Wind Energy

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Lecture 22: HAWT- components

welcome back to the discussion session of horizontal axis wind turbine so we continue to discuss about different components which we have been looking at it so what we have started doing that we looked at the brick history of horizontal axis wind turbine specifically when it got started, how things got changed over the years and their application. And, now then we are looking at the different components of the turbine and how they play a critical role in generating the power from the wind. So, now we talk about driving. Okay, so this is another component of the component of horizontal axis wind turbine. So, this we talk about drive train. So, the drive train actually consists of low speed shaft, bearing, coupling, gearbox, high speed shaft.

So, one hand if you look at the picture here, this if you refer to that then you can see the low speed shaft which is here this is low speed shaft you have bearings which are sitting with this all this joint then you have coupling generator gearbox high speed shaft so all these are connectedly we call it a drive train now What is the purpose of the low-speed shaft? So, each of these now, we are now talking about drivetrain. So, some of the important components that we will talk about. The low-speed shaft is also called the main shaft. The reason is that if you see the low-speed shaft is here and with the low speed shaft is connected with these rotor blades.

So, that means when due to the wind, these blades are rotating, this low speed shaft is an important one. Typically, the rotor RPM is low, 30 to 60 RPM. the height is torque. So, our torque is quite high. Since these are large structure, since the diameter is quite high, so the torque is quite high.

Obviously, we have already seen that with the increasing rotor size, the torque and movements correspondingly increase. So, this will also increase with increasing rotor size. But at the same time, rotor size Increase means area increases. So, that means power increases. So, have a kind of one has to have some kind of an trade-off between this power output that one would like to have or would expect to have for a given conditions or given location or given wind speed but how much rotor diameter would be affordable or this is where your system level optimization integration and optimization become important because for all given conditions and within the constraints that it would have how much maximum power or power can be maximized so that is what so this is one of the things that one has to look at it the torque and moment would also increase that torque transmission path is also called as a load path because obviously, this is the important path to which there would be load transmission which is going to take place then you have the main and low speed shaft which is usually made of steel and must be able to carry very large torque loading So, low speed shaft, main or low speed shaft is here which would carry the large torque loading because this is connected with the rotor blades and the rotor blades are rotating.

So, when a large structure is rotating then obviously that would generate a lot of torque and that torque loading would come on this particular shaft. So, we will consider these things when we look at the dynamics aspect of the turbine. Then this shaft transfer torque from the rotor to the rest of the drive. While, also supporting the weight of the rotor. Obviously, all this shaft is supported by bearings which transfer the reactionary loads to the mainframe of the turbine and things like that.

Now, we use the same picture here but then we are looking at the gearbox. Now, gearbox connects the low-speed shaft to the high-speed shaft. So, here is the high-speed shaft, which is connected with the generator. And now this is connected with this gearbox or gear mechanism. So, between the low-speed and high-speed, the transmission of the energy is happening through the gears.

And now, obviously, these are all mechanical components. So, the loading on the gearbox, loading on the gear, their gear design become important. The gearbox also, what happens is that it increases the rotation speed from 30 to 60 rotation per minute, about 1500 to 1800 RPM. That means the main shaft, so the low speed shaft, which is rotating at 30 to 60 RPM, when it converts to high speed shaft, it goes to 1500 to 1800 so that means almost 50 to 30 times increment that happens here which is the speed required for generator to produce electricity because generators rpm is quite high for production of the electricity the gearbox is usually very costly or expensive and also heavy part of the wind turbine obviously as you can see this is the one which is transmitting the power from one shaft to another shaft and so now there are research which is going on for direct drive generator that operated low rotation speed but do not need gearboxes so what one can have There could have some choices. You can have planetary or parallel gear mechanism, shaft bearing and location, number of stages, speed up ratio.

All these are choices that one can have. Now, the turbines with direct drive technology, the rotor directly drives a synchronous generator. So. combined with a range of advanced control, which are these deliver several benefits including high energy and quiet operation long term reliability. So, these are the advantages of the direct drive.

