Wind Energy

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Lecture 12: Wind turbine technology (contd..)

Welcome back to this particular session. So, we'll continue our discussion on this wind turbine technology. So, we have looked at different kind of turbine generator and how those generator play a key role in electricity production. And, then we looked at the characteristics of the wind, which is very, very important because the wind characteristics plays an important role in terms of design because as we have looked at it, see, wind distribution is.

.. not uniform across the, I mean, daytime, not over the week, not over the month. So, there is a variation and that variation is kind of an probability distribution function of that distribution.

So, there is one kind of distribution is the Weibull distribution. There are other kind of distribution that we will talk later. So, what happens is that because of that different distribution now you can generate wind power at for different capacity factor and all these things and how that varies we have looked at now the important thing that we would like to talk about is the capacity factor, so, the capacity factor is essentially ratio the capacity factor Usually termed as a ratio of the mean power output of the turbine. So, essentially this is mean power output of the turbine to the peak or rated power output. So, that's how you get the capacity factor.

So, typically the mean power output is computed as the power output in the center of each wind speed interval times the probability of that interval and summed over all the intervals in the total probability. So, this is how one can estimate the capacity factor and this is an important parameter to characterize the wind speed, wind turbine performance and all these things. So, obviously one can immediately think about this is a performance parameter. So, this is nothing but a performance parameter. So, what you can look at it here, the variation of the capacity factor with wind speed for three different we will say parameters so, we will say parameters are varying parameter over kappa so one can see how the capacity factor is varying probably over a different range of point speed so this gives you an idea how the capacitive factor changes and also one can see the capacity factor variation for different kind of wind turbine this N90 is a 90 meter rotor blade diameter, this is 80 meter, this is 100 meter, you know their power output pretty much of the similar range 2.3 to 2.5 but you can see how the capacity factor variation is there with the variation with the different mean speed okay so, this this gives you an idea this capacity factor is pretty much dependent so one important aspect of the capacity factor is that you can see this is very much dependent on the, i mean obviously, the turbine size but at the same time they depend on the wind distribution and that is why if you go to different country so you show a different variation of the capacity factor because the country wise distributions of their wind profiles I mean wind distribution profile these are quite varying since those parameters are varying so you get to We see different capacity factors over there. Now coming back to that, we talk about wind farm. So, wind farm is, it's a cluster of wind turbines which are kind of placed in a given region where you have good availability of winds. They are typically spaced five to nine rotor diameters apart and along with the directions.

and also three to five rotor diameters apart in the cross twin direction these are coming from the best practices i mean i mean the reason behind placing them because once we place this turbine one after another so there are issues related to the wake effect drag and all these things which we again talk about that how these wake effects impact the turbine performance and things so that's what these turbines, i mean, one can think about that, okay, this one turbine this is one turbine this one turbine then the back turbine has sudden distance so because the effect of this front row turbine is going to impact the second row of turbine so that's what the turbine placing is very very important to have a optimized performance of the farm obviously clustering reduces cost and takes better advantage of the best wind side but this one has to be very very careful about placing of this turbine because otherwise what will happen is that most of the time if your wind is blowing from this side, the front row is going to generate the power and the subsequent rows will be essentially impacted by the front rows. That's why this clustering has to be proper. When you look at the large wind farms, I mean impact of the wind farms on the weather and climate. So, large wind farms which have let's say a few hundreds of wind turbines, and they are kind of closely spaced, separated roughly by seven rotor diameter, it will have a noticeable effect on the regional winds, also on the vertical fluxes of heat and moisture in the atmosphere. That would also change the surface air temperature in that region of the wind farm and downstream from the wind farm.

So, if I have a space where I have these wind pumps, I mean the cluster of turbines which are located, then obviously this has huge impact on the local atmosphere, temperature and all these things. So, ahead and downstream locations are also getting impacted because of that. So, interference with the winds also reduce the overall power output from wind pump by 30% compared to the case where the winds are assumed to be unaffected by the wind. If we have some kind of an obstacles or some kind of an interference of the interference with the wind there is a likelihood possibility is that the winds are going to be affected by this wind farm, what happens in the wind farms these are so like and typically this, i mean, the examples shown with the comparing the swimming of fish, you see that the back of the fish, these are the vortical structures. This is going to happen because the fish, I mean, if you assume here the fish structure is having some kind of an aerofoil shape with the same similarity goes with the turbine blades which are also having some airfoil shape.

So, behind that shape there would be vertical structure. So, the placing of different turbines is very very crucial parameter because one turbine should not be spacing right behind the other turbine so this kind of placement is usually not desired because then the second row of turbine is going to be impacted by the vorticity formation of the front row of turbine So obviously, always what happens is these turbines are always placed in the form of a clustered manner. That is something that is very common practice. And, the primary reason behind that practice is that it is avoided that the second row of turbine or tertiary row of turbine should not be getting impacted by the wake behind these front rows or preceding rows of the turbine. So, this is clearly visible from this fish-like structure what is going to happen.

