Wind Energy

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Lecture 09: Wind Turbine Basics (contd..)

Welcome back to the ongoing discussion on wind turbines. So we are looking at the different aspects of this wind turbine technology. Obviously, we talked about how wind is generated. and now, we are looking at the different components of the turbine and the issues related to the turbine installations and all this.

yeah, the last time that we talked about that as we are increasing with the size specifically we are talking about oriental axis wind turbine where power production capacity can be increased by increasing the turbine area or the swept area but yes when you try to increase the turbine area you will have different challenges regarding installation regarding production, regarding design, regarding system level integration and transmission of the electricity, regarding transportation all these things so, now we can look at that the wind turbines which are working so these are horizontal axis wind turbine which are offshore wind turbine obviously you can see these are installations are offshore wind turbines so that these are working nicely these are vertical axis wind turbine you can see these are it's more like in the blades rotate in this direction so the radial span of the turbine is not that much. okay so, these are the turbine which are which works works nicely now there are some fancy turbine i mean obviously, these are conceptual and people are working towards that so this is some fancy design these are some fancy design these are at the certain height on the roadside where you use the wind which are generated due to the passing cars that can be used and then this one these are all fancy stuff and this can be designed, I mean obviously, one has to do detail analysis and then figuring out the proper manufacturing process and how this can be done now, coming back to the simple thing that if one has to estimate the wind energy power then one can find out the wind kinetic energy and then the wind power this is your swept area Then the power generated with some of this constant multiplied with that. So key wind is the wind power or the, what is generated from the energy of the wind due to the rotation. But then you have this constant.

- Wind kinetic energy: $E_k = \frac{1}{2} m_{air} v^2$
- Wind power: $P_{wind} = \frac{1}{2} \rho_{air} \pi r^2 v^3$ (swept area)
- Electrical power: $P_{generated} = C_b N_g N_t P_{wind}$
  - $C_b \approx .35$ (<.593 "Betz limit")
    - Max value of $P = \frac{dE}{dt} = \frac{1}{4} \rho_{air} \pi r^2 v_1^3 \left(1 + \left(\frac{v_2}{v_1}\right) - \left(\frac{v_2}{v_1}\right)^2 - \left(\frac{v_2}{v_1}\right)^3\right)$
  - $N_g \approx .75$ generator efficiency
  - $N_t \approx .95$ transmission efficiency

This is called the Bayes limit. So, this is a theoretical limit. We'll talk about that once we go and do the detail analysis. then this is coming from the maximum power value then you have a generator efficiency, you have a transmission efficiency, all this you can include in the this what how much power. I mean one is that how much wind is generating or through the wind one can generate the power and then how much can be useful power after considering all these factors and all these things okay, so, what happens is that this is a simple horizontal axis wind turbine okay if you see that wind is flowing through this and once wind flows around these blades due to the forces there are two forces lift and drag forces so when the wind so this cross section area which is you see here this is what it is shown here that means i have the blades over which the air is passes by then if i look at the cross sectional area which is an airfoil and once the wind flows over that then there is a lift and the drag force obviously, the lift force allows this to rotate the blades and this rotation is the main or key contributor for the power generation so obviously, if you see the this is the direction is not correct the air flow motion is this way so when the air flows through the above the airfoil you can have two forces which are generated lift and drag and obviously now you change the air pulse so this is a some angle of attack now this is let's say this is alpha 1 this is alpha 2 which is greater than alpha 1 this is alpha 3 which is greater than alpha 2 So, once you change the angle of attack you can see the flow separate.

