Wind Energy

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Lecture 11: Wind turbine technology (contd..)

welcome back, so, we'll continue our discussion on this turbine wind turbine technology and what we have talked so far regarding the updates that in terms of wind speed versus efficiencies and all this. Now, the next topic. That we would like to talk about. Or little bit touch upon.

The turbine generators. So, obviously. These are electric generators. Okay! So which are.

Having. Three. Stationary magnets. As part of a stator. Which is a circular ring.

Within which. rotor with further magnets rotates. Where is wound around each of the stator magnets, the rotating rotor magnet induces the fluctuating voltage of each of the stator magnets and, since the stator magnet is offset by one-third of the circumference, the current produced in each wire is also one-third of the adjacent rod that produces what is called the three-phase AC, alternative currents. we can see a schematic here. This is a two-phase synchronous generator.

Okay, so this is a typical schematic which shows how this, around this, these magnets are located. And, obviously these are now wearing around the magnets for this, I mean the electron flows which are essentially going to produce the electricity. So, you look at the voltage versus time. This is three-phase AC current. So, there would be one, I mean this current is.

This shows that voltage versus time and it's a different variation in the curve. Obviously, they have some phase difference. Okay. Now, typically in three-phase AC current, the frequency of the electricity produced by the generator rotor with one magnet would equal to the rotor frequency. So, that from a rotor with two magnets would be twice the rotor frequency.

because, the rotor would need to rotate only half cycle to go from one to the next one and so on. Typically, if you see the electricity in North America has 60 hertz, that means 60 cycle per second, but wind turbine rotor might rotate at 10 cycle per second. So, most of the turbine system gears is needed to step up from the turbine rotor speed to the required generator rotor speed. See, in India, it is a 50 cycle per second, so we have a kind of 50 hertz and things like that. So, what it means that what your turbine produces, then you have to do some kind of a necessary adjustment to make it usable.

as per user demand and things like that. So, there are some basic variant of the generator. Number one is the asynchronous or the induction generator in which the magnets in the stator are induced by an electric current supplied by the grid from the grid to which the turbine is connected. Okay! So, that's an asynchronous or induction generator. Then you can have an asynchronous generator which may or may not have permanent magnets, not requiring any electrical current from the magnetization in the state.

So, these are couple of the variants of such kind. Then you have this asynchronous generator further can be divided into squirrel cage induction generator, which is ACIG, or the wound rotor induction generator, WRIG, which is different in how the rotor is constructed. I mean, next slide will show how they look like. So, that means the asynchronous generator can be divided into to this kind of squirrel cage and the wound rotor generator. Now, this is a schematic diagram of the squirrel cage induction generator.

So, one can see this view of that three phase stator. This is the rotor shaft. These are end rings and conduction bar in the squirrel cage. so, that's how the schematic looks i mean and similarly, if you look at the wound rotor induction generator so, these are old rotor induction wrig and this is the squirrel cage induction, so, there is a difference you can clearly see the way this has been. So, here the coil is here, then you have the laminated core, here the laminated core and copper coils.

So, these are different kind of induction generator, which is going to, I mean, obviously depending on the choice that, but the choice of generator would strongly affect how the wind turbine rotor rotation rate varies between speed obviously that is one way to look at it but the other thing that would happen is that the it would affect the wear and tear efficiency and noise and all these things so which means choice of particular generator also has an impact on the other issues which are kind of in terms of noise, efficiency and all these things, losses. So, now when you look at this asynchronous SCIG or WRIG, so if your generator rotor rotates at the same frequency as the electric field in the stator then there will be no electricity would be produced whereas when the rotor of the generator rotates faster than the stator a strong current is induced the harder one cranks on the rotor the more power that is transferred as electromagnetic force to the stator so which is converted to electricity and fed to the grid and the difference between the rotor and the stator frequencies is known as slip at peak power it is only a few percentage that is the rotation rate of the turbine rotor varies by only a few percentage between zero and maximum power so that allows some variation in the rotor speed from minus 30 percent to plus 40 percent from synchronized speeds, the dfig which is doubly fed induction generator which was developed that means the stator and the rotor of the w or iv type are connected to the grid, the stator as usual with the current that induces meditation the rotor directly fits 30 percent of the power output through a partial scale frequency converter that produces ac current as that when it is rendered with the stator output, the resulting current exactly matches the frequency of the lead even as the rotor rotation rate varies. So, if you look at the schematic diagram of that DFIG, so here is the blades which are rotated, this is gearbox generator. You have AC-DC converter, then you get the power output. So, that's kind of an, there is an evolution that has taken place in the Starbank generator and one is that permanent magnet synchronous generator.

