Wind Energy

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Lecture 18: Wind Data Analysis

Welcome back. So, we'll continue our discussion on this surface roughness and all this. So, what we have talked about this flat terrain, non-flat terrain, how we kind of classify this flat or non-flat. So, quickly, what we talk about now on this, how this flow over this terrain and how to take care of that. In a nutshell, what this is going to do is that when flow passes over this terrain, obviously some kind of roughness effect would be there and due to that there would be some profile and the profile can be estimated like either logarithmic or power law profile and what you do that that kind of get you an effect of this boundary layer which would allow you to estimate the winds here and the wind shear in turn, the design part of it. So, what we now talk about is that flow over terrain.

So, this could be flat. This could be non-flat. So, I mean, whenever flow over terrain, for example, you have Like this is one. So, there is a flow like that.

So, when the flow comes, passes over that, you have recirculation zone. So, you have shear layer. You have outer layer. You have inner layer. all these are possibilities this is one of the things that when the flow passes over that how it kind of so this terrain structure could be different so i mean it could be let's say some kind of a this kind of a structure where you have a flow field and the flow passing around that so you might have different structure.

So, what you can have, essentially flat terrains are quite simpler, but the non-flat terrain, there would be different roughness effect. There could be small scale features. For example, if you have a surface like that, if you have a flow field and maybe this kind of roughness is there. So, the velocity profile here is going to be some kind of a deflected. So, this is small scale features.

Okay. this can then there could be large scale feature also which could be possibly you can have then different kind of shapes also possible okay also possible Now, elevations are possible, which means sometimes flow over elevated terrain also. One can resemble that flow structure like around an obstacle. So, effectively, what you think about, then you can have depression is one kind. Now, these are all having flat terrain, non-flat terrain with small structure.

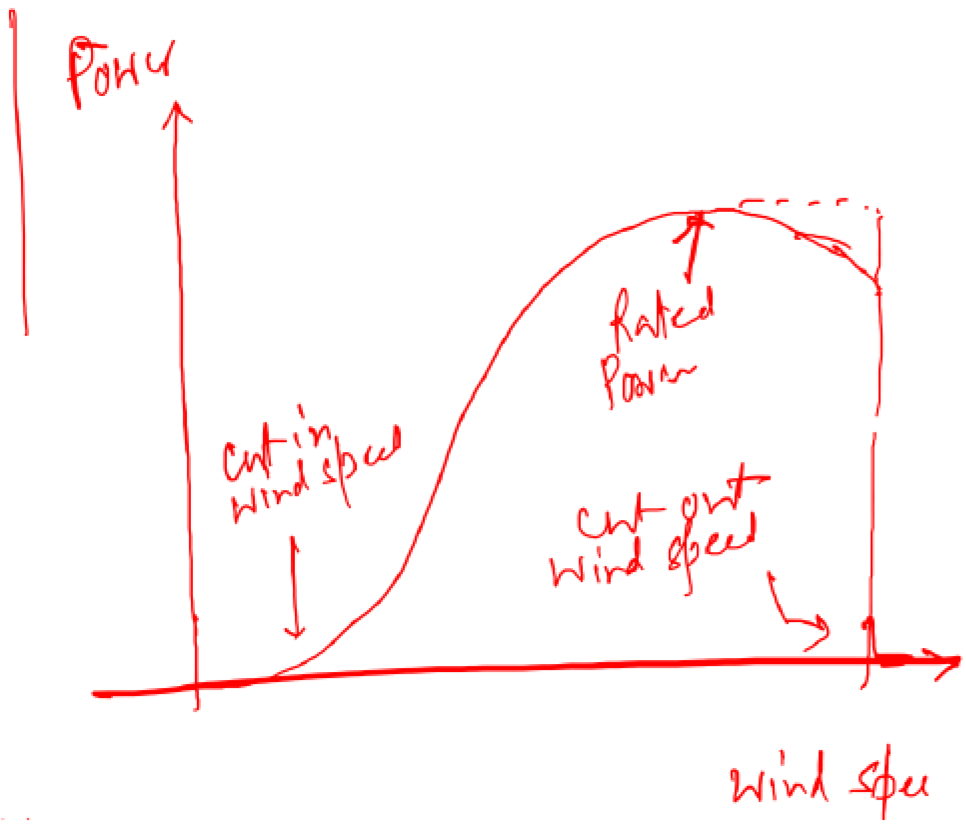
Now, if you have a non-flat terrain with large structure, then there could be non-flat with large scale feature. large-scale feature so you could have valley and canyons okay you could have slow points you could have revealing wins in alignment. Okay. You can have revealing wins in non alignment also alignment or non alignment gaps passes, saddle, large basins. I mean, all these are kind of characteristics of non-flat terrain or the large scale features.

