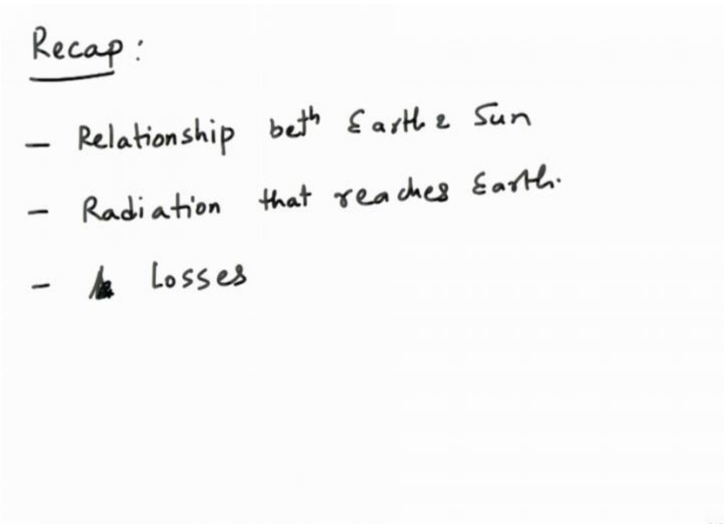
Lecture – 03
Atmospheric Effects on Solar Radiation

Solar Photovoltaics: Principles, Technologies & Materials

Prof. Ashish Garg
Department of Material Science & Engineering Indian Institute of Technology, Kanpur

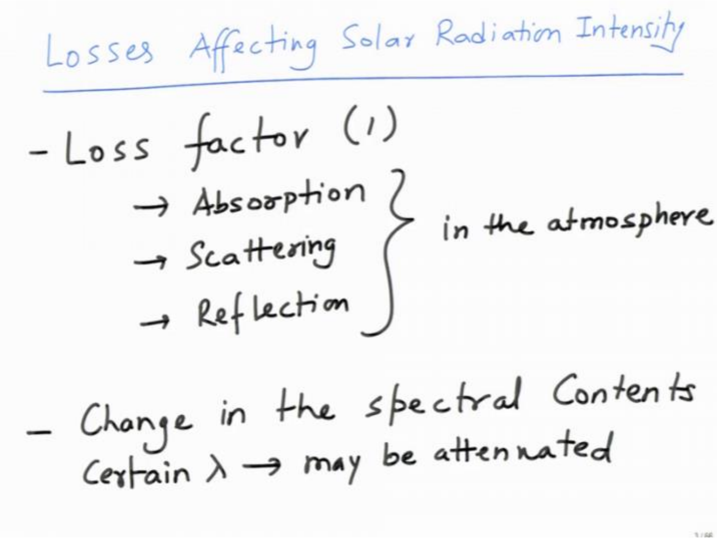
So, welcome again to this lecture 03 of the course Solar Photovoltaics: Principles, Technologies and Materials. So, let us just recap with the last lecture.

(Refer Slide Time: 00:25)



So, we looked at the relationship between earth and sun. We also looked at the radiation that reaches earth and we discussed at the end about the losses basically. Amount of energy that reaches us is dependent upon variety of losses that take place in the outer atmosphere of the earth. So, now we will further dwell in to those aspects of losses.

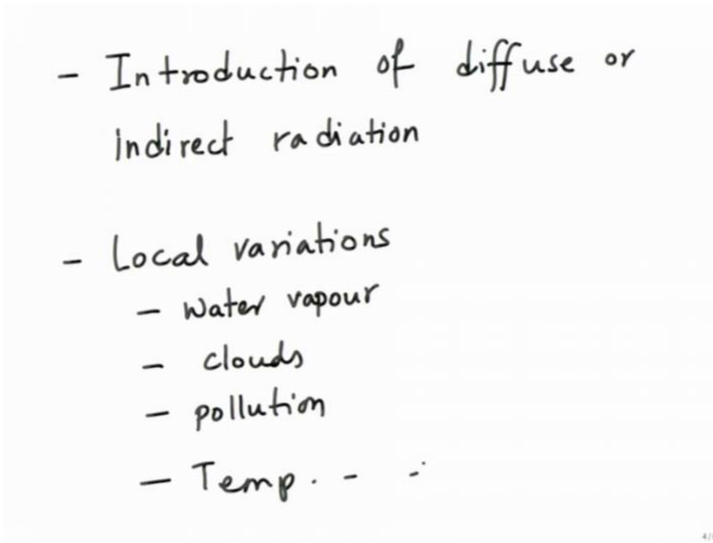
(Refer Slide Time: 01:21)



So, we look at the losses affecting solar radiation intensity. So, in first reduction, the loss factor can be 1 because of absorption, scattering and to some extent reflection also; this is in the atmosphere.

