Wind Energy

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Lecture 35: VAWT

Continuing the discussion about this late performance. So, we are talking about these different unsteady effect here. So, and essentially all our calculation that we have or analysis that we have looked at in BEM theory and others are unsteady state calculation but there are changes that takes place during actual or practical operation. So, some of them are always unsteady in nature and those unsteady nature one has to take into consideration while doing the design. So, some of the aspects we are talking here and later on when we will be talking about the structural dynamic aspect of it, we would kind of try to bring in those effects into the analysis. So, we talked about the tower shadow, we talked about the dynamic stall, there are then another important aspect is the dynamic inflow.

So, ideally, what happens is that we always talk about that power production is proportional to incoming flow speed or the Q of the incoming flow speed. So, if we try to keep on increasing the speed, then obviously our power production would go up. But that condition is more like an idealistic situation where you can think about that with continuously increasing the speed, we may have more and more power. one hand it is yes but at the same time one has to understand that once you try to increase the incoming speed so you have larger flow field to turbulence and changes in the rotor operation could be pitch or the rotor speed changes for example so what happens is that also Instantaneously if you increase the speed too much or the instantaneously your induction factor on the axial induction factor that would change, so, overall what can happen is that with in i mean having a dynamic inflow or, that can have dynamic effect on the turbine operation and that can lead to fluctuating, so, obviously fluctuating load and that may have subsequent impact of the power and all these things.

What we can finally have is the rotational sampling, so, that is another one, rotational sampling so that causes some unsteady aerodynamics effect and increasing fluctuating load on turbine so obviously all these dynamics is having essentially fluctuating load on wind turbine okay! so, the General flow turbulence may bring wind speed changes on time scale of about 5 seconds, but the turbulent radius may be smaller than the rotor disc, so, which could result in different winds at different parts of the disc. So, if the blades are rotating once a second, then the blade sampling sample different parts of the flow field at a much faster rate than general changes in the wind field itself. So, that would have rapidly causing change, rapidly changing flow field at the blade. So, there are other aspects in the, I mean, other computational approach to this aerodynamics design. So, one can have some other approach, obviously, computational approach.

approach other approach to design obviously this is aerodynamic design so what we have talked or looked at is that the mostly the beam theory has been used to predict power performance there are iterative approach to blade design has also been talked about There are analysis methods. Obviously, there are other approaches that we have discussed to predict blade performance, designing of the blades and obviously, some cases provide you different kind of solution. Some disadvantages of BEM theory including errors under conditions with large induced velocities or EOD flow, inability to predict delayed stall due to rotational effects. So, all these we have kind of Then there are vortex wake methods which can be used in addition to BEM theory. These are pretty much very often used in the helicopter theory.

So, vortex wake method calculates the induced velocity field by determining the distribution of the vortex in the wake. Obviously, that is quite intensive analysis, also has advantage of yacht flow and operations subject to three dimensional boundary layer effects. Then, there are also other possible theoretical approaches. I mean, asymptotic acceleration potential method, cascade theory, which is often used in turbo machinery design, also been kind of applied to wind turbine performance. obviously, and then finally one can go for complete computational fluid dynamics or CFD approach computational fluid dynamics or full CFD which we'll discuss towards the end of this particular course that when we use the full CFD approach, kind of get to this.

Then, you have other modeling issues, validation, etc so, there are efforts which have been made to validate rotor performance models obviously is quite difficult though because, i mean, instrumenting the complete turbine under rotating conditions and taking measurements under typical operating environments with here turbulence etc, is not very easy task so this is quite challenging but obviously, that there are ways to put the sensors and measure some flow field there are also database available from the farm applications which now these days, i mean, especially in northern europe where you can get those data available and those can be used for validation purposes and further improvement of the analysis challenges that you face because if you have turbulent flow field by the time the turbulent flow field reaches the turbo I mean wind turbine blade things got changed so that's what there are a lot of unsteady, I mean, essentially the unsteady effect but, wind tunnels provide I mean nevertheless field tests have been provided important insight lot of measurements have highlighted issues considering in modeling codes and wind tunnel provide more control environment for testing but large wind tunnels large wind turbines and to achieve all these things and that is where your dimensional analysis dimensional analysis become important and that's what you try to go for wind tunnel testing etc with the reduced size and all these things then obviously, i mean, other issues like you can include variety of wind speed your angle bit pitch angle rotor configuration so which could be titered configuration rigid configuration upwind or downwind of the tower So, one can put measurement techniques over the blades, angle of attack, loads and movements, output power. So, obviously, what you need data for having this kind of performance calculations and things like that. Obviously, what it needs the whole the whole modeling effort or analysis modeling efforts or analysis, i mean, can be categorized by the type of the model used to do the analysis so one can have performance codes obviously performance codes which are using steady state steady state aerodynamics. Okay, aerodynamics. So, that all that we have talked about all this.