So, what it does is that, so this kind of things are essentially you are having some kind of an obstacle. over which your flow passes so obviously when it passes through this obstacle there could be some velocity deficit momentum deficit effectively your velocity profile gets affected and once your velocity profile gets affected that would impact the changing wind shear and that is what is going to play key role in turbine power calculations and the design part of it so now what we move on to look at is that wind data analysis okay and also some kind of a resource in a run What we are going to talk is the large quantity of data is when it is collected to measurement or instrumentations as whatever is possible. So, then one can analyze that data in a number of ways. So, obviously, one can do that in a direct way. one can do that in statistical way.

So, you can analyze the data in different techniques. So, what we would now discuss is that when we'll talking about this wind data analysis, we are going to look at the wind turbine energy production in general. Direct method of so direct method of data analysis. Then some statistical analysis. And then statistically based wind turbine productivity estimates, so which are kind of.

Again, connected to that. Distribution mean variations and all this. So, we would look at this different ways to estimate those things. So, the general aspect of twin turbine energy production is the available available power from wind, let's say P up to Q.

Okay. So, now one can see a graph which shows power output curve for a wind turbine. If this is my wind speed, then it goes to some kind of thread. OK. So, this is cutting wind speed. this is power this is rated power this is cut out wind speed, okay so, this is how the typical curve what it looks like, so, this has three important portion was in the cutting velocity and it did velocity at the rate emitted power calculations and rated velocity cut out velocity so when you talked about different methods, so, that would also have some impact on this how to analyze that especially when you try to use this direct data which is averaged over a short time interval and sometimes we can use method of beans we can use velocity now let's look at first is that what are the direct methods for analysis, so, the direct method for analysis, Let's say, let's say you have a series of n wind speed observations and each of them are ui and this is average over time which is delta t.



available Power from wind : $(P) = \frac{1}{2} \rho A U^3$

 Then the long-term average wind speed, long-term average wind speed, that is UR, that can be estimated as 1 by N summation of I to N UI. Similarly, one can find out the standard deviation which is sigma of u root over 1 by n minus 1 from a sum of i equals to n u i minus u bar square. if, you arrange in slightly different way then you can write this summation i equals to 1 to n ui square minus n ur square, so, what you can also get average wind power density that is P bar by A. So, that is the average wind power available per unit area which one can write up to half rho 1 by N. Similarly, we can have wind energy density wind energy density per unit area for a given time period of N delta T e bar by A half of rho delta t 1 to n which is P bar by a n delta t.

wind sp.

(1) Long term average wind speed $\bar{U} = \frac{1}{N} \sum_{i=1}^{N} U_i$

(2) Standard deviation $(\sigma_U) = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (U_i - \bar{U})^2} = \sqrt{\frac{1}{N-1} \left\{ \sum_{i=1}^{N} U_i^2 - N\bar{U}^2 \right\}}$

(3) average wind power density $(\bar{P}/A) = \frac{1}{2} \rho \frac{1}{N} \sum_{i=1}^{N} U_i^3$

Now, we can have average wind machine power which is that is 1 by N, 1 to N PwVy. So, this is the power output by a wind machine. So, you can get this. Now the last one that one can estimate the energy from a wind machine that is heat blue. that you write i equals to one to n pw entity okay these are different parameters that one can directly estimate from these things now second way one can do that method of means.

Wind energy density/area for a given time period $N\Delta t$:

$$E/A = \frac{1}{2} \rho \Delta t \sum_{i=1}^{N} U_i^3 = (\bar{P}/A)(N\Delta t)$$

(4) average wind machine power $(\bar{P}_w) = \frac{1}{N} \sum_{i=1}^{N} \underbrace{P_w(U_i)}_{\text{Power output defined by a wind machine}}$

(5) Energy from a wind machine, $E_w = \sum_{i=1}^{N} P_w(U_i)(\Delta t)$

Here, if your data is in this kind of a, let's say, this is your wind speed, and you have some data like that, So these are, you can say that number of occurrences. So, you have kind of, at every wind speed, there is a, these are, at every wind speed you get some kind of data which are in forms of a, so it's an, this particular method also provides a way to summarize wind data and to determine expected time productivity obviously what one has to do the data has to be separated into the wind speed intervals or bins in which they occur it is most convenient to use the same size bins let's say if you have let's say in B is the number of bins and been with his wj where the midpoint is MJ and with number of if j is number of occurrences in each bin or frequency so that you have n is summation j equals to one fj so then one can find out similarly this average wind speed would be J equals to 1 to NB mj fj. Similarly, one can find the variation which is 1 by N minus 1 J equals to 1 to NB mj square fj minus which is 1 by n minus 1 j equals to 1 to n b m j square f j minus n Similarly, you get P bar by A, which is half rho 1 by N, NB, FJ. Then you have PW bar, which is PW So, you can have data and then from there actually you can estimate all these things from there. This is how you can use this method of beans.