And then we have a change in the spectral content because of specific absorption or specific changes in the specific wavelengths; because of presence of certain constituents in the atmosphere. So, at certain wavelengths, which means that certain lambda (λ) may be attenuated because of propensity of those wavelengths to be absorbed by certain constituents present in the atmosphere.

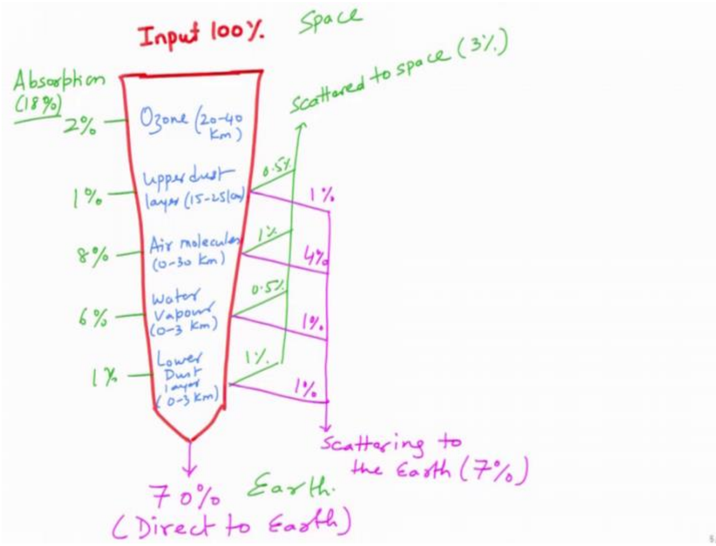
(Refer Slide Time: 02:57)



And then third is introduction of diffused or indirect radiation. So, when on one hand, we have direct sunlight coming into the object, and on the other hand we have light which is coming onto the object from the surroundings. So, this is called as diffused or indirect radiation because the sunlight has been scattered; some of that sunlight which is scattered and absorbed by various things again falls onto the surface, this is called as diffused and indirect radiation.

This component actually increases as compared to direct radiation; when we have lot of pollution, we have cloud, we have various scattering and absorption centers present in the atmosphere. And then of course, we have local variations such as water vapor or moisture which can change from place to place. And then there can be clouds, pollution, temperature so on and so forth and these have additional effect on the power spectrum.

(Refer Slide Time: 04:29)



So, generally if we draw a sort of a flowchart let us say this kind of flow chart in which let us that we start with input as 100%. So, absorption can take place at various layers let us say you have thinner ozone layer, which is about 20 to 40 kilometers.

Further down we have upper dust layer; which is about 15 to 25 kilometers. Then we have air molecules which are at about 0 to 30 kilometers. Then we have water vapor, at about 0 to 3 kilometers and then we have lower dust layer about 0 to 3 kilometers .

So, if we look at absorption on the left side. Ozone has absorption of about 2 percent; upper dust layer has an absorption of about 1 percent. Air molecules absorb about 8 percent, water vapor absorbs about 6 percent and lower dust layer absorbs about 1 percent. So, total absorption is about 18 percent.

