Wind Energy

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Lecture 21: HAWT-history

welcome back so we'll continue discussion on this wind energy topic so now what we will do we would move to talk about now the horizontal access wind turbine so the plan here is that we initially look at, i mean so far, we have looked at in general of what happens when you talk about these wind turbines in the context of their boundary layer turbulence then how one can think about their site selections what are the issues uh what are the some of this technological advancement that has taken place now specifically what we'll go and talk about horizontal axis interval so the plan is like the following. We initially look at some of the history and all this of the horizontal axis wind turbine. Then we go and try to see how this calculation of the different forces and based on the momentum theory, one dimensional momentum theory. And then we would look at some of the airfoils and wicks related matter. and before we move to the vertical axis wind turbine so that's how we're going to talk about so first looking at different aspect of horizontal axis wind turbine and then look at this issues and then vertical axis wind turbine and then we could probably would be talking about this mechanics dynamics and all these things of the turbine designs and related things okay so that so this is a very known or already we have seen this picture this is an oriental axis wind turbine they are kind of so these are in the southern part of the denmark which provides electricity of 1.66 megawatt so 1.66 megawatt okay so obviously we have already seen that european uh countries are the major hub or this for the these things what you call the offshore offshore wind uh installation so there are plan for more and more addition to this offshore turbine So, now these you can see how these are kind of so these are the kind of a form kind of things how these are located. So, if you go to little bit of history of horizontal axis wind turbine so that kind of goes to old when we started a different time. I mean, you can see how old these things were designed. And this probably towards the modern era, these two.

But these are other old concept of the design where originally the horizontal axis wind turbine was used for grinding windmills, sailing boats, mean different purposes that was a major thing that was used so now if i go back and talk about this is a little bit of history of horizontal axis wind turbine i mean so 6th century BC the Greek philosopher experimented with amber rod and these were first studies into production of electricity. So, this was the first one. Then 1600 William Gilbert first coined the term electricity from electron, Greek word amber. So, this is where we get to see the terminology of electricity. Then 1800 Alessandro Volta invented the electric battery and the term Volt named in his honor.

So, this is where we have been commonly using, okay, how much is the power capacity and things like that in terms of Volt. Then 1826, George Ohm defined the relationship between power and voltage and this is a famous law of Ohm's law. which is commonly used in electricity. 1821, Michael Faraday from England discovered the principle of electromagnetic rotation and that would run the key development in the electric motor. So, that also we know Faraday's law by his name.

1876, Charles Booz invented the open coil dynamo that the generator could produce steady current of electricity. So, after the invention of electricity in the late 19th century, inventors turned their attention to generating electricity from the wind. But although, I mean, windmills were there for a long period, they are mostly used for non-electrical purposes. But this is the time when you had understanding about electricity voltage these different laws and their relationship this is the time when it was kind of turned into that okay now we have this resource of in terms of wind turbine which could be used to produce electricity so that was the idea behind that and In 1887, the Scottish Professor Blake developed the first electricity generated wind turbine. The turbine was inspired by the concept of wheel mill design and had four blades with cloth sails to control the over-speeding of the rotor.

So, this person is the one who was who first introduced that concept to use this turbine or rotating machine to convert electricity because and again these are all continuation of the history of horizontal axis wind turbine, okay so, this is Charles Bruce developed, so, this we have seen wind turbine in North America, 1888. So, the 12 kilowatt turbine had a 71.1 meter rotor along with 140 wooden slots. You could see the design here, which is a, I mean, it's a different kind of design. Then these are again continuing with the history part of Alexander Alexis wind turbine.

the smith anemometer wind turbine had three blades with rated power of 17 kilowatt and 24 meter of diameter so this is the diameter that we call is 24 meter, so, this had a three bladed turbine which was then if you go back and try to see in europe the early fasted fastest running wind turbine This is O.H. Hunter, an aeronautical engineer in Germany who had developed a 34-meter two-bladed downward turbine in the 1950s with a hopping design-tip speed ratio of 9.5. To withstand this rotor speed, hunters introduced the idea of blades manufactured with fiberglass.

and attached the fiberglass blades with hub through flanges in a novel way, which was later become hotter flanges. So, these are the key scientists. I mean, sometimes when you look at the history of things, it becomes often kind of a little boring, but at the same time, it's good to know how things got evolved over the time so that you know. And interestingly, the terms or some of these components which are commonly used terminologies, those came by some of these great scientists who invented or who first made their contribution towards that. So that's all.