But, obviously this is not heavily used at this moment because this is quite expensive and mechanically more complicated than indexing generator. When you say that, that means the production of these things are not that happening. Then the permanent magnet requires rare earth elements like neodymium or dysprosium. So, that could be in short supply in the future. So, that is another reason why they are not heavily used.

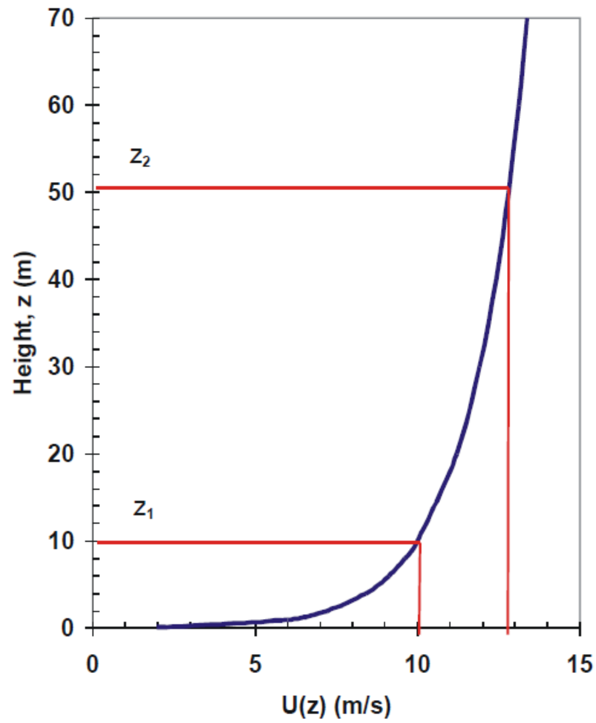
But obviously, if this permanent magnet synchronous generators are connected, those turbines are more efficient, allow a wide variation in turbine rotation rate, and then land themselves to eliminate the gearbox altogether. Presently, about 10% of the wind turbines being sold using permanent magnets, but this fraction will likely to grow. More and more this kind of generators are produced and kind of installed along with the turbine blades and other things. So, this is the production of neodymium and dipso-disposium for permanent magnetosynchronous intermediate energy is anything but clean as toxic waste dumped next to a processing plant of China, which one can see. The challenge here is that once you try to use this kind of rare earth elements, then it's quite a bit of challenge to have the waste also, which should not have indirectly having an impact on the environmental aspect.

Now, from below, the AC output of the wind turbine or variable frequency is converted to DC and then converted back to AC of the exact frequency and phase needed to match the grid. But, so, what it means that the turbine output is AC, it is converted back to DC and then converted back to AC for frequency math and use. However, if we are about to transmit the electricity as DC, we could skip the DC-AC conversion at this point. It's a problem related to this transmission and other things when we have to do this ac dc conversion when it is coming out of the turbine output. Okay! so, these are the things which are handled by the generators so, different improved generators can improve the operation of this turbines and all this now.

Another important aspect of the wind characteristics. So wind characteristics, that is what is also very, very important. We have been talking about the availability of the wind, so offshore or onshore installations and their differences, advantages and things like that. But having said that, one can consider that there are certain variations in the mean wind speed there. But, that is there with the height and all these things.

Obviously, turbulence intensity is also varying. You have these wind speed variations with the distribution function. So, that is also varying. So, all these are taken into consideration. So, these are the important factor.

And one has to understand while designing the turbine, these are the factors which are going to impact the day-to-day operation of the turbine. So, question is that these variations are quite natural. So, it is not somebody artificially has created this but these natural variations are also kind of they have impact on the, if you look at the variation of the speed with height so that follows some kind of an logarithmic profile but, what i'd like to comment here is that this is kind of a boundary layer profile, at surface. Okay! So, that's the reason, why we have earlier, discussed about boundary layer and all these things, because when the wind flows over surface, then definitely it will have some boundary layer effect and here is an example where you have the velocity profile which is very good the height i mean effectively it's generating a boundary layer this requires but, this input required to be fed while designing the same system rather than so, which means that I can have a turbine like this and there is a flow so, should not consider that uniform flow which is going to hit the turbine. an alternative representation with the height.



$$U(z) = \frac{u_*}{K} \ln\left(\frac{z}{z_0}\right)$$

$$1n\,(z_0) = \frac{U(z_1)\ln(z_2) - U(z_2)\ln(z_1)}{U(z_1) - U(z_2)}$$

B/L profile at surface

So, you at a particular height with the reference you can with the height put some polynomial to the origin. The logarithm relationship is theoretically valid in neutral atmosphere only. But, this one does not have a theoretical I mean doesn't have very strong theoretical basis although it provides a very good fit which one which is typically observed when atmospheric wind profiles again, we look at this so now what we get the power output of the wind turbine is multiplied with the efficiency swept area, power density of the wind so power density of the wind is up to v cube so that's what you get now coming back to the another important aspect of this is the webel distribution function, now, why that is important we have talked about this distribution function or probabilistic or probability distribution function which gives you an idea about the variation of any field with some space and time. Now since wind speed kind of fixed for a particular location and all these things. But what it is varying is that over the year since the earth rotation is different heating on the surface is different so there is a variation in the speed.