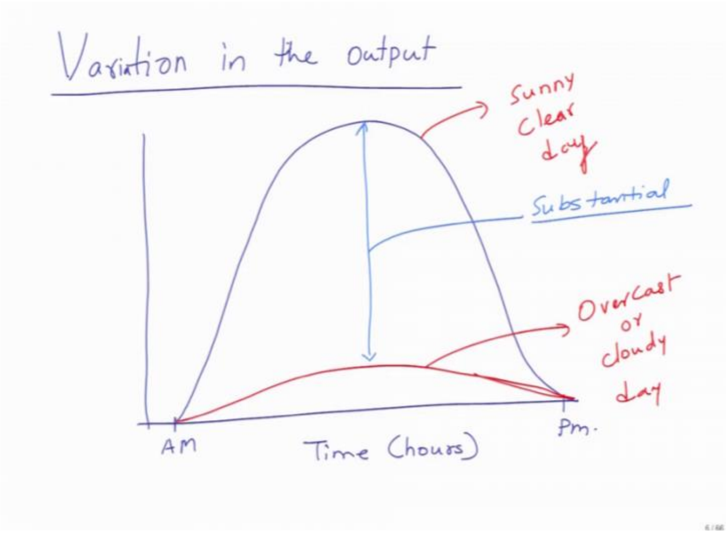
Now then we look at the scattering; so scattering takes place to the space as well as to the earth as well. So, scattering to space is about; so if you have you have a scattering from this side you have a scattering from this side, you have scattering from this side, you have scattering from this side.

This side is a space and this side is earth. So, scattering is nearly 0.5 percent, this is about 1 percent, this is about half a percent and this is about 1 percent; so, this is about total of 3 percent.

And then we have scattering down to earth. So, down to earth would be here, here, here, here again if we combine them together. So, this is scattering to the earth and this starts at about let us say 4 percent; somewhere here. This is about 1 percent this is again about 1 percent and this is again about 1 percent; so total this is about 7 percent of radiation. So, if you do the mathematics directly to earth it is about direct 70 percent.

So, this is from about 100 percent we lose about 30 percent and what comes down to us at about 30 percent. So, if you look at for instance the variation of solar radiation if I look at the variation.

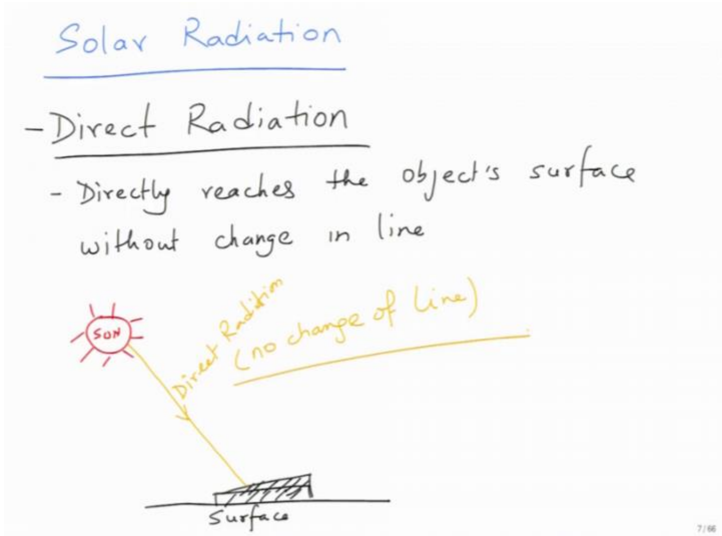
(Refer Slide Time: 08:17)



In the output; so this is for a given location. So, this is as a function of time hours; we have AM somewhere here and PM somewhere here. So, on a clear winter day the output varies parabolically with higher intensity shown in blue colour and on an overcast when there is intensity will be low compared to on the sunny day , shown in red.

