continue the final discussion on vertical access wind turbines which we started so, what we have done so far we just recollect that that in the vertical axis wind turbine we also tried to look at different aspects of the vertical axis wind turbine, then this basic nomenclature of the vertical axis wind turbine, then the different types of specially the lift-based and the drag-based, and then we try to analyze them as we have done in the horizontal axis wind turbine. and this is what if you see in the last session where we stopped finally we have found out these things what you call the the analytical expression for power coefficients and all these things but there we have used two different theories one is the single stream tube theory the other one is the double stream tube theory and obviously these are simplified analysis to some extent obviously with some kind of an what you call some kind of an assumption associated with that okay, now this is where we stop so today what we'll do we'll finalize that thing so now the another option that could be possibly this so what we are going to talk is that the double multiple steam tube theory so this is again a extension so this is an extension multiple steam tube theory so, what we have discussed about multiple stream tube theory so, this is the extension of that now here the approach is pretty similar one can think about the situation so, the approach is pretty similar to the multiple stream tube theory which we have already described um so, here the only difference so, what one can think about the approach is similar to this multiple stream tube theory. So, if I sort from like multiple MSTT but the difference here is that there is a slight difference here in the induction factor in the upwind and downward positions need not be the same. I mean, there are different, I mean, there's double multiple stream theory based some simulation tool has been developed by Sandia National Lab. Obviously, one can devise that kind of tool and analyze that. So, that much only we'll talk about here.

We are not going to be very much detailing out about those details because that's not I mean, essentially required at this moment. Quickly, we look at aerodynamics of Darius rotor. So, I mean, typically, if you see the Darius rotor, I mean, if you try to sketch it, so then you have one goes like that then that come here is goes like that and the other one is like that so that would come so, that's the thing and if we talk about that the base plate okay, and this is your main shaft okay so that is how and then in between you have the other shaft and all this okay now so, the darius rotor this can be analyzed using single or multiple stream cube. Either of that one can use it what we have already discussed so far.

The main difference here to do with so the main difference that one can that is the because orientation of the blade element one which are now different from one another and the analysis that we have carried out there is more like a single steel blade and so on can say which are now different from one another and second point would could be the distance of the blade elements from the axis of rotation which is again, which is not constant for the length of the blades, length of the blades. So, I mean, these are the two major differences that one would encounter if you see the previous single string theory or multiple string theory that we have discussed. assuming some single blade or under certain but realistically the Darius turbine would look like this and so the analysis would be slightly different what we have done so, you have to probably incorporate some changes and one of the reason is because of the orientation of the blade elements you can see one goes convex another goes concave and the distance of the blade elements from the axis of rotation so, if this is the axis of rotation then which is not constant, okay so, i mean more about this analysis will not go in the details within the scope of this particular course when one interested they can go through the textbook which are available which talks about only detailed analysis of various type of rotors okay, similarly we'll quickly talk about Savonia's rotor, okay so, this is also a kind of kind of vertical axis wind turbine okay kind of that but this is s shaped cross section when viewed from top okay so, top view shows like an s shape cross section This is not Darius. This is not Darius. This is Sabonius.

Okay. So, that's a small correction here. So, the picture is for Sabonius. Please note the same. This is not Darius.

Okay. This is the picture we are referring here. when you look at from the top, it looks like an SM. So, essentially, it is a drag type. So, this is a drag type device.

But, there may be some amount of lift contributing to the power as well. So, here the power in Savonius obviously is primarily based on the pressure difference across the blade retreating from the wind and that advancing into the wind. So, the power calculation here is primarily based on the pressure difference across the blade retreating from the wind and advancing into the wind. This is essentially equivalent to the difference and say that equivalency is the difference in the drag coefficients associated with the convex side of the blade and the conclave side of the blades. So, I mean there is a textbook by in 2002, which talks about detail of this Sabonius and Darius rotors.

So, we will not go into the much more details of this discussion. So, again please, this picture here that we have drawn, this is not Darius, this is for Sabonius. So, please make a note of that. So, that was a correction. So, in Savonia's case, it is again, you have this convex and concave side of the thing.

So, the obviously drag type of device, some amount of lift may contribute to the power production. So, this is primarily the pressure difference across the blade which is going towards the wind and coming out of the wind which is again the difference between the drag coefficients associated with this convex and convex. So, in general what happens is that this Sabonius rotors or turbine of low efficiencies okay but although the power coefficient is close to 0.3 so cpu would be close to 0.3 and that peak power coefficient could reach a tip speed ratio of one or something like that it's uh i mean in general it's a very low efficiency device So obviously, there could be other issues which are associated with this kind of rotor on the turbine.

There could be issues with that. I mean like each time Darius has some kind of a starting talk issues, whether Sabonius doesn't have that, but Sabonius power output is low, but whereas in the Darius type power is high. So, one can think about some design which is mixed in nature. So, all these are kind of possibilities. So, that's pretty much that we would like to talk about.