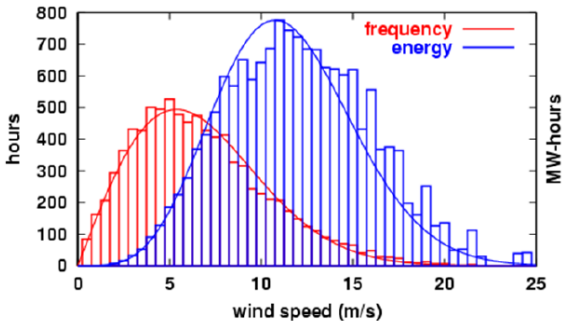
So, this is the region where the flow separation occurs and you have an adverse pressure gradient. Obviously, once you have a flow separation which is occurring here then you have more drag than the lift. But, here this picture shows you when the air passes over

these blades and then this produces this lift and drag force and this lift force allows that blade to rotate. Now, there are other factors which are also an important role that is wind versus weavel distribution. So, this is a distribution.

This is essentially the one can think about distribution of wind flow and these are mathematically represented by that which has some of this so the red here shows the wind distribution of wind speed over a time and this shows the wind energy which is power De by dt why this distribution is so important we have already talked about it, okay! what we have talked about it is that wherever we install this turbine one of the important consideration is the availability of the wind or, wind availability is very very important because The wind pattern or wind flow pattern over the year is different, over the month is different, over the week is different, over the day is different, over a 24 hour clock is different, even within an hour that is going to be different. So this Weibull pattern distribution is one of the patterns which is usually taken into the design consideration of these wind turbine blades that for a particular location, assuming that, okay, the distribution is going to be such kind. Obviously, it's based on some data that one has to measure. And that measurement typically done by the meteorological department where they try to see the wind. I mean, they provide this wind forecast and that wind flow pattern and all these things.

So this distribution, you think about it's one kind of probability distribution function. So it's a probabilistic distribution because wind is not uniformly, I would say uniformly flowing throughout the day, neither throughout the week, neither throughout the month, neither throughout the year. So there is a distribution pattern. Some time of the year, it's very high wind flow rate some time of the year. So, what one has to consider is the peak wind speed or the rated wind speed or average wind speed and then figure out the estimate of how much energy you can or how much energy you can extract from the pattern that you have for a particular location or a particular turbine.

Weibull Distribution: $W(\lambda, k) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{(k-1)} \exp\left(-\left(\frac{x}{\lambda}\right)^{k}\right)$



Data from Lee Ranch, Colorado wind farm

distribution of wind flow

Red = Weibull distribution of wind speed over time

uniformly

Blue = Wind energy (P = dE/dt)

Now, optimization opportunities, which I have talked about it, height selection, which is one of the key aspects. So, one has to see what is the altitude, what is the wind strength or wind availability, constancy, grid access, how far is the grid, how much you have to transmit. So, all these need to be considered that site selection. Then, turbine selection, whether horizontal axis wind turbine or vertical axis wind turbine, hood, the bender, size, quantity, then turbine height, generation precision, then local topography, whether you have hills, ridges, so the turbulence caused by the other turbine. Then, if you talk about the wind farm and the multiple wind turbines are installed, then how they are interacting with each other.

Then, prevailing wind strain, ground stability. Then, you talk about grid upgrades. Then, you talk about non-power constraints or preferences. So, all these are kind of an, that means environmental aspect, birds, aesthetic, radar class. So, all this one has to understand.

How the turbine has been evaluated? You see this turbine was used for pumping water, grinding grains. Now, today, this is primarily generating electricity. So, if you look at over 5,000 years ago, the ancient Egyptians used wind power to sell their silk on the river. So, that's how the wind energy history starts off. later people build windmills to grind their grain in 1891, the first electrical output wind machine was developed incorporating the aerodynamic design principles.

So, all these are consideration for generation of the wind power now if you talk about offshore installation it is very very important what is the location one has to carry out this installation. This has to be a few kilometers from the shore. So, you don't go too far,

neither you go too close to the shore so that you generate proper power. The key feature for offshore is high reliability wind. So, that means you do not have other obstruction in terms of hills, local construction all these are not going to be blocking so that you get the complete free win for innovative move turbines are placed on floating platforms and anchored to the sea bottom so but these are innovative ideas definitely having some advantages but at the same time one has to understand there are challenges of having this kind of platforms which are kind of a floating in nature because the design and all this.