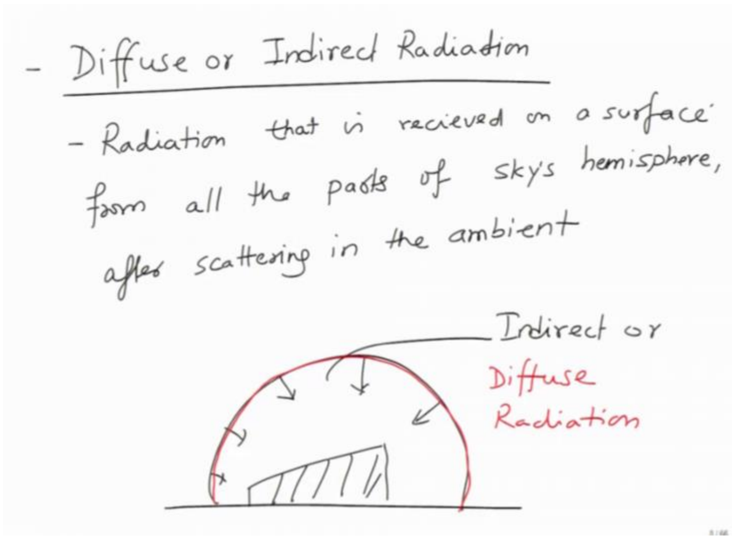
So, there is a huge difference and this is for a given certain tilt angle and so on and so forth. So, this is for a solar surface, amount of energy that is incident is going to determine the output current from a solar panel. So, there is a huge difference between the output and this is substantial. So how much output solar cell is going to produce is dependent upon what the sky condition is or the cloud condition is on that particular day. So, based on this absorption and so on and so forth there are two components of solar radiation.

(Refer Slide Time: 10:11)



So, the first component of solar radiation is called as direct radiation. Direct radiation is the one which directly reaches the object surface without any change. If you have this as a horizontal surface and let us say somewhere here you have your panel ok; this panel may be inclined like this.

(Refer Slide Time: 11:45)

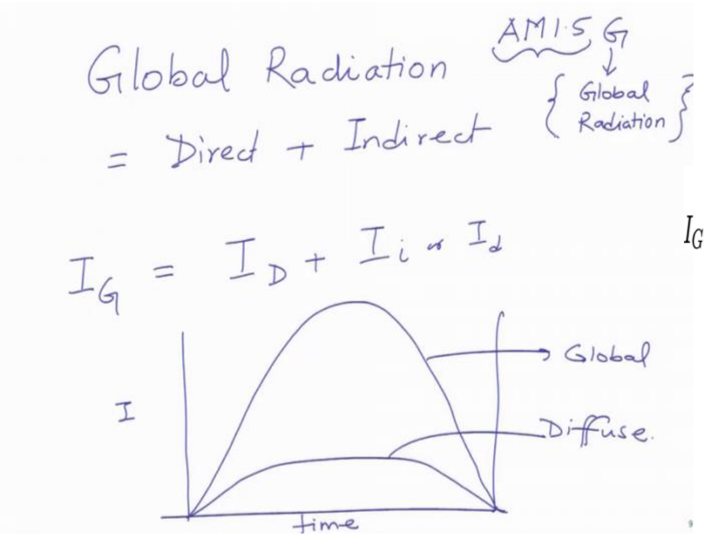


And the second component of this is called as, diffuse or indirect radiation. This term we already introduced at certain place , now we will just elaborate on it. So, this is essentially the radiation that is received on the earth's surface or object surface from all the parts of sky's hemisphere , essentially it is coming from all the sides.

And this happens after scattering in the ambient. So, whatever has undergone is scattering that is redirected on to the surface. Of course, some of it goes into the space and some of it goes back to the object; so this is what is called as diffuse or indirect radiation . So, we have this surface again and let us say this was a solar panel so that diffuse radiation would be coming from all the sides it is coming from different direction as shown in figure above.

So, this would be the indirect; so this is your solar panel and if we color it differently this is what is your indirect or diffuse radiation. So, there are two components first is called as the direct radiation which is in line with the sun, second is called as diffused or indirect radiation that comes from the ambient sum of these two is called as global radiation.

(Refer Slide Time: 13:47)



