Wind Energy

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Lecture 17: Wind Velocity profile

We'll come back to the discussion of this, particularly this atmospheric boundary layer in connection with wind shear. So, we are kind of talking about how this profile that can be represented in the lower close to the Earth's surface. So, there are two ways. I mean, if you look at the ongoing discussion on that. So, we have talked about that this is primarily arising because of so primarily arising because of this profile that's which are turbulent in nature. And mathematically we can represent this one is that log law or logarithmic profile.

The other one would be power law that we'll talk about here. So, and then this was our point and we kind of arrived at this logarithmic profile, but here one can see the integration is from Z naught at the surface, not zero. Okay. And that because any natural surface are never uniform and smooth.

Because any natural surface are never uniform and smooth. So, that's what you kind of integrate between. So this, so you can have, let's say, different kind of fields you can have, like, let's say some terrain, you can have open area, you can have like, so different surfaces have different Z0 values. So, that kind of provides you an information or idea about the roughness because this Z0 is kind of taking care of the surface roughness. So, if you have terrain, if you have trees, if you have buildings, if you have a desert area, if you have some hills, if you have some small for it's I mean I mean there could be a different surface so that one can of estimate that this equation here we can rewrite in different forms.

So, we can do ln of z, a of u star, u of z plus ln of z0. So, this is what can be plotted on a semilog graph. And the slope of is Kappa by u star. And, from a graph of experimental data, u star did not can be calculated. So, this log law is often used to extrapolate wind speed from a reference height to any height at z are to another level using this following relationship.

Rewrite: $\ln(z) = \left(\frac{\kappa}{U^*}\right) U(z) + \ln(z_0) \longrightarrow$ slope is $\left(\frac{\kappa}{U^*}\right)$

$$\frac{U(z)}{U(z_r)} = \ln\left(\frac{z}{z_0}\right) \Big/ \ln\left(\frac{z_r}{z_0}\right)$$

So, what we can do, let's say u of z by u of zr that would be ln of z by z zero ln of z r by, this is a little bit of kind of an algebraic reorientation of this whole thing so that you can use it also sometimes it can be modified to consider mixing at the earth surface. So, sometimes it is modified to consider mixing at the earth surface. So, we can express Express the mixing length. Let's say L as Kappa of Z plus Z0. So, then my log profile becomes U of Z Ustar by Kappa ln Z plus Z0, so this is what you can get and you can use this thing so what we can use the second one is so second option is that we can use power law profile okay so power law represents a so this represents a single model i mean simple model rather simple model for the vertical wind speed profile.

$$l = \kappa(z + z_0)$$

$$U(z) = \frac{U^*}{\kappa} \ln\left(\frac{z + z_0}{z_0}\right)$$

So, this kind of represented as U of Z, U of ZR, Z by ZR to the power alpha. So here, UZ is wind speed at height of Z. Zr is wind reference, wind speed at Zr and alpha is the power law exponent. So, which is very common in the turbulent photoprofile, I mean, certain conditions this alpha could be for certain condition alpha kind of 1 by 7. So, it indicates a correspondence between wind profile and the flow over a flat plate, which was done by the great scientist Lister in 1968.

But in practice, alpha is a variable quantity. So obviously, alpha would vary with some kind of height and all these things. The dependencies of alpha could be parameters like elevation at the time of the day, time of day, season, nature of surface or and speed, temperature, various thermal mixing parameters. Okay. People, I mean, many researchers feel that this complicated approximation reduced to a simplicity and applicability of the general power law that wind energy specialists should accept the empirical nature of power law and choose value of alpha the best fit available wind data.

$$\frac{U(z)}{U(z_r)} = \left(\frac{z}{z_r}\right)^{\alpha},$$

α → elevation
→ time of day
— season
— nature of surface/terrain
— wind speed, temp.

represents a ~~single~~ simple model for the vertical wind speed profile.

$U(z)$ = wind speed at height z,
$U(z_r)$ = reference wind speed at z_r
α = power law exponent
for certain condition: $\alpha = 1/7$

, various thermal & mechanical mixing parameters.

So there are, I mean, typically, the thing is that in turbulent flows, depending on Reynolds number, this alpha parameter can vary from, I mean, it's 1 by 6 to 1 by 7 and all these things. So here also, the flow that is being represented as a turbulent flow. one can see for this particular case alpha has a lot of dependencies like elevation time of the day season nature of the surface or the terrain whatever wind speed temperature unit, i mean, various thermal mechanical mixing parameters so what researchers have suggested that the best possible fit for the wind calculation that should be used so there are certain correlations which are already or which already exist which can provide a best fit for this kind of alpha variation and if that can be taken into this power law profile probably that represents the more generic situation or solution for that kind of a scenario so some of these are your here the I mean alpha is only function of let's say velocity and height so if you consider that then one way of handling this type of variation this was proposed by justice in 1978 So the provided expression is that alpha is 0.37 minus 0.088 ln of u reference 1 minus 0.

088 ln of z reference right there. So, here u is meter per second. and Z is in meter. So, this was given to consider the velocity and the height. So, you get some variation of alpha which can be used to estimate that.