So, this picture shows you how the typical offshore installation of wind turbines are. You can see the wind turbines are installed in this kind of a curvature so that each turbine is not impacting the other and you are exposed to all free available wind. So, that's a Now, you talk about wind power penetration. So, up to 10% is the short term goal for many countries. If you talk about Germany in particular, several power utilities are expecting contribution to be as high as 30%.

Uncertainty of wind constitutes a challenge to achieve much higher degree of grid penetration. And obviously, you need to work on getting predicting power for 24 to 48 hours and things like that. So what are the criteria? Criteria for identification of an potential site. Sites having wind power density greater than 200 watt per meter square at certain 50 meter height and things like that. Now, quickly touch upon the indian status so if you look at indian status you can see this coast west coast of the india is having most of their installation of the wind turbines now, environmental impact - One of the key impact in terms of noise, there are mechanical noise which is coming out of the gearbox, generator, so which are definitely unavoidable because these are the mechanical components, so without that you cannot generate power.

You have aerodynamic noise which is switching sound, Then you have wind power at 350 meter area. Then you have noise level, electromagnetic interference, visual impact, shadow flicker, ecology, loss of bird lives. So, all these are there. Obviously, one has to also consider the annual energy production, capital cost, capital charge rate, payback period, operational maintenance cost, Life cycle cost analysis. Annual energy production depends.

Speed power. Wind speed frequency. Availability of the wind turbine. All these are.

There. That one has to. Consider. For moving forward. So. What are the benefits? Yes.

Important. Benefit is the. the cost is competitive obviously in 2016 what was the average cost was there now this has come down and obviously different countries are envisaging

more and more wind energy production so that they can bring down this average cost to an affordable one so that people can use it more. And also, you move towards that sustainable effort towards the clean energy production instead of using conventional fuel or the fossil fuel. Second important benefit that you have, it creates jobs. because more and more if you get into this particular domain then you generate i mean yes, you require everything starting from your design to manufacturing or production to installation maintenance and everything so you require every. So, it will open up jobs at every sector every different kinds of job so which could be low paid to very highly paid jobster and obviously since this is an very defined specialized area you need trained manpower to handle that kind of things but not sell it open up market where you can generate a lot of jobs on the other hand If you generate more and more wind energy, it can change or diversify the energy portfolio of a particular country.

Yes, one of the important aspects is that you move towards renewable energy production. Once you increase that, your conventional technique would come down so that's what the all other government level policy national level policy the stakeholders these are going to be but not only that one has to note that it can create income for farmer ranchers as well as economic benefit to the communities so if somebody I mean think in more depth so, you can see that it is going to create those jobs or income avenues for people. So, it's not like that these people are going to be obviously in top of all these the important part is that your wind energy is an exhaustible renewable energy source. It's a plentiful and readily available and it's available in nature. But yes, you have to utilize it, harness it with an optimized fashion.

I mean, availability is something in one hand, but then utilization of that or getting it generated and then making it useful for the common people is something different. So, these are one has to work on to find out the balance between two. Okay. So now the other advantage that one has is wind turbines if you install they do not consume water. If you do not consume water it can avoid that this drought and all these things by a large amount.

So that's another thing that one has to kind of think that why this is advantageous, okay? Yes, certainly this is clean because that energy that you generate using wind turbine doesn't pollute the water. We drink on the air we breathe. So wind energy means less smog, less rain, and fewer greenhouse gas emissions. If we increase wind power's contribution to eastern grid by 30%, we'll reduce carbon dioxide by almost 90%. So, these are some of the statistics which shows that if you do something, then how much you can contribute to the nature and in an other way towards the this global climate change and things like that wind energy system have low operating cost obviously one of

the major issues that you don't have associated fuel cost because your wind is the fuel which is available in nature so, It has low operating cost.

It can be used in a variety of applications. Like earlier, it used to sell the boards, cutting woods for grinding. So, it depends how you would like to use it for small scale business purposes, commercial use, household use. water farming, farming, ranches, telecommunication. So, there could be plenty of places where one can use this one or the generated energy to be used in that kind of fashion.