Now, if you look at different gear system, so this is an example of planetary gear system. So, this is planetary. gear system. So, these are usually parallel to each other and concentric. So, this is what happens.

There are some disadvantages of this kind of gear system. It's a high bearing load in accessibility and design complexity. So, these are obvious things to have that this kind of situations may, So, but there are some advantages of this planetary system because these are planetary gears over parallel axis gear compact in size, have higher efficiency, have low noise level. So, these are also very, very important that you have this kind of planetary gear system. now, you can look at some of this drive train configuration this is the double bearing layout and this is the single bearing layout okay so obviously your configuration depends on and one can have integrated bearing layout so these are direct drive layout with so this is your integrated bearing layout and this is your direct drive layout without gearbox okay so you can have this kind of different configuration of the gear box and all these things so important thing to note here is that, i mean, we are talking about uh some components of this and most importantly we are looking at the component which is kind of housed inside the nacelle and they play an important role so this um gearbox is one of that or gear mechanism is one of that the reason is that your all rotor blades which are really really large in size they are connected with the low speed shaft or main shaft so there the rpm is very low but that shaft is exposed to heavy torque or dynamic loading because when the blades rotates depends on the wind speed or wind gas there could be some kind of an even a small offset in the motion it can increase the loading on the that's that's rpm is increased to 50 to 60 times which is the high speed set that is connected with the generator and generator is a key component which generates the electricity So, this design of the gearbox system, gearbox mechanism, gear things there and all the gears, the kind of gear it's going to be used, they are important.

Now, we look at some couplings. So, couplings are kind of a, one can think about they kind of as coupling state, they connect the shaft together and transmit torque between the two shafts. Couplings can be effectively used to dampen torque fluctuation in the main shaft before power is converted to electricity. They are typically found between the main shaft and the gearbox and between the gearbox output and the generator. So, wherever this kind of connectivity is there, the coupling is kind of there to have or avoid those fluctuations in torque or any unwanted fluctuations that may arise during operation.

So, the coupling is an important component where these unwanted fluctuations in torque and all these things, they could arise due to unforeseen situation. We also have just like brakes. So, what happens is that the turbines cannot be operated beyond certain speed or design speed because that could be damaging for the system or maybe from the structural point of view. They are associated with high winds or loads. So brakes, a disc brake can be applied mechanically, electrically or hydraulically to stop the rotor in emergencies.

for maintenance and when the threshold speed is exceeded. So, whatever the design speed it is meant for, when it crosses that limit, then this emergency disc brake could be applied to put a top on that thing. Fail-safe brakes, these are spring applied brakes, allow the braking action to start when the hydraulic pressure to the brake disappears. So, fail-safe brakes can be used for a range of wind turbine application, such as parking, emergency stopping in case of power failure. And the orientation can either be horizontal or vertical.

So, these are all talking about the brakes and all these things. And now we can talk about rotor locks. so, rotor locks are this is what you can see this picture here and this is probably the rotor blade and you see the rotor locks and their kind of the position where it is placed so they are used in turbine industry and are typically mounted to turbines main rotor shaft between gearbox and generator So, a rotor brake is primarily intended for use as safety brake during emergency stops under high wind conditions. So, that means if the unit experiences high wind condition, which is beyond the design limit or cannot be withstand, in that case, the rotor lock is applied. so, this is activated running the lock bolt into the lock disk using hydraulic power and since it's a hydraulically controlled the locked signal would go to the control system and then control system would put that lock and the brake and whatever emergency thing so that the rotor rotation can be so the brake rotor lock units are engineered to handle the large output torque generated by this.

So, if you see that this is where the generator in the thing. So, this is where generator, controller, anemometer which senses the other thing. National housing means a pitch and a rotor. And you have your mechanism. These are all kind of housed on top of the Now we have your system.

