Solar Photovoltaics: Principles, Technologies & Materials
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Lecture – 03
Atmospheric Effects on Solar Radiation

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

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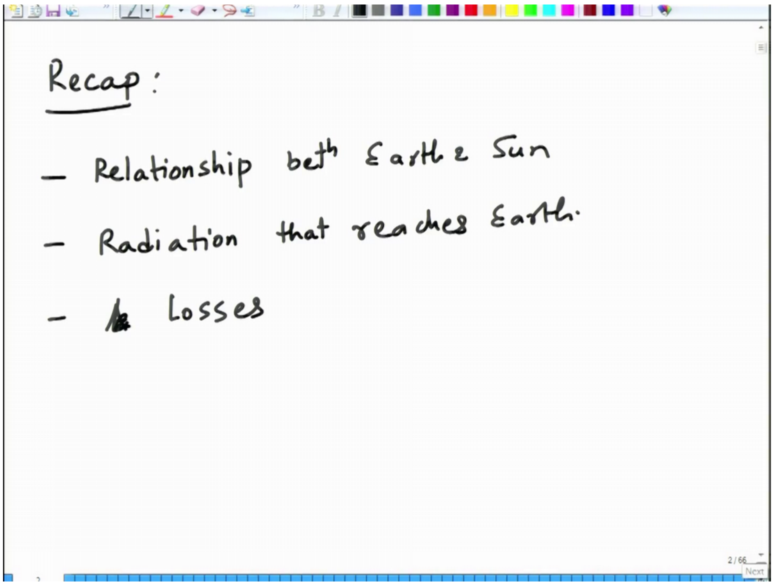

So, the recap goes as we looked at the relationship between earth and sun. We also looked at the radiation that reaches earth and we also; we were discussing at the end about the losses basically. Amount of energy that reaches us is dependent upon variety of losses and that take place in the outer atmosphere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

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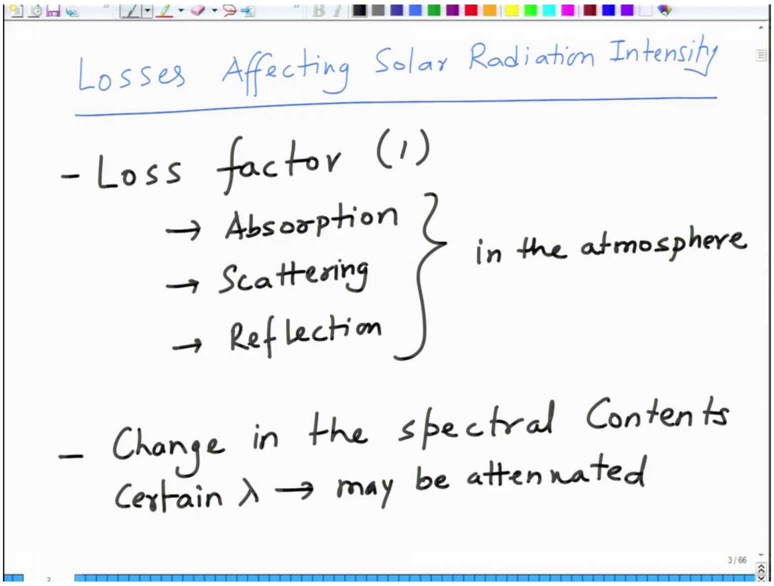

So, we look at the losses affecting solar radiation intensity. So, first reduction in happens; so the loss factor you can say 1 is because of absorption, scattering and some extent also reflection; this is in the atmosphere.

And then we have 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, certain wavelengths which means that certain lambda may be attenuated because of propensity of those wavelengths to be absorbed by certain constituents present in the atmosphere.

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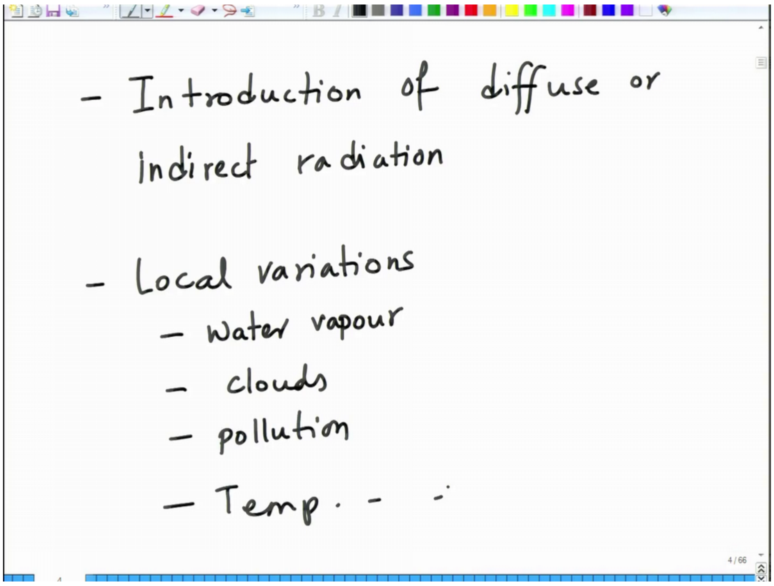

