Wind Energy

Prof. Ashoke De

Department of Aerospace Engineering, IIT Kanpur

Lecture 10: Wind turbine technology

We'll come back in our continued discussion of this wind energy. So, now what we're going to talk about new different technological development that has happened so far. And then what are the challenges that one can face? and some of the component-wise issues. So, that's what now the topic that we are going to cover is on wind turbine technology. So, it's more like giving a complete overview of the technological progress that has happened so far. Some of them probably we might have already discussed upon.

And then, what we would like to take you from there is that this technological advancement that has taken place so far, where we stand in terms of technological challenges, then what are the issues that you have as a need of the hour, and then how we can improve our system or design and things like that. This is important in one hand is that just getting to the more like a group of this discussion of this development and then from there slowly will kick off on the aerodynamics part of it. I mean, and then move on to the design constants and things like that. Okay! So, what we are going to talk is more on the turbine side and turbine technology.

So, the thing has to start with is the installations. So, what is the situation at this moment? Obviously, these are taken from this global energy report. what is the status at this moment and then what is the projection that we have so if you look at the situation at this moment the new installations are almost globally 76 point 6 gigawatt in 2022 and then bringing total installed wind capacity of 906 gigawatt which is a growth rate of nine percent which is compared to 2021 so, in between 2021 to 2022 there is a substantial amount of increase in the new installation across the world and the important players there, obviously China, US, Brazil, Germany, Sweden. All together, they made up 71% of the global installation last year, collectively 3.75% lower than 2020.

Obviously, when you talk about this new installation, this has to do with a lot of other economical challenges that every country would face. so, their market value new partner investments it has to do with a lot of other economical balances to take care into the system. So, that it can talk about these things now up to 2022 the spread across different subcontinent is different. Obviously, this graph shows how this, again, this report was there in 2023. That is why the data is there tabulated up to 2022.

If you see 2020, there is a huge installation, then there was some deep between that portion. But one of the important thing to be note here, majority of the installations in onshore instead offshore. If you go to North America, you have 60 gigawatt of onshore wind capacity expected to be added in next five years, which will be 92% built in the US and the rest of Canada. Europe, with strong demand with Germany, Spain, UK, France, Italy, Turkey, obviously UK is out of that European Union though. 2024, then Africa has 17 gigahertz of new capacity expected in 2023 to in the span of five years up to 2027, out of which 5.3 gigahertz would come from South Africa, 3.6 from Egypt, 2.4 gigahertz from Saudi Arabia, 2.2 from Morocco. If you go to Latin America or Southern America, obviously 26.

5 gigawatt upon shore wind to be added in this region in next five years over Brazil, Chile, Colombia contributing total 78% of the additions. Okay! We have this kind of new installations which are going to come over. for next four to five years now what is the projection, the projection for 2030 is quite heavy or i would say the obviously every country is taking different measures different nationwide policies, somebody would like to reach some target by 2030 some countries would like to target reach target by 2035 some by 2040, 2050 these are global worldwide some scenario and this is what by 2030 so so global wind market so what it there is that capacity build up of 143 gigawatts. So, obviously the key reasons behind this upgrade include energy system reform in Europe. They try to replenish the fossil fuels with renewables to achieve energy security in aftermath of Russia's invasion of Ukraine.

China's commitment to further expand the role of renewables in its energy mix and anticipated 10-year installation uplift used even by IRA. So, you see this curve, what is projected is quite heavy. What is the total cumulative global installation that is expected? So, it's a two terawatt milestone is expected to be achieved in next six to seven years. So, that's quite a bit of humongous target. But yes, every countries who are having the feasibility to exercise this wind energy harvesting capability they are into the game and they try to do this process and there are some onshore demand, there are some offshore demand, so, obviously onshore wind demand and some benchmarks demands or dominates the global onshore wind turbine which is within 82 gigawatt of annual capacity.

Europe is the world's second largest onshore turbine production base, followed by US

13.6 gigawatt. India is also not very bad, which is 11.5 gigawatt, and then Latin America. So the supply chain in India, China, Latin America will have enough national production capacity to accommodate demand while the rest of the world in a business as usual scenario will continue to rely on important wind turbines to cope up with that anticipated.

So, this is onshore installations talking about that. Now, when you go back to the offshore demand within the projection between 2023 to 2030 or 2030 to 2031, Compared with onshore demand, the chain of offshore wind turbines is more concentrated due to the fact that more than 99% of total offshore wind installation is presently located in Europe and APAC region. Yes, I mean having said that China is world's number one offshore turbine national production center with annual assembly capacity of 16 gigawatt of which 1 gigawatt is owned by own western turbine manufacturer. So, these are the situation challenges in terms of demand production can that means what we would like to achieve by 2030 with this kind of production capability that's quite challenging so, this is a wind farm and pincer peak in alberta which just to give you an idea this is a picture that how the farm is installed and all these things but you have to keep one thing in mind that whenever this farm installation is taken care of or done so there are plenty other things need to be taken care of because One is planning to install this kind of farm wind farms and sure it is optimized in terms of every aspect. But there are challenges.