So, your system consists of your motor, pinion gear, bull gear and your brakes. So, it also has, your system also has some components and you can see that, that you have your motor, your drive and all these things. so, those which are two litigate turbine they kind of apply this your drive and direction sensor to orient the rotor blades into the wind the difference between the orientation of the rotor and the direction of the wheel is used to activate the your motion, so so, the your motor powers the your drive and your drive it's the upwind turbine faces into the wind so the your drive is used to keep the rotor facing the wind as wind direction changes downwind turbine do not require a your drive pre or typical is so what happens is that let's say this is my turbine and this is my wind this is my wind direction and the wind direction got changed let's say then the your drive is something which will So, the purpose of the geodrive is to make the rotors to experience the wind as parallel as possible. Yes, there could be restrictions, even then in the sophisticated turbine, there could be your mechanism, you could have your drive, but you could have a limitation of your angle. I mean, you cannot really, because you have to think about that's a big, if this is the.

.. So... this structure is really big so your structure is when it is too big since the structure is too big then changing that whole structure or the orientation of the structure to make it facing towards the wind is a challenge but yes having a your drive or your mechanism into place could achieve to some extent but it is with some limited part because you cannot have an infinite i mean one cannot change the turbine blades completely from minus 30 degree to plus 30 degree or above that so those are some numbers i'm talking because the u angle change would be very very small with a few degrees it cannot be even too high because too high your mechanism is just not going to be possible and that's going to increase the torque loading everything on the system so, that is something also always avoided because nobody would like to have a system which would be exposed to too much of dynamic loading because the systems are rotating and there are wind speed which is associated with that so the they are kind of exposed to uh too much dynamic loading so i said that if you see so far what we have talked about you have talked about gearbox we have talked about generator controller anemometer low speeds pitch rotor wind direction your drive your motor tower and all this so these are already the schematic that we have seen but every time we are looking at it now we move to the other component which is generated. So, what it does it converts the mechanical energy which is the rotational energy into electrical energy. That means there is an energy conversion process takes place. So, usually AC current or alternative current operated at constant speed to produce utility grade 60 hertz AC power. Now we have earlier looked at the generators.

We are talking about the turbine technology. So, there are induction generators fixed RPM based, full rotor induction generators which are variable RPM based, double feed induction generator variable RPM based, double feed induction generators which are most commonly used today, very efficient over a wide range of wind speed, minimizes gust induced power strokes and things like that. and, then you have permanent magnet direct drive generators but yes the permanent magnet case you need those rare earth elements which are not very easily available but the df ig which has been used uh it's been quite successful and very commonly used today uh in the system generator system to now the next component is the nacelle which is the essentially one can think about house of all these mechanical and electrical components this is the house of that so, it actually contains or houses all major component of the wind turbine system except the rotor. The rotor is outside the nozzle because that's a big rotor blade which is rotating so that's there. So, you can think about it's more like a protective cover for the components and made of lightweight material but which is true for, Now a new challenge for design, there's more and I mean, as larger we grow the size of the turbine, the weight has to be as much as laser as possible.

So, the nozzle doesn't carry any load and this is not the does it is not a structural member. Okay. now what you can now talk about the towers okay the towers are heavy units because that is going to host the nacelle and also the rotor blades so they are made of gs or truss portion may be made of concrete as well. The tower's support nacelle transmits static and dynamic forces movements to the foundation. Its height has usually the same order of the rotor diameter or rather slightly higher than the rotor diameter because more modern tower means the tower is the most expensive part.

So, You could see some pictures here of different towers. So, you may think about how they are connecting with the foundation base to the main unit and all these things. Now coming to or moving forward to the control unit, So the control unit, the main purpose is to limit the power which is extracted at high wind speed or above rated speed. High speed typically happen when for short time. However, if they are not controlled, they can damage the drivetrain, gearbox, generator.

So, aerodynamic control is more effective form which is stall control, passage control or teach control which is active control. Okay. So, anemometer, which is kind of in the part of the national unit or close to the national unit where it is, how this reads the wind speed and transmits wind speed data to the controller. Because anemometer is, so if you see again, going back to the picture, you see now the tower, you have gearbox, you have low speed shaft, you have high speed shaft, generator, and anemometer, which actually feeds this data to the controller. So, the controller actually kind of sense the speed and accordingly try to control the complete system.