Global Radiation, AM 1.5G$---->$ *GlobalRadiation* $=$ *Direct*$+$*Indirect*

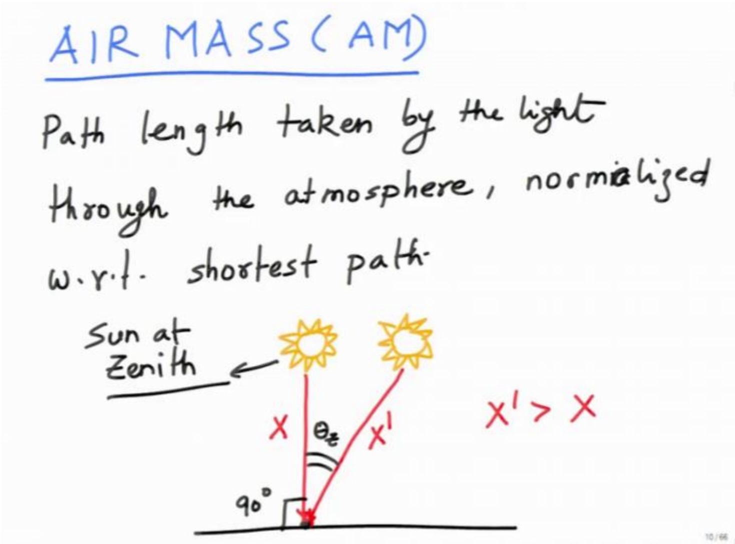
$I_G = I_D + I_i$ *or* I_d

This is direct plus indirect. So, when we say I_G which is the intensity of global radiation that is equal to I_D plus I_i or we can say I_d like that. So, global radiation is sum of these two. So, for (a) if we now plot I as a function of time; the diffused radiation would be something like this and the global radiation would be; so this would be global and this would be diffuse.

Diffused would be a lot more broader whereas, global would be lot more sharper and this is basically because of variation in the direct radiation as a function of time. And then there is a term something in solar terminology called as called as G.

You will see we depict the radiation as AM 1.5 G we will come to AM 1.5 later on, but this G is the global radiation which means it is a total radiation; direct plus diffuse. Now we will come to what we call as air mass and that is what is called as AM.

(Refer Slide Time: 15:27)



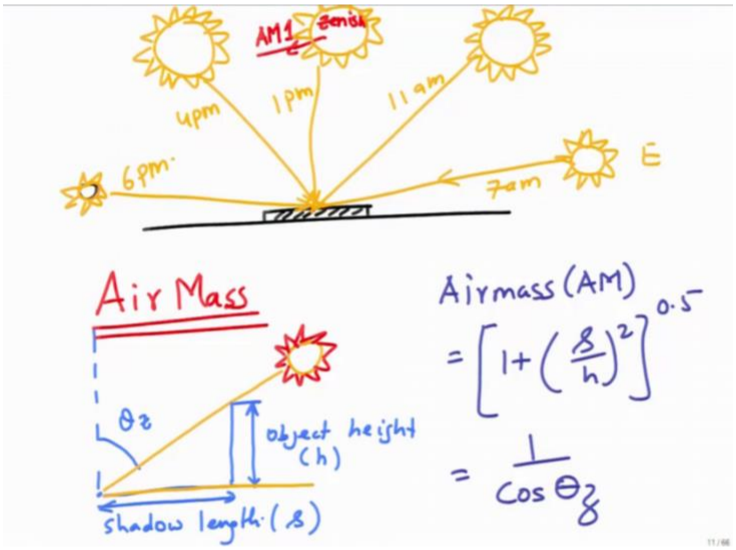
So, this air mass is basically the path length taken by the light through the atmosphere; which is normalized with respect to the shortest path. So, shortest path would be, if you have a horizontal surface and let us say we have sun at some point and then we have sun at some other point. And the point of consideration let us say is this; so in the first case the light is coming in this fashion and the second case light is coming through in this fashion.

So, the path length is let us say X; this is X' ; so X' is greater than X. So, this is position when the sun is absolutely vertical to the point of interest; let us say point of interest is this; so this is called as zenith. So, this is sun being at sun at zenith; that means the angle between the beam and the horizontal surface is 90 degree.

So, this is 90 degree and at other location; the sun makes an angle let us say θ_z; this is called a zenith angle and this θ_z is the angle between the vertical line and the line along which the beam is coming. So, naturally we can see that when the sun is not at zenith, i.e. position which is away from zenith the light has to travel longer distance through the atmosphere to reach that particular point on the surface.

This leads to losses in the intensity because it has to travel a longer distance which means there will be more absorption because of atmospheric content and other things. As a result the amount of intensity that is available at this point will reduce; so we need to consider this factor into account. Now what happens during the normal course of sun's motion; so on a horizontal surface?