So, this concept is quite advantageous in the firm optimizations or the design of the firm, because what happens is that once you avoid this placing of the secondary or tertiary turbine avoiding the weak structure then you can improve the efficiency and that could be advantageous for the turbine performance and so on cool turbines usually mounted on the seabed and water up to 50 meter deep can double or triple the cost of turbine plus connections the grid but there can easily be twice the electricity production net result electricity about the 50 percent higher price weight twice the capacity factor turbine specially designed for offshore conditions have been built so, you can yes, i mean, offshore performance could be the always higher this is a picture of the offshore wind farm and you can see how the turbines are placed across this so I mean the offshore installations are quite high in the European countries. So, that's now when you talk about that. So, these are talking about the foundation. So, the foundations also. So, this is a gravity based support structure.

This is monopole support structure. This is tripod support structure. So, foundations are something which goes inside the surface, support this whole turbine unit. Obviously, this is our tower. And these are the blades.

And this, you have the other structure. This is also important because your support structure is going to play an important role in holding the whole unit. In terms of design, one has to be again considerate about the support structure, their frequency vibration which will again talk. This is again taking the picture from the Belgium offshore wind farms which is having producing kind of a 2244 megawatt of power. So, it shows these distributions and the placement of the turbines.

So, the source is there so one can look at it. Here is another one which is North Sea Wind Farm Network concepts. So, you can see these are mostly you see these are offshore installation. So, the offshore installations as we have talked about earlier in the Europe has the most of the offshore installation at this moment in the whole world because this is some one of the several u.s east coast and east asian right concept, so, this is in the asian offshore this is the u.

s east coast installation but yes i mean these countries the offshore installation are quite late but in europe compared to europe because europe has the most or majority of the offshore installation. So, there is another concept called floating wind turbines. So, this is one concept which involves triangular shaped floating platform with a 3.2 megawatt turbine at each corner and outward inclined tower. One rotor would be on an airfield-shaped tower that would act like a tail of an airplane, serving to continuously and automatically orient all three rotors perpendicular to the wind.

So, this is an example of the wind turbine prototype. So, this would float. And always anything on the offshore could be advantageous. because wind availability is quite high. So, if you have high wind availability, it allows you to have more power or allows you to generate more power.

This is Fukushima Floating Wind Turbine Platform, which is again, you can see this kind of a basis there. So, then you have this floating wind turbine has an output of around 7 megawatt. This is in Fukushima, Japan, where it was kind of installed in 2015. So, these are some of the information which would be quite valuable in terms of giving you an or getting a knowledge that what are the possible scenarios and which countries are having those kind of platform in place so that they are kind of using those obviously it has to support So, this was the northeast coast of Cotland in 2017, the first commercial floating wind turbine which installed capacity of 30 megawatt. So, obviously that could cater to around 20,000 homes.

If you see, these are the kind of an underneath of the, I mean, this is the water level this is underneath of the water level and this is the structure which is the above that above the, so, you have a certain height of 19 meter, the size of the rotor diameter is 154 which is quite high but it shows that this was commercially commercially launched structure which could produce now when we again come back to look at the capacity factor, so, the offshore areas tend to have stronger winds than onshore winds, so, going to offshore wind turbines but close enough to the shore to be mounted on the seabed big improvement there is a big improvement So, the typical capacity factor on onshore is 25 to 30%, fixed bed offshore is 40%, floating offshore is 50%. So, you can see how the capacity factor is increasing. Obviously, the capacity factor higher means higher power output. So, double the capacity factor, that means capital and maintenance costs can be doubled where the unit price of electricity would be the same but yes i mean we have earlier seen that the offshore installation is advantageous compared to the offshore installation But the floating offshore installation is further more advantageous than normal offshore, fixed-weight offshore. But yes, I mean, something advantageous means there would be some challenges associated with that.

This is a network of floating offshore fund proposed for the North Sea. This is the complete area. You can see that, I mean, but.

.. use that available wind in north sea the available wind and then utilize that for the so the countries which are going to be quite closely associated with that the france, Belgium, Netherlands, united kingdoms, and all this now coming back to an important aspect the fluctuation in wind electricity production So, what can happen is that there might be times when the wind speed might be less than the cutting wind speed so that the new electricity is produced. Some amount of non-wind backup capacity is needed. Then, also wind is variable, some power unit that can go up and down to offset the variation in wind electricity productions. The problem is that the units most able to fluctuate rapidly tend to be less efficient than the units that would normally be used, such as coal, steam turbine, or combined cycle natural gas system. So, one has to minimize the variation in the electricity production from the wind.