Although, I mean, there is nothing fancy about looking at the history or things like that, but it is always good to know the contribution of these great scientists over the different time to time. Then coming back to this discussion here, STWG-34 at the test field in Swabian Alps. So, the turbine was also connected to a grid in Testville near Swabian Alps in 1956 and began testing in 1958. Similarly, now if you move towards Denmark, you have this 200 kilowatt wind turbine at Zetser. So, that was a landmark achievement.

So, this Zetser means the grandfather of the Danish design concept. It is a port town on the Baltic Sea in Denmark. So, this was the first landmark turbine which was producing 200 kilowatt of power, which was definitely a remarkable achievement in that sense. Now, so, that's kind of give you an overview about this evolution of the horizontal axis wind turbine and the different things which are termed in the name of these different scientists, which made significant contribution towards the development of this wind turbine technology that we are talking today. I mean, having said that, I mean, I would like to re-emphasize here is very importantly, See, I mean, we can do our analysis, we can do sophisticated calculations, we can do our very highly efficient or optimized design, but it is at the same time good to see how things evolved and why things evolved, how the user demand forced to make things allowed or forced scientist or researcher to think to make their design changes.

I mean, as you see, the concept of wind turbine was there, but it was used for sailing boats, windmills, grinding. But then slowly, I mean, in 1880s, 90s, that time people started thinking of using that for electricity production. This is where things got changed. And now today's demand because of your climate change, environmental hazard, your limitations of the fossil fuels across the globe or on Earth's surface, forcing us to rethink that, okay, there is a natural resource available in terms of wind, in terms of solar, sometimes water, geothermal. So, how to make use of that to fulfill or cater to our everyday's energy demand.

Because with the growing population, with the growing technology, with the all kind of development across the globe, the energy demand is increasing. Yes, the spectrum of the demand varies from continent to continent, even country to country, but our goal or objective is to cater to that demand using renewable sources and wind is one of the major contributor towards that. Now, this again we have kind of looked at it, but this gives you an idea, again I am re-emphasizing these points or keep on bringing time to time so that you have an understanding about the global picture in your mind. I mean, when you go and look at the force calculations, momentum theory, you probably will be looking at only the blade part.

Okay? Yes. When we again look at the dynamical aspect of it, then that time will again come. consider the gearbox or generator or maybe this nacelle altogether, then the tower altogether, probably the foundation, all these we are going to take it up. But the overall picture, always good to have in your mind that how the system works, how the flow of the process. Okay. So here, this shows that again in context of horizontal axis wind turbine that this is your generator obviously this is what is converting this rotary motion into electricity your gearbox to hold this rotor and the blades and all this your power cable goes through the tower connected to the transformer which is you have the foundation here you have foundation here and that is connected with the switchyard and all these things too now if you look at the this picture was taken from the this is a cement turbine okay cement turbine it was taken from book of hansen you could see this is a kind of a view of the nacelle okay open nacelle i would say so that gives you an idea how that looks like and how these blades through these flanges connected with this shaft and then it connects with the generator which is going to produce the i mean converting this mechanical rotation to an electricity so that's what this photograph shows i mean it's an kind of an open picture of the nacelle where you have this gearbox you have this turbine shaft which is passing through that gearbox and how the gearbox shaft flanges and the generators are connected and these are the key components which are connected with a single shaft so that the rotary motion of these turbines is going to be converted to the electricity.

Now, this again coming back to the components part of it. So, I would say these are the components of horizontal axis wind turbine. So, you can see again this is the complete nacelle which is kind of an open in that sense. This is the wind direction. This is the wind direction here.

Okay. And then you have, so you see this wind direction. Then you see this, the rotor blades. So, this is how the pitch motion can happen. You have low speed shaft.

You have the gearbox. You have generator. You have controller. You have anemometer.

you have wind vane, high-speed shaft, you have brakes, you have your drive, your motor, and then powers and all this. So, the rotor actually contains the blades and hub.

Drive train contains low-speed shaft, bearing coupling, gearbox, high-speed. Electrical component contains generator power electronics. control component contents, pitch motor and gears, your motor gears, brake sensors. Then support structure is the tower and all these are kind of there. So this gives you a very detailed picture or overview of this particular open, I mean, what sits inside this nacelle.

Now, at the same time, this kind of gives you the overall flow of the process or connections. So, you see this wind is coming through these turbine blades. Then these turbines are rotating. So, obviously, they are connected with the control mechanism. Then, it passes through the gearbox, which is a mechanical power coming to generator.