And also what you can estimate, you can estimate the velocity curve. You can estimate the power duration curve. So, all this you would be able to estimate using this kind of methods. So, now what we can also the statistical analysis, statistical method or analysis. So, the statistical analysis can be used to determine the wind energy potential of a given site and to estimate the energy output from wind turbine installed in a given site.

N_B – # of bin, bin width = w_j, mid point : m_j

f_j # of occurence in each bin

$$N = \sum_{j=1}^{N_B} f_j$$

$$\bar{U} = \frac{1}{N}\sum_{j=1}^{N_B} m_j f_j$$

$$\sigma_U = \sqrt{\frac{1}{N-1}\left\{\sum_{j=1}^{N_B} m_j^2 f_j - N(\bar{U})^2\right\}} = \sqrt{\frac{1}{(N-1)}\left\{\sum_{j=1}^{N_B} m_j^2 f_j - N\left(\frac{1}{N}\sum_{j=1}^{N_B} m_j f_j\right)^2\right\}}$$

$$\bar{P}/A = \left(\frac{1}{2}\right)\rho \frac{1}{N}\sum_{j=1}^{N_B} m_j^3 f_j, \qquad \bar{P}_W = \frac{1}{N}\sum_{j=1}^{N_B} P_W(m_j) f_j$$

$$E_W = \sum_{j=1}^{N_B} P_W(m_j) f_j \Delta t$$

→ Velocity curve

→ Power duration curve

So, then for statistical analysis the probability distribution is the term that describes the likelihood that certain values of random variable which is in this particular case is unit speed will occur. Probability distributions are typically characterized by the probability density function or cumulative. So, you need probability density function or cumulative density function. So, what is probability density function? So, if you talk about probability density function which is pdf or p of u or wind speed probability density function. So, it is that the you can say that p of u, the probability of occurrence of u between these two value is the probability distribution function of u.

That is what it is. So, it's a probability of occurring wind speed between UA and UB. This is how one can define the distribution function. So, that means we have specified a particular wind speed. Probability of occurring that is the one that.

.. So the important property of probability density function is that the total area, total area under probability density curve, probability density curve is 0 to 1 p u du 1. So, once the probability density function p is known then you can find the mean speed which is u bar using the u p u d u similarly you can find standard deviation so sigma u which is zero to infinity So, mean available wind power density that is P bar by A that is half rho 0 to infinity So, half rho u bar cube or one can say u cube bar is expected value. So, once the probability density function is known then you can estimate all this value and the distribution function Cbf represents the time fraction or probability that wheel speed is smaller than or equal to a given wheel speed u. fu which is cumulative distribution function is the probability of u prime less than equals to u. Here u prime is a dummy variable.

Statistical Method / Analysis : PDF, CDF

Probability density fn (PDF) : $p(U)$ | $P(U_a \leq U \leq U_b) = \int_{U_a}^{U_b} p(U)\, dU$

Total area under PD curve : $\int_0^{\infty} p(U)\, dU = 1$

Mean speed $(\bar{U}) = \int_0^{\infty} U\, p(U)\, dU$

Standard deviation : $\sigma_U = \sqrt{\int_0^{\infty} (U-\bar{U})^2\, p(U)\, dU}$

Mean available wind power density $(\bar{P}/A) = \frac{1}{2}\rho \int_0^{\infty} U^3 p(U)\, dU = \frac{1}{2}\rho\, \overline{U^3}$

CDF : $F(U) = \text{Probability}\,(U' \leq U)$, U' → dummy variable

$F(U) = \int_0^{U} p(U')\, dU'$ | $p(U) = \frac{d}{dU}[F(U)]$

So, what you can show that f of u is 0 to u u prime du prime. Also you can have probability density function of u is the derivative of f of u. So, the derivative of cumulative distribution function is give you the probability density function. So, that means the velocity duration curve is closely related to the cumulative distribution function. Commonly used probability density functions, okay, which we have already that like Gaussian distribution, you have Weibull distribution.

So, you have a Rayleigh distribution. These are the standard distribution function that you already have discussed. What we can do We, so, I mean, we are reiterating these things again because these are very, very key aspect in context of wind power estimation. because since you don't have the continuous similar kind of wind, so there is a distribution of the wind and all these things. So, we'll quickly again recap those distribution function and then like to calculate some of these parameters in next session. Okay. Thank you.