And this variation or fluctuation can be effective in how one can think about it. It would minimize the rapid second to minute fluctuation wind output so what is that use of variable speed turbine provide some smoothing of output at time scale of seconds together several turbines in wind from provide some cancellation of fluctuation at a time scale up to a minute implement short term storage of excess energy flywheel supercapacitor flying hybrid to a connection to the grid so this is kind of a second to minutes is a short term fluctuation to mitigation strategy. There could be long-term mitigation strategy, which is hours to days and months fluctuation. So, I mean, these variations are quite obvious and they are very much geographically location dependent. because every location has its own wind speed.

So, one can link together with the wind farms over a broad region, electrolyzer and fuel cells making and using hydrogen, flow of batteries, underground compressed air, energy storage, CAES, hydroelectric reservoirs, heat pump, flexible use of electric loads. So, these are some of the mitigation strategies to mitigate this fluctuation of wind electricity production, short term fluctuations and the long term fluctuations. So, that what happens is that the production cost doesn't fluctuate too much, which would allow the users to have it. So, this is amalgamation of the dispersed wind farm. So, you can see at different country, their monthly mean wind turbine power and this is the time over the i mean the month is the scale and you see the i mean obviously the carbs here just to show the some kind of an variation so that's the important thing this is an variation in electricity production okay so this is what primarily.

So, what one can do this is where importantly, I mean, one can making use of strategy like short term wind forecast. So, the short term wind forecast, this is where one can use that technique like AI ML, that if you can forecast what is going to happen, then you can try to counter that situation, so, this variation that you have so the aspect here is that these variations are obviously going to be there so one can mitigate using different strategies but, if you can forecast that variations few hours ahead of advance then what you can nicely tackle that situation and you can have some backup plan for that. Wind forecast strategy based on these days AI-ML kind of technique is a good open research area. But yes, to do that, one has to have some data set or database which is again very much important or concern to a particular site because the data that you get in a particular site is going to be, I mean, quite varied to a different site so site to site different data so that means one has to set up some strategy or techniques to measure data in a given particular site and once you have a major database and those database can be used for tuning these aml models and or maybe coming up with a new AI-ML strategy which can forecast better and see this forecasting technique so there could be long term forecast there could be short term forecast and this forecasting technique would allow you to mitigate the situation that you can have due to this variability in the wind power production so this is again as I said this is an open area where then Coming back to the you can have these electrolyzers and the fuel cells. So, electrolyzer generate hydrogen and spitting water using electricity.

So, could be in excess wind electricity. So, this can be other thing. Hydrogen can be stored as a compressed gas. when there is a shortage of wind electricity, additional electricity can be generated by running the fertilizer backwards as a fuel cell. That means, you have to have some system which will combine this kind of different mechanism like wind with the hydrogen-based fuel cell or electrolyzer, so, that when there is a variability of the wind electricity production, so, this backup can be used to provide that.

So, that means as an end user, you will not get to see the fluctuation. Rather, you will get a constant supply of electricity, which is coming from the wind power. So, these are the things then. one can think about compressed air energy storage system so then you can that can be also combined using the gas turbine about half of the turbine power is used to compress the air needed for combustion and then only about is used to drive the generator produce electricity if excess wind energy is used to compress that air and store it underground the compressed air could be directly used in gas turbine generate the electricity when there is a shortage of wind power then wind more than double the efficiency natural productivity, so, these are so that compressed air energy storage system is an another alternative, so, So, that means when you have the extra wind energy produced, that can be used to run the system. Also, you can have geological formations suitable for CAES, that's salt domes, salt beds, porous sedimentary rock and waste.

Underline 75% of the local area in the US, salt domes closely coincide with the best wind resource region in Europe. can also be excavated in hard rocks and then would be considerably more expensive. So what is this? Could be a schematic of the wind series energy flow. So, you have some kind of a spill, then you have a compressed air energy storage which can be used and the fuel and then so, this is the total output. the wind out input and then from total output.

So, I mean this is a kind of a situations where, so CS was initially developed in 1970s and 80s as a means of absorbing excess nuclear electricity. okay, now only two such plants were built one in germany one in alabama now there is a revival of CAES with many plants under construction and plant, so, she is is a good alternative where this excess wind energy can be used then the existing CAES facilities require some more supplementary fuel like natural gas at present but it could be classified biomass. The new CAES are development conditions which are called advanced adiabatic CAES. So, in this particular system which is the advanced one, supplementary fuel is required. Instead the heat that is produced when the air is compressed is stored in form of hot.

molten salts and insulated tank and use instead of fuel along with the compressed air. So, these are some strategies one can adopt to mitigate this wind energy production, the fluctuation in wind energy production. So, you may have less energy produced, but that could be provided by the backup support, which is the excess one is stored or the excess wind energy can be used for something else. So, this is what, I mean, these are the things one can connect with the wind energy system to have a better utilization of the wind power production, okay? So, we'll continue this discussion further and stop it today. Thank you.