So, there are ways one, right, to think about it. So, in the US, it has been widely used and it's a growing demand for that country where they use these wind powers and things like that. And yes, more we contribute towards that, that will be helpful because every other country is also stepping in towards that. So, this wind and solar energy productions and all this. What it can do is that once you have these high levels of wind energy, which can be integrated with minimal cost increase while providing environmental benefit.

So, one can see how this CO2, NOx, SO2, these are going to decrease. So, more and more you can produce wind energy, you can indirectly or rather directly help the cause towards climate change especially the CO2 emissions it can reduce so those are the advantages that you have obviously, I mean, More details one can find out this website if you are interested and because these are the pictures and things are taken from those sites so that but it gives you a fairly good amount of idea of what are the benefits, what are the advantages you have and how one can utilize those advantages towards the development and things like that. So, coming back to the important question. So, what is needed? Allow wind turbine projects on agricultural land where cultivation is not affected.

That is important. More offshore wind power needs to be accessed and explored because offshore wind turbines are having greater availability of the wind. So, that means wind reliability is quite high. What is the need of the hour? There are national plan. This is what we are talking about in context of India. So, there are nationwide committee which has been established to have a proper picture of wind shore potential of India.

Obviously there are other international agencies which are also pitching in. Wind turbine installations of 50-meter height or above, obviously, Himalayan region, Jamban, Kashmir, Himachal Pradesh, Ladakh area, desert, foreign desert, Arab and Asian in particular, other inland areas in general, so wherever we can use some inland. If you look at offshore installation so higher in indian context which need to be more at the of bengal arabian sea andamans and Nicobar island, lakshadip for wind atlas of the third area so, what has to be done is that one has to quantify the offshore part how much inter-energy

potential you have with the advanced technique at several places along the shoreline. Then it has to be connected with the national level. Some efforts need to be made, indigenous development, commercialization of the turbines.

It requires massive effort in training manpower for inland offshore wind turbines, simulated software, efforts for developing engine-based wind analysis, simulation, modeling software, wind farm design software. Education sectors want us to develop these courses on wind energy, postgraduate level, and so that different institutes can train their students on these things, how this wind energy works and how it can be used further. Then you can do repowering, so replacing older, less efficient turbines with the smaller number of more powerful recent ones. You can meet the targets for renewable energy, develop national regulatory frameworks to expand renewables, including financial frameworks, lead access regulations, and all these things. So, these are highly important so that you can meet certain fulfilled targets and things like that.

specific policy mechanism. So, there are the market for generated power needs to be clearly defined at national laws including long-term fiscal measures to also to minimize investor's risk ensure an adequate returns of the investment one has to also look at the electricity market reforms So, you have to have removal of the batteries to market entry, removing substitute to fossil fuel, nuclear and so on. So, these are more like in most of the electricity market now is kind of occupied with this kind of stuff. So, that one has to. So, these are the things.

Then there are obviously research areas. which one can work upon or rather the scientific community needs to address integration of the WCS which is wind energy conversion system with large buildings, wind power forecasting model for short-term and long-term so where basically AI kind of stuff can be very handy. penetration limit in the great system integration of wind energy, lighting protection of the blade and tower structure, testing and reliability, modeling, I mean, verifications, application. This also standalone non-grid WCS solar conversion system, vertical access wind turbine, where aerodynamic studies, various configuration, offshore their foundation, cable, particular marine operation, human resource development, wind farm design, flow modeling. All this could be part of and all these things. So, these are quite a bit of open areas where the community needs to work together to have better design, better installation.

So, obviously if I conclude by saying that wind power is an emerging as an environmental friendly alternative to meet the ever-increasing world demand from electricity at an effort but lot of effort has to go in obviously there are plenty of efforts have gone in but still there are areas to improve upon and then depending on the country

some customization is required and this can stick to the longer way towards the renewable energy products. Okay! So thank you. I'll stop this discussion here. And now, we can look at the wind turbine technology and things like that. So slowly you can see how we are moving forward with the discussion in this particular. Okay! Thank you.