Now, wind direction and upwind turbine operates facing into the wind. Other turbines are designed to run downwind, facing away from the wind. that's how and wind vane it measures the wind direction and communicates with the your drive to orient the turbine properly with respect to the wind so these are different kind of measurement technique that one can have to have this now you could have controller which could starts up the machine which could start the machine set up the machine and turbines do not operate so What is the purpose or process of shutting down of wind turbines? It shall be required to have a readily accessible manual shutdown button or switch. Operation of button or switch shall result in a parked turbine state that shall either stop the turbine rotor or allow limited rotor speed command.

So, that's how one can do that. You have pitch mechanism which basically the gear house the hub and activated electrically or pneumatically. blades are turned or pitched out of the wind to control the rotor. So, then you have the transformer which the power from the generator goes to transformer and converts the electricity from low voltage around 480 volt to the 33 kilo volt. Okay! So, what it does is that you have the speech mechanism so it actually try to do like this so slightly avoid the wind directions again avoid the dynamic loading and torque and things like that so what you have the rotor of the wind turbine extract kinetic energy okay and convert them to into turning shaft so So, wind speed is the main component which determines the kinetic energy of the air and then which is like the blades of the rotor. Rotor area is the area of the swept area, then density is there, then that's how we get the power like that.

So, the important aspect of that blade shape, I mean in terms of cross-sectional, they are made of aerofoil so there are different kind of aerofoil you can see, so, this is low speed propeller blade supersonic intercopter so we will see this in details that different kind of aerofoil shape that, so, what happens in that aerofoil is that when the flow passes over the aerofoil there is a pressure difference that is created so this is P L P upper and that pressure difference that delta P is going to generate the lift and obviously if the flow separates between this and this that's going to get the drag, so, primarily the lift force is something which allows the rotor blades to rotate okay and here the drag force is going to be lost so if you see this picture again so this is our power available but then this is our power coefficient that means whatever we get actual output to the available power Okay, so, that's the power coefficient. Now, the thing about airfoil shape what it impacts is that you see these are because the rotor blades are exposed to the turbulent conditions. So, there could be separation. So, these separations are obviously again, it's changes the angle of attack. So, more and more separation, the more separation, means the drag increases.

And you could see the CL versus alpha that is the angle of attack. So, that typical feature of the airfoil that and these are some of the airfoil you can have. This is a different series of the airfoil and the some flow structure around that, that, So, this flow structure gives you an idea when the flow passes over this rotor bed because at different cross sections there are different aerofoils. For example, if you see here, you can see how the flow passing over this and at different sections these are the aerofoil and how the flow passing over that. So, when the flow passes over this aerofoil, then there could be flow separation.

There could be an active mechanism there could be passive mechanism. So, passive flow control and active flow controls are also area of research where you can actually try to have. So, in passive flow control, you try to have this kind of modification. and active flow controls you try to change the pitch or have some your motion, so that, so whole point is that when the flow passes over these rotor blades which are at the different section there are different aerofoils the flow patterns are different even a blade over here you could see here the flow is separated but in this particular case the flow is kind of an attach So, this particular condition, there would be drag. But it is eventually going to contribute towards the complete drag or the loss of the system.

So, what one has to do is that while doing the design, you have to take into account some kind of a control mechanism that one has to design so that the separations and all these things can be minimized. So, this is again the aerofoil nomenclature. This we will talk about in more details after talking about this momentum theory and all these things. But you can see how this hydrofoil and all this they are looking at it. So, what important here is that you can see the both the views.

This is probably the side view and this is the front view. So, this is front view. and this is side view and how these wind turbines are operated under the wind conditions and how these different components play important role getting the wind energy extracted for our electricity okay so now we can go and look at the aerodynamics of this turbine and look at the momentum theory to estimate the power productions and this other parameters okay that will do discussion in the other lecture thank you.