Then, it's a wind energy to mechanical energy to electrical energy. So, it's simply energy conversion process. So, if you go back to your undergraduate level understanding about first law of thermodynamics, energy can neither be created or destroyed. It just changes from one type to another type. So, this goes to power interface to grid.

This is how. Now coming back to the little bit of detail component of the things. Again, we talk about the components. So, we talk about the rotor. The blades and the hub generator all together are called the rotor. So, that means we have blade and hub together.

So, blades can be pitched and can have control surfaces which could be flaps which is typically like your aircraft wing where you can have flaps. blade can be twisted tapered cone so blade has a different kind of so this is a tapered twisted blade picture then blades materials are wood and cloth glass reinforced fiber polyester fiber epoxy carbon fiber epoxy so aluminum steel which could be very heavy but Whenever we talk about these kind of things, then we don't want them heavy. And, we have already seen with the increasing power demand or increasing power capacity, our blade size or the rotor diameter is getting increased. So, we do not want very heavy material there.

Now, again, hub. So, blades are attached to the hub. So, they could be rigid or pitching, tethering, hinged hub. So, this is a rigid hub, the picture of a rigid hub. Rigid or pitching hub, this is the picture of that. Tethering hub, this is the tethering and hinged hub, this is the picture of a hinged hub.

So, in terms of tethering or teetering, These couplings arise when the rotor speed is such that the sequences of different modes get closer to resonance. So, that time this teetering kind of hub is used. The presence of teeter hinge between the rotor and the hub can mitigate this uneven load. so, this allows the rotor to rotate in force up direction reducing the out of plane bending moment fluctuation, so, that means the design of this kind of hub just to counter the mechanical load balancing so that we would see if we would talk about the load effect and all these things when it comes on the this rotor blades and all these things so that way what happens is that every every component will have their natural frequency but now this system is exposed to this dynamic loading and we'll talk about these different kind of loading but just to touch upon because we are having looking at in particular cutting kind of hinge and why they're important because when the wind gust comes or the wind comes then blades can have different kind of frequency because that's a structural component so just to avoid that that reaches to the natural frequency or resonance takes place so what it does this kind of tethering can counter that situation so that's the advantage of having these things then we can here is a picture of an the three bladed wind turbine with rotor of radius r it just how it is connected with the hub and this is the complete rotor radius r this shows the local angle how the relative wind velocity so so what happens is that it just like this any of this section that section this would be having an airfoil kind of shape now this airfoils are of different kinds because there are different kinds of airfoil which are there. Some of them can be used for wind turbine operations, some of them are not.

So, what you can see here is that angle of attack because this particular airfoil of the rotor blade could be exposed to wind and that angle of attack is alpha and the pitch angle if it is theta. their complete flow angle that flow angle phi how it is relative to the velocity that shows that so then you get a different velocity triangle across the rotor plane so that gives you an idea how these are this system dynamics is going to be exposed and we'll see this calculation we see this calculation when we look at this momentum theory where we bring in this velocity triangle but yes what happens is that when you talk about the these things the when you talk about this airfoil and all this so what happens here is that now this is again the picture of when this is to the tower and this is the total connection and this is the rotor blades when they are you see that the blade which is symmetrically so this is where the pitch control mechanism which is sitting inside the nacelle that takes care of it and this is passive pitch control where you have a titer rotation and then try to when the blade pitch is asymmetrically So, this teeter coupling or the teeter coupling or this pitch mechanism or pitch control mechanism is just to avoid to reach any resonance of the structural components. Because these are large in size and they are also rotating. So, one is that large in size and then plus they are rotating. So, the dynamic of these components are quite heavy.

And the load which is going to come on this shaft and all these things, they are also going to be heavy. And these are all arising because of the wind. And obviously, that's the primary mechanism, that wind is supposed to allow these blades to rotate. And due to rotation, you are going to generate the electricity. But at the same time, I mean, as you can see, there is nothing free in this world.

So, because of that, since these are large structures, heavy structures, obviously not massless structure, we are having finite mass and they are rotating. So, there is a huge mechanical load on the structural components which are going to hold these blades and this whole unit. So, those things we will consider when we go to the talking about the load balancing and the aspect of it. But you need to have some mechanism to have control over those things.

So, that's what it is talking about. So, we will stop the discussion here and continue about these different components and all this in the next session. Thank you.