I would say there are challenges for wind farm optimization. So the challenges in a sense this is slightly away from your single turbine optimization so one hand you can talk about single turbine optimization but when you talk about the wind for optimization these are the different channel challenges that you have here you have to optimize collectively group of or set of turbines positioned together again expected growth offshore turbine size globally which we have already talked about that again I would like to re-emphasize because we are somewhere here close to 8 megawatt projected by 2030 11 megawatt and the one design that we are talking about in a real now working on a 15 megawatt turbine So people have been doing a lot of research on that. So that's the projected path. So in this path, key challenge is that the design, manufacturing. OK! So, design includes everything.

So, we'll talk about those things later on as well. That is like talking about the aerodynamic design, talking about the structural design, how they are coupled or interlinked. So, these are the things that we would be discussing in details as we move on with our discussion offshore turbine the turbines for offshore application is also growing from 4.1 megawatt in 2015 to 11 megawatt by 2030 but there have been discussion of offshore turbine reaching 15 megawatt and even 50 megawatt capacity so this is an key challenging area Because more and more power that you would like to generate, the thing that is going to be, because power is, higher power is proportional to higher area. So, that means higher D, rotor diameter.

So, more and more larger rotor diameter, so that's going to cover a larger swept area. So, once you have larger swept area in that fashion, you need serious development in terms of materials as well. Because the larger turbine is going to be, even a three-bullet turbine is going to have a huge weight to carry. And the important part is that these blades are going to be in rotating frame of reference. That means there is a rotor which has to hold this and then rotates for generation of power then you have your mechanism pitch mechanism these drives are also sitting inside the nacelle and they have to kind of move these turbines blades depending on the wind direction to accommodate the wind availability.

So, the challenge here is that also the apart from your aerodynamic design apart from your structural design you need light material or literally ultra light material so that there is no extra load that comes on the tower or the foundation and things like that and also the rotor mechanism because these are mechanism if you have a because if you have a two larger area and this is a rotating body there is a chance of damage or collapse due to this dynamics of the system so we'll be talking about the dynamics vibrations partly and quickly try to see about that so key thing is that as you grow or expect to have more power producing capacity with larger diameter you also need to have ultralight component materials using c fibers composites and things like that so that you can have less weight on the structural design curves, okay! you can see some example of power curves for wind turbines with different rotor diameter this is 80 meter, 87 meter, 90 meter and the power generating capacity 2 meter so this is a wind speed which is exposed to and these are different diameters i mean 80, 87, 90 and all are rated or capacities to make a generator so you can see what happens is that, even the 90 meter diameter turbine once you increase the wind speed beyond 20 21 meter it drops other two remains flat at that rated power now, one can immediately think about why this is happening. This is happening because once you have larger rotor diameter once you increase your wind speed your turbulence levels are also going to increase, so, once that happens there is a likelihood chance of separation is taking place which we are going to talk about soon that separation is going to take place over the blades or rotating blades. So, those separations are going to cause increased drag and that's why subsequently we have drop in the power production. So, because these are different kind of challenges one face in rotating I mean, I would consider this wind turbine is like a rotating machine. If some of you are mechanical engineers or electrical engineers, you know how these rotating machines work.

I mean, for mechanical engineer, you have seen pump, turbines, steam turbines, gas turbines, compressor, these are rotating machines, fans. So, the rotating systems are bit challenging to handle. So, there always would be a range where you can operate very nicely or with an optimal way. As soon as you go beyond certain level, there could be a drop in your output. So, what is causing that thing? So, as we have talked about it, when the wind passes over those airfoil or the rotating blades which are I mean if we just draw a blade like that which is connected to the hub and if this so at different locations you have these are the aerofoil shape that you have over which the flow passes and once the flow passes over an aerofoil typically due to this theory of aerofoil there is a two forces which are going to be coming out of this one is the lift force the drag.

Now, for aircraft the lift force is required to take off drag is required when it touches down or during landing here the lift is what makes the rotor to rotate so that, once it rotates that's why the rototic motion gets converted to that electricity production. So, the aerodynamics of a wind turbine have much in common with the aerodynamics of air wing but obviously with some differences. So, this should be slightly much bit clear so you can see this is my rotor and this is the this is hub and this is the tip and this is how it is rotating so this is an section where you can see obviously this is the wind direction and then is kind of an aerofoil section which has been projected here then this aerofoil is exposed to different component of these velocity triangles. And finally, what you get out of is the lift force, drag force, and their components. But the aerofoil is exposed to different angles, flow angles, angle of attack, pitch angle, and all these things.