So, this vertical axis wind turbine and horizontal axis wind turbine. And rather, I would like to make a stop here. and say that so, we have done quite a bit of theoretical or analytical analysis how to design the blades of horizontal axis interval and followed by this discussion on vertical axis wind turbines but, what we have not talked so far I mean, this is what we have rather discussed everything based on the aerodynamics of this horizontal or vertical axis so the aerodynamics what we discussed is primarily contributing to your power production and then whatever analysis we have done or looked at it how to improve your power output. Obviously, considering some of the efficiency of the different components and things like that, but that we have taken into consideration and then how much power you could generate. So, everything based on your aerodynamic analysis.

Now, what remains not discussed so far is the part of the structural loads and all these things. So, now what we are going to look at it, look at the loads on this turbine. So, rather we look at some of them we look at as a component wise and then we move to some looking at the total, the whole turbine unit and their loads and all these things. So, as I've said that now we are going to look at the mechanics and dynamics of wind turbine. We start with some component level analysis and then we could move on with that.

So, the first thing to do that kind of things what we have to understand is what are the loads. forces. So, that is important. Loads and forces are acted on the turbine. Where are the forces of these loads? Obviously, the primary load source is due to the aerodynamics which contribute to lift and drag.

You could have gravity, you could have inertia which could be gyroscopic and centrifugal. You could have electromechanical that is generator rotor you could have operational load so which is coming from brakes your mechanism pitch actuator okay so, these are essentially your sources of loads. So, what we have discussed in detail so far is this component, the component A, which is the aerodynamics load. So, we have looked at everything, how you get lift, how the aerodynamics analysis could be done. But if you see the whole turbine unit is also having exposed to this gravity load, inertia load, you have electromechanical due to generator, operational loads and other things.

Now, we can also look at the, so these are the sources of loads, but we can think about what are the types of loads. Okay. So, one could be, let's say steady, that means it can be static and rotational so, it could be static and rotational okay, then you can have cyclic okay, this can have in terms of multiples which are essentially your harmonics okay of rotation frequency. So, here we can say that 1p is that once per revolution, you could have 3p, 3 terms per revolution.

Okay. So, in general you can write BP that means B times per revolution and B here is number of blades and one can say this b dot p as a blade passing frequency, okay! so, you could say that this could be my blade passing frequency fine so the third load could be resonant That is due to vibration of tower and blades. Then, you could have transient load. Transient, which is due to your starting of the machine, stopping of the machine, yaw, all this. And there could be stochastic load. And this is primarily due to wind.

Because wind is turbulent and that could be kind of affecting that whole thing. That's what you have different kind of I mean a simple steady load calculation what can do let's say I have this turbine this is my and then I can have tower like that so this way is weight which is f of g this is my thrust so f of p And the resultant could be like that. So, this is a steady load during normal operation. So, these are the first components.

So, it's a schematic. So, it's not needed to be very actual and things like that, just to kind of demonstrate situation a bit details so, what you have the f p is p by 2 third u infinity and f g is m of that mass and g so, these are typical calculation of this so, you have the some thrust and all these things so, that's a some let's say simple approximation of the thrust and all this i'm not here trying to give you an exact first expression on things like that because in order to include every effector it's just to demonstrate how things can So, let's say for example, you have power is 6 megawatt. Your U infinity is 9 meter per second. And your aim is 360 ton. Okay. Then what this gives? If T would be, okay, it is pi T by two-third U infinity.

So, essentially 6 megawatt. by two-third into nine so this would be one mega newton okay one mega newton and my fg would be m into g 360 into 10 to the power 3 kg 9.81 meter per second square so, this would becomes 3.6 mega newton So, that gives you an idea kind of quantum or the forces that are going to act on a turbine. I mean, it's a simple example. And we're using a simple expression of the thrust.

And obviously, thrust includes all the details. So, this is what the whole unit in a total is exposed to. Obviously, the horizontal axis wind turbine exposure is much higher than the vertical axis wind turbine. One of the primary reasons being the vertical axis wind turbine is very small in size. So, if I quickly recap the thing, You have different sources of loads.

Primary loads comes from your aerodynamics. Then you have gravity. You have inertia, which is because it's a rotating system. So, gyroscopic motion, centrifugal motion. You have electromechanical system, which is generators and all these.

You have some operational load because it suddenly breaks your pitch. And you could have different types of loading, static loads. You have steady, which could be static and rotational. You could have cyclic loadings or revolutions, which brings you the break-pressing frequency. You could have resonant, transient load, stochastic load.

I mean, we'll go in detail analysis of all this, how you incorporate and all these things. And this simple example shows what kind of forces that would be acting on the body. So, we'll stop here and continue this discussion in the next session.