(Refer Slide Time: 18:47)



$$Airmass(AM) = [1 + (s/h)^2]^{0.5} = 1/cos\theta_z$$

Let us say your solar panel is here. So, you are starting from this point; so your sun in the morning is somewhere here; let us say this is east. It is coming in this direction and then sun goes through this direction.

Then the light is coming in this fashion; somewhere in the day, sun goes on top which is the let us say the noon; the light comes like this. In the evening; in the afternoon sun goes somewhere here and it comes like this and then in the evening at the sunset it comes like that. So, we can see that that distance which the light has to travel changes as the function of time. So, this is let us say 7 am; this is let us say about 11 am, this is about 1 pm, this is about let us say 4 pm and this is let us say about 6 pm.

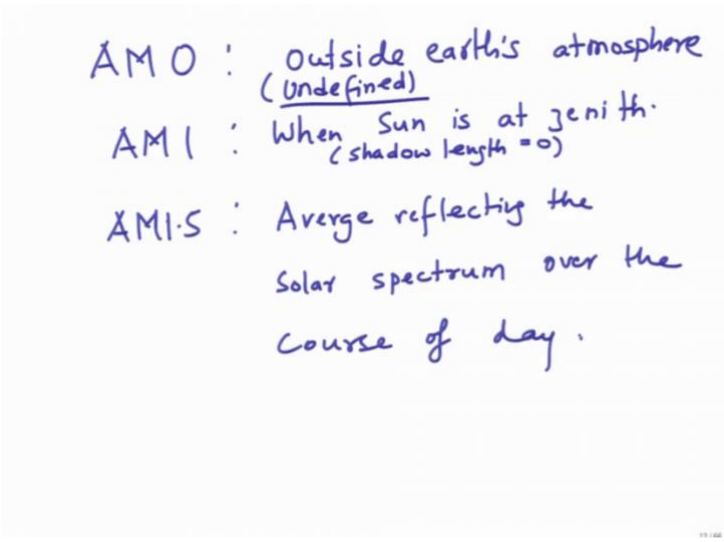
So, this is how the sun is going to travel which means that distance; the light has travelled to reach that particular point has changed and we need to normalize it. Because we can do one thing that your solar panel can remain vertical in at an angle; which gives you maximum absorption with respect to sun position all the time; which means we will have to make the solar panel move also with the sun.

If we cannot do that then we will have to position our solar panel in such a fashion so that we average out the rotation of sun. So, that we position it in such a fashion so that the average intensity received on the surface of the solar panel is maximum. And this is where we define a quantity called as air mass to make it is sort of an index.

So, what we do to quantify it is let us say we have this sun being somewhere here. So, this is your sun and somewhere here we are; so that the beam is coming in this fashion. We define a few distances here; so this is let us say the object length sun. So object length could be somewhere here.

So, let us say this is the object and this would be the shadow alright. So, this is the object height and this would be the shadow length alright. So, let us say this is h and this is s. This is the angle if it was a zenith; this would be θ_Z . And so air mass index is defined as AM is defined as $[1+(s/h)^2]^{0.5}$. And this is equal to $1/\cos\theta_Z$.

(Refer Slide Time: 23:07)



So what would AM 0 mean? It means its outside earth's atmosphere; what would AM 1 mean? AM 1 would mean when sun is at zenith. So, if you look at AM 1 what would it mean? That is equal to s/h and is equal to 0 right and the shadow length will be equal to 0 when the sun is directly at the zenith.

So, if we now go back to previous equation. So, if this is at zenith which means the shadow length will be equal to 0. So, this would give us AM 1 and AM 0 would basically mean s/h ; AM 0 would mean that $1/\cos\theta_Z$ is like its undefined in the meaning of $\cos\theta$ because $\cos\theta_Z$ can take values between 0 and 1.