So these are the details of these things that we'll work out later on. but similar kind of things happens on the airfoil wing same thing you so that's the similarity but so here the only difference between the aircraft wing or this is that these forces are going to especially the lift force is going to rotate the turbine so, that you have a generation of power. So, this angle distribution of the forces that again we will see in details and then from there we try to see how we get these productions of the power. So, now once you talk about power productions or energy productions the key player is the efficiency. We have seen earlier That we talked about some limit like bridge limit, we talked about some transmission efficiency, we talked about some of this mechanical gear efficiency and some of these things.

So, when you talk about the wind turbine efficiency, it's a simple thing to characterize. It's that the amount of electric power that is produced. to the wind passing through the area by the rotor blades or the wind power. So, it is the wind power, how much wind power converts to the electrical power or electrical generation because when the wind passes over this aerofoil or the passes over these rotating blades So, they allow these blades to rotate and that motion getting converted to this production of the electricity. So, the amount of electricity or electric power produced and how much is wind power getting in that is what the efficiency of a turbine.

One of the important efficiency factors is the aerodynamic efficiency, which is nothing but the ratio of the mechanical power of the rotor to wind power. That means how much wind power I give an input and how much I get an output as a mechanical power. That's how the aerodynamic efficiency, because the wind power is purely aerodynamic power. And that's the conversion efficiency, how much I will get into the mechanism. and then i have mechanical efficiency which is again connected with the mechanical rotor axis generator and all these things so there would be this machine components which has this conversion efficiency that it doesn't convert the completely amount of this then you have electrical efficiency so that is the electrical power fed into the grid to the mechanical power of the generator that means I have stage-wise these efficiencies.

One is that the wind, which is when the air passes around these turbine blades, how much wind power one can generate from the aerodynamic point of view. And that wind power, how much is getting... So that's your aerodynamic efficiency.

Using that, how much can be... The generator axis gets a power which is mechanical efficiency. Then that generator power to how much electric power would be output as the electrical efficiency. So all these efficiencies are going to affect. So that means wind power, which is from the aerodynamics point of view multiplied with these efficiency that much converted to the electrical output. So that's a total efficiency of my wind turbine.

That's how you characterize this thing. So the maximum possible aerodynamic efficiency is given by the base law or base limit which is 59.3 percent so which occurs in turbine by two by two third of its original speed aerodynamic efficiency of a real time varies with wind speed having a typical peak value of 44 percent and average values of 25 percent so what happens is that typically the mechanical efficiency is order of 96 to 99 percent electrical efficiency is order of 96 to 97 percent then multiply these efficiencies get the overall efficiency obviously if the overall efficiency then mechanical efficiency electrical efficiency into bridge limit or internet efficiency so all these efficiency multiplied together gives the overall efficiency of the system that's how you get these efficiencies into place now if you look at the output versus efficiency okay so you can see the variation of the power output efficiency with the wind speed so this is again a typical say series this is in 90 is the 90 meter rotor diameter 2.3 my god is the output x-axis shows the wind speed And this side is the efficiency.

This is the output. So you can see how efficiency is getting into that constant line with change in wind speed. So beyond the wind speed, there is no change in the efficiency. That becomes pretty much up to this point one can think about. That means beyond 13 meter per second is efficiency.

Obviously, this is part of it. so one has to have different turbine map for that and then this is the output so up to a certain maximum output and then you get to see this is the max output you have and then there is a down once you increase the wind speed so that means your power output Again, this kind of curve can be generated for different kind of turbines. Because once you change the diameter of the turbine, then that's going to change the characteristics of this curve. But this is an example for this particular turbine. This is just to showcase. how this output varies with the wind speed, how the efficiency varies with the wind speed.

So, what is clear here is that if you keep on increasing the wind speed or if your turbine is exposed to very high wind speed, neither your output power is going to be more, it rather decreases. That means there is always an optimum range of wind speed where a particular turbine can produce the maximum power and there is a range where your efficiency goes to maximum and after that it remains constant. that's the key message here that every turbine has an operational limit and that is coming from your design parameter so, if your turbine is exposed or if you try to operate your turbine beyond that limit then you are going to have an reduction in your output in terms of power output in terms of efficiency so that's how one has to think about it in designing the system okay So, we will stop the discussion here and continue about this different aspect of the technological part of the wind turbine in the subsequent. Thank you.