So, that variation is there over the month, the variation is there over the week, the variation is there over the day, even within 24 hours there is a variation. So, we take some kind of a probability distribution function in terms of Weibull distribution which matches that distribution probably quite well. So, that function is typically defined with some kind of a k by c. This is the definition. So c is the scale parameter, k is the set factor.

And these are kind of, depends for a particular location, if you kind of measure the wind speed variation, then you can come up with these factors, I mean how they look like and all these things. If you look at this Weibull wind speed distribution with c equals to 5 second and kappa is 1.6, you see this probability distribution function with the variation in the speed. so, this is quite useful in terms of when somebody is like to design the system. Similarly, you can compare this variable distribution function and corresponding the cumulative probability for c equals to 5 second and kappa 1.

$$f(u)=k/c(u/c)^{k-1}\exp(-(u/c)^{k})$$

6, this is the probability distribution and this is the cumulative probability over a variation of the own speed. So, you get to see how the wind speed is varying and how your cumulative probability is also varying so these are the things which is going to be important so what is important is that the mode is the wind speed where peak is the peak of the probability curves open it can be read off from the graph or computed by setting the derivative of the weibull distribution function to zero and salt point and also you can find out the median based on this distribution and then you look at this distribution for different shape factor scale factor you find so all c and kappa value for a different situation so, the kind of i mean get distributed over now here is an example which shows the interesting things the two level distribution probability distribution is almost the same means wind speed but a very different mean wind power, okay, one case the kappa is 1.6 other case 2.4 so you can see even the you can have almost same mean wind speed but they are having different mean wind power this is the probability and all this so you can see that differences with and that happens is that when you try to find out the mean wind power and things like that then you need to integrate that cup So, whole point is that that the wind power varies non-linearly with wind speed. So, the mean or average wind power for a given mean wind speed depends on the shape of the probability distribution on either side of the mean wind speed.

And the mean wind power based on wind power computed at many different wind speed and then weighted by probability is about twice the wind power computed once in the So they are going to be different. One can see a smaller K means a more spread out. This is smaller scale. This is medium K.

Wind speed distribution. So, more winds at both very high and very low wind speed. But the high wind speed proportionally contribute to the wind power due to cubic dependencies. So, the mean wind power is greater at a given mean wind speed with smaller k. So, this is clear more from this comparison chart if you see here I mean it is computed the average wind speed. So, basically wind power is computed using average wind speed and the distribution.

average wind speed 3579. So, if you look at the wind power at average wind speed, so you get 16, 75, 207, 439 like that. This is based on the average wind speed and you calculate with all this. Now, typically the wind speed varies and there is a distribution. now, due to that distribution let's say the distribution have a kappa factor 1.

62 or 2.4, i mean that can be also radiation but what pointing out to this particular thing is that now, if you have a distribution and then using that distribution if you find out the wind power then you can see it is quite higher than what we have obtained based on the mean wind power so now there is a different kappa factor but nevertheless these factors are quite less than these factors do so that means for a given location it is very very important to know the wind speed distribution or the wind speed characteristics not only their variation with the height also that spreading the distribution because the distribution if you consider the distribution then obviously you can estimate or generate more power rather than if you try to see okay my average, i mean, i would like to compute the power based on average wind speed always you are going to get the low value of that so what it says that the power output at any given wind speed obviously, it's given by the wind power in the sweep material and the efficiency so the efficiencies matter more when the wind power is larger than when then it's smaller An approximate mean efficiency will involve the efficiency at each wind speed times probability of that wind speed interval and that divided by the mean power. Okay. So, the mean efficiency versus wind speed term shows that different turbine power curve we will distribution so this is mean wind speed this is mean efficiency and shows that the different curve so these are using again these are using different shape parameters, okay! so, if you use different shape parameter so this shows the variation so here the more than a number it's an idea or the understanding how the power output varies because of this distribution of wind speed and its variation and things like that. So, that is something that is very, very important here to know. that yes due to the rotation due to uneven heating there will be variation of the wind speed for a particular given location but that distribution is very very important to be considered rather than considering the mean wind speed because that's going to change my power output as well okay, so we'll stop the discussion here and continue in the next session