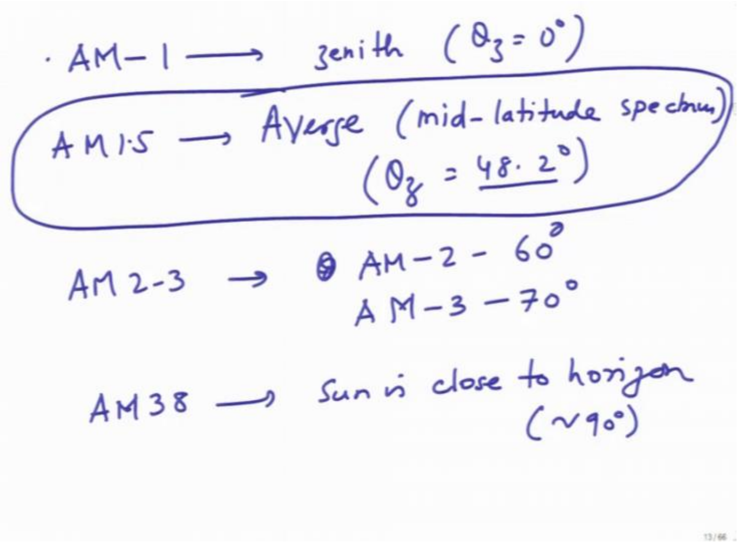
So, we cannot define it on the basis of that, but what basically it means that AM 0 will mean that you have nothing falling alright. So, it is outside earth's atmosphere. And then when another value which is defined is called as AM; so, you can say AM 0 is basically undefined. And what basically it means is that the sun is outside earth's atmosphere; it does not reach earth's surface

AM 1, when the sun is at zenith which means shadow length is equal to 0 and AM 1.5 is a value which means that average value reflecting the solar spectrum. So, as you can see when it goes from let us say this position to that position to this position; what is going to happen to AM?

At this point when the sun is at this particular position; the shadow length is going to be extremely large. If the shadow length is going to be extremely large as compared to h which means air mass is going to be higher. And when it again goes beyond the noon again the shadow length is going to be larger; the air mass is going to be higher. It is only when sun is at the zenith; the air mass is equal to 1.

So, this is the standard value 1; we need to calculate other values with respect to 1. So, basically the average value over the day is going to change from 1 to higher values. The average value which reflects the overall spectrum of the sun turns out to be AM 1.5. So, this is the average value which reflects the solar spectrum over the course of day.

(Refer Slide Time: 26:45)



So basically you can say AM 1; when sun it has zenith. AM 1.5 you can say the average value which is basically the mid latitude spectrum. So, this means $\cos\theta z$ is equal to 0; now this means θz is equal to nearly 48.2 degree, AM 1.5. AM 2 to 3 is about theta; so AM 2 is about, we can see that $\cos\theta z$ will be equal to 60 degrees which means it will be equal to 1/2. So, AM will be will be 60 degrees.

Whereas, AM 3 would be at about 70 degrees and AM 38 would be nearly when sun is close to horizon. So, you can see that the value changes for 0 degrees to about close to 90 degrees; not exactly 90 degrees, but close to 90 degrees because I mean if it is 90 degrees; it would become infinity. So, it is about 90 degrees when AM reaches 38; so it varies from 1 to 38 during the course of day or 38 to 1 or to again back to 38 during the course of the day. The average is somewhere at about 1.5; this is why during photovoltaic measurements we consider the value AM 1.5 ok.

The average intensity which is received during the course of whole day and this is basically a corresponding to as if; so if you keep the solar panel like this the sun rotates from east to west going through the top; it is equivalent to saying that sun was stationed at an angle 48.2 degree for the whole day. This is what it means is that it goes from angle close to 90 degrees to 0 to close to 90 degrees; on an average it means that sun was positioned at 48.2 degree at a fixed location, but that is not there.

So, that is why we make the measurements based on this average intensity taken at AM 1.5; So, in the next class what we will do is that we will look at the geometric relationships between the earth and the sun. And we will look at some of the expressions which are used to calculate the; solar intensity at various locations.

For example there is a difference between when the sun is on top and the 12 noon. So, 12 noon is not really equivalent; so we say 12 as noon and what does noon mean? Noon means that some sun should be on top, it should be at the zenith, but that is not the case all the time. Sometimes you have depending upon the time of the year and depending upon the location; sun may not be at the zenith at 12 o'clock; it is at zenith that may be at 1 o'clock or may be at some other time.

So, we will see that there are discrepancies within the time itself which need to be corrected to calculate the sun intensities in a more precise manner. So, we will do those things in next couple of lectures.

Thank you very much.