Then there are correlation where correlation based on the surface roughness. So, alpha is a function of surface roughness okay so this was kind of proposed by conihan in 1975 okay, so, this includes alpha is 0.096 log base 10 z naught plus 6 log 10 z 0 square plus 0.24 so here this is kind of an validity here is that z 0 valid between 10 meter to 0.

001 meter. This is the range of validity where Z naught is surface roughness which is in meter. You can get this thing. So, there are another option where you have alpha is a function of both surface roughness velocity. So, this is what so this one can find by this was proposed by proposed by NASA researcher and you can look at the reference of Pira which tablets some kind of that kind of variation. So, even in the all a profile, you can have different correlation.

So, that simplifies the dependency of the alpha, which we have talked about that there is a multiple dependencies of alpha, like elevation time season and all these things. So, it can reduce to some kind of a correlation. Okay. So, that would now the issue is that all these two things that logarithmic profile or the power law profile they try to so these two approach they try to provide the velocity profile close to surface, So, essentially that takes into account the atmospheric boundary layer. And to accommodate that boundary layer, either you use this kind of logarithmic or some kind of profile.

α — f(velocity & height) — proposed by Justus (1978).

$$\alpha = \frac{0.37 - 0.088 \ln(U_{ref})}{1 - 0.088 \ln\left(\frac{z_{ref}}{10}\right)}, \quad U\ (m/s), \quad z_{ref}\ (m)$$

α — f(surface roughness) — proposed by Counihan (1975)

$$\alpha = 0.096 \log_{10} z_0 + 0.016 (\log_{10} z_0)^2 + 0.24$$

$0.001m < z_0 < 10m$: z_0 = surface roughness (m)

α — f(surface roughness & velocity) ← proposed by NASA research (Spera, 1994)

Velocity profile close the surface ← ABL

So using that, what happens is that you would, using this, you can have predicted profile Okay. And there is an actual data. So, this is important to characterize this variation between the profile and the actual data, because eventually this is going to kind of contribute towards the estimation of wind shear. for a given site or all these things. So, typically what has been seen that these profiles are quite a good fit to predict wind shear under most of the general conditions.

But wind shear can change by I mean, let's say atmospheric stability. Then you have surface roughness. Then change in surface conditions. terrain shape. So all of this can change.

I mean, obviously you can think about all these are going to, I mean, in a one hand, these are going to impact on velocity profile. So, that in turn is going to affect on So, it's a situation of some kind of a closed loop where now one can quickly look at the effect of rain on wind characteristics. I mean so, the terrain effect would include so this effect that include velocity deficit velocity deficit unusual wind shear and also you can have wind acceleration so the terrain can impact in that fashion so this would impact the velocity profile unusual shear and all these things so the influence indirectly affect the turbine power output. So, that kind of lead to the site selection, other economical aspects, et cetera. So, there is a kind of an connectivity among all these effects so i mean we can one hand say that okay we have parents and all these things but eventually it's going to impact your turbine power output and once that is impacted you tend to look at it that which site is to be selected whether the other viable conditions or for the economically viable same there are different classification of terrain So, if you, the terrain types, if you classify, there could be two major classifications.

One could be flat terrain or you can have non-flat terrain. So, sometimes this non-flat terrain also turned as an complex terrain. And flat terrain is terrain with small irregularities such as like forest, shelter belts etc. Non-flat terrain has large scale elevations or depressions such as hills, ridges, valleys, canyons. So, once you try to classify these flat or non-flat terrains, there are certain conditions that must hold.

So, for flat terrains, terrain to be considered as a any irregularities on surface or the terrain to be considered as a flat terrain you must hold so one is that that the elevation differences between the wind turbine height and the surrounding terrain are not greater than about 60 meter. So, in an radius of 11 or diameter of 11.5 kilometer of the turbine side. So, within that, the elevation difference between the wind turbine side and that should be very less. Then no hill has an aspect ratio not greater than one by 50.

That is again within four kilometer upstream and downstream of site. The elevation difference elevation difference between the lower end of the rotor disk and the lowest elevation on the terrain is greater than 3 times maximum elevation difference. So, that is within 4 kilometer of of steel. So, these are the conditions kind of one can consider this to be a flat terrain. So, similarly non-flat or complex terrain so that can have variety of features so if you talk about the non-flat on then that has you can have isolated elevation or depression be mountainous terrain.

Okay. So, these are obviously where you have different kind of, so flow conditions in mountainous terrains are complex because the elevation and depressions occur in random fashion. So, in such terrain can be divided into two classification walls and large scale. obviously the distinction between these two we made with comparison to the planetary boundary layer which is assumed to be about one kilometer so one important point to be made here is that information on wind direction should be considered when defining the terrain classification for example if an isolated trail which is 200 meter high and thousand meter wide are situated one kilometer south of the proposed site then the site could be classified as non-flat if however the wind blows only five percent of the time from this direction with a low average speed say two meter per second then distance should be classified as a factor so point here is that this flat and non-flat terrain can be also varied depending on the conditions where your proposed site is and then what is the wind direction so wind direction also plays an important role here depending on the wind directions and which is the radius or whether it's the upstream or downstream of the site that would also going to identify or helps to identify whether it could be flat or non-flatted. So, we will continue this discussion on the Terran mode. We will stop here and continue this in the other session. Thank you.