So, you can have aero elastic codes, which are essentially Indian codes using BEM methods with modification and blade motion. you, can have weight-based codes, you can have full CFD codes. So, these are different kind of codes that you can have, which you can kind of, so that means this analysis effort, so that is what we have talked about mostly the theoretical part is the performance points kind of analysis that we have done, which includes steady-state aerodynamics while incorporating some of the unsteady effects like variation of the EOR, pitch angle variations, tip losses, weak rotation. So, some of the unsteady effects which could actually be taken into consideration. but the elastic codes or full safety codes these are not something we have talked about but regarding some of the cfd applications or how this can be done that we will discuss later on but yes one can have i mean the best possible that i mean either you have some analysis technique which could be numerical based or some kind of performance with codes and all these things get some initial design parameters and things like that and then you fabricate it and then go for testing and then finally validate and finalize the design or one can do fabrications go for final measurements and all these and then do the rectification go ahead with that but Well, the next approach is quite often not preferred because these days the numerical techniques have matured enough to handle this kind of situations or that kind of.

So, it is very unlikely for any industrial purposes design now solely based on the measurements. But yes, the measurement cannot be avoided. So, it could have, but it should be complemented by some of the theoretical analysis or full CFD analysis and like that. So, once you get some also full CFD codes, including I would say, including aero-elastic behavior. So, that could be probably highly nonlinear multi-scale kind of approach.

So, you get initial data and then you do fabrications, go for testing, validate and finalize the design. Sometimes one can have wind tunnel testing because the kind of turbine blades you talk about, it's very difficult to have that kind of tunnel across the globe. So, you can use your dynamic similarity or dimensional analysis concept and have a model and then match your non-dimensional number and do internal test on this small scale model and then take it further scale it up for the actual prototype. So, this is what is the state of the art situation as of now for horizontal axis wind turbine in terms of your aerodynamic analysis and things like that. okay so, what we'll do now we'll move to our discussion on vertical axis wind turbine, okay so, so, now now we'll move to our discussion on vertical axis wind turbine so here we can start with or begin with by looking at different types of vertical axis wind turbine and their kind of use and how to calculate the forces and things like that in vertical axis wind turbine so you have these are different kinds of vertical axis wind turbine you can have this is your horizontal axis wind turbine which is in modern days vertical axis wind turbine you have this Sabonius kind of turbine then you can have Darius kind of turbine or Giro mill kind of turbine so obviously these are the two major classification that you have Darius and Sabonius and they are and there are some advantage and also at the same time there are some disadvantage that you have in both this sabonius and various kind of turbine so it's like with having some advantage some disadvantage for this kind of different things so there is no comparison to even talking about some comparison about vertical axis wind turbine technology to horizontal axis wind turbine technology so, we have talked so many details about wind turbine i mean vertical axis i mean horizontal axis wind turbine and that their performance so, vertical axis wind turbine has one advantage is that this is independence of the wind direction of the uh its operation and obviously if you look at the schematic here these are your turbine blades if this is coming the wind this is and the gearbox at the bottom so the gearbox or jet generator they are placed at the bottom of the turbine and then have simplicity of the tower construction obviously here if you see this is the tower height so this is the tower height in horizontal axis whereas in the vertical axis and those are quite simplified compared to so this is again a side by side picture of the so this is horizontal axis wind turbine and this is the vertical axis wind turbine if you see how this rotor diameter then, the gearbox generator nacelle the whole structure and here you have a generator at the bottom and then you have the rotor tower and all these things so obviously the operational print is quite high so if you compare this picture in a larger way so if you see wind direction and the rotor diameter here is the total rotor height is this much and again depends on the blade design this could be also this rotor height could be much lower as well so you can have different sizes obviously requirement based size if we talk about some of this key feature of the vertical axis wind turbine then effective device which can extract useful energy this is small in size for small scale power production or small scale energy production these are quite handy this is for small scale domestic application to large scale electricity production but this could be portable compared to horizontal axis wind turbine There are three main types.

One could be, as we talked about, Savonius type. Multiple steam tube analysis of vertical axis turbine shows how the complex aerodynamics may be analyzed using relatively straightforward techniques. So, that is the advantage that you have. Then you can have double multiple steam tube analysis, which could be used to illustrate the details of the performance of vertical axis wind turbine in terms of turbine blades, loads and all these things. These are some pictures.

Now, some historical picture. It's an example in Sistan Basis in border region of Iran and Afghanistan. It's a picture from 1971. so, how the right hand side shows how the upstream wall is used to expose only one of the rotor and this side you can see how this could be so it's more like an you have the turbine and you are trying to kind of guide through that so, that your power production is increased okay that's something then there is an in 20th century this vertical axis turbine used to pumping brine at china so that shows in picture so these are i mean slight or little bit of uh historical aspect of the turbine now coming back to the different types so this is your Savonius type. You can see these crates are having some kind of curvature so that when the wind comes, so either of that from this direction or this direction, it hits it and it rotates.

So, this is Darius type. So, this is each type of Darius. It shows kind of an alphabet H. This is helix shape so that you have some kind of a blade twist and all these things. Now, just simple design perspective if you look at it then you have this vertical axis turbine here you can see this is type how it looks and the blades which could be going around that there is some schematic and shows how these are fits into more different section of the thing and here is a nice picture in from australia that how this vertical axis wind turbines are placed at the top of the building to assist ventilation and generate electricity the advantage of this kind of vertical axis wind turbine can be used for small scale operation and this can cater to the small buildings maybe some offices housing or i mean localities where neighborhood now the one of the one of the classification of the turbine is the drag based vertical axis wind turbine.

So, what happens is that this is my rotor I mean shaft and then you have these blades which is let us say this is the upstream of the flow and this is convex in that side and that way it is let us say T1 and T2 these are two blades. one side is convex i mean for T1 it is concave side which is facing the upstream wind and this is convex side and that goes in a rotation like that and this go and you have a relative velocity so the drag base because this wind will come and hit this blade and it will actually go and rotating that so that's why it creates more drag So, the net torque that you will get from this would be the difference torque of the between these two turbine T1 minus T2 and the Tn would be half rho Av square. So, here this is the blade area, rho is the density, R is the distance of the net force from the center. Then, what you need to have that the drag coefficients downstream side cd1 upstream side Cd2 you have wind velocity and if you look at this typical drag coefficient plots over the reynolds number you see this is stokes law of analysis then this is for sphere this is for this and where is the cylinder and at the beyond a certain reynolds number there is a drop in the drag so this zone is known as the drag crisis So, basically, with increasing Reynolds number beyond a certain point of time, you will have a drop in the drag. So, that is something one has to kind of consider while talking about this vertical axis interval.

Now, there are So, how do you estimate the drag which have already I mean the drag is simple you can have the dynamic head drag coefficient into the frontal cross sectional area that means and then there are different kind of shape where the drag coefficients are already available. Those drag coefficients I mean they are why they are important because in vertical axis wind turbine the major challenge here is that it's primarily drag based. You could have this particular blade shape so the design of the blade shape would be important and that design would depend on what kind of shape one can use and these are the different kind of shape which shows that like this is a sphere, then it has a half sphere, you have different drag coefficients. You have a half sphere, you see, then you have a cone, the 60 degree, then you have a cube, you have angled cube, low cylinder, short cylinder, streamlined body, streamlined half body. So, you have different kind of, obviously important is full streamlined body, you see the drag coefficients is 0.

04, where the half-circuit body is higher. So, there are different shapes and they have their drag coefficients. So, it depends on the shape that how you have. So, these are different kind of design one can conceive and those design can be used for designing these blades of the vertical axis wind turbine and there are concept that the blade could be twisted obviously later we'll talk about this Savonius or Darius type and their issues with issues with the starting torque and their power production capability and things like that so, but what is important when you look at the compared to the vertical horizontal axis wind turbine and the vertical axis wind turbine is much smaller in size it is quite compact it could be portable It can be installed on top of the buildings in some neighborhood to cater for small housings in a few neighborhood housings. Obviously, it can be installed for industrial purposes as well.

So, there are quite a bit of thought these days to look at the different vertical axis wind turbine to be installed at different places. since the wind availability for installing a horizontal axis wind turbine is a challenge or a big consideration whereas, i mean, your vertical axis wind turbine the operational issues could be much less and that way it could be quite effective if, we make use of this vertical axis wind turbine for purposes where the it can serve the small scale requirement. Okay. So, we'll continue the discussion of this vertical axis wind turbine in the next session as well. Thank you.