And then third is introduction of diffuse or indirect radiation. So, when you on one hand you have direct sunlight coming into the object, on the other hand you have light which is coming onto the object from the surroundings. So, this is called as diffuse or indirect radiation because the sunlight has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

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

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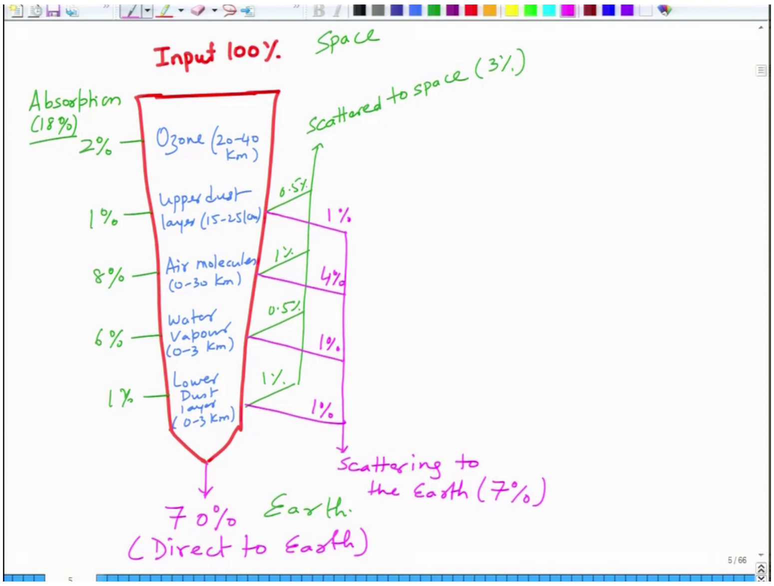

So, generally if I draw a sort of a flowchart let us say this kind of flow chart let us say you start with input as 100 percent ok. So, whatever energy it is let us input is 100 percent. So, absorption is about; so total and at various layers let us say you have ozone here, ozone is at about 20 to 40 kilometers; let me just write it here thinner.

So, let us say I begin with ozone; ozone is it about 20 to 40 kilometers. Further down we have upper dust layer; this is at about 15 to 25 kilometers. Then we have air molecules which are at about 0 to 30 kilometers. Then we have water vapor, they are at about 0 to 3 kilometers and then we have lower dust layer. This is at about let us say 0 to 3 kilometers again ok.

So, if I look at absorption on the left side; so let us say absorption on the left side. So, 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.

So, all of these scattered to; so this is scattered to, so of course; this side is a space and this side is earth. So, this is scattering is nearly you can say; so this is 0.5, 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 I 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 is about 70 percent is direct to earth ok.

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.

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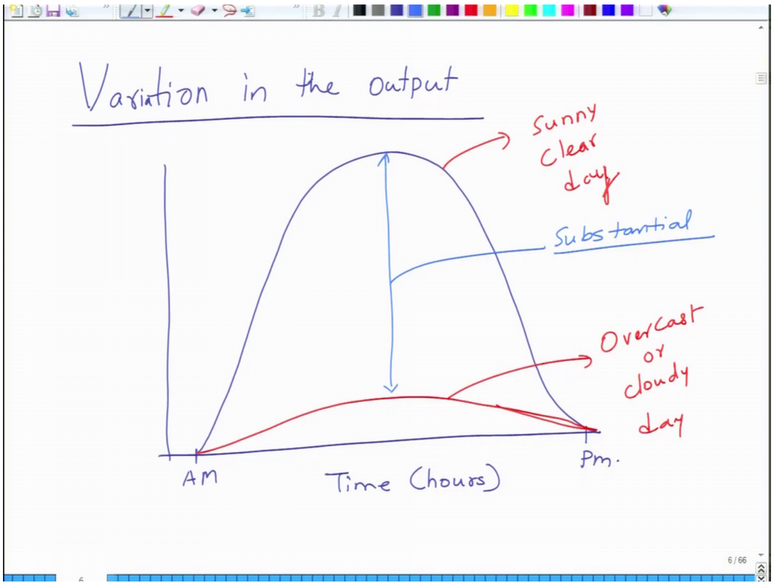

In the output; so this is for a given location. So, this is as a function of time hours; you have somewhere here you have AM somewhere, here you have PM. So, on a clear winter day the output varies like this and on an overcast; when you have cloud and I can draw this using a different color maybe and this would be; so this would be for a overcast or cloudy day, this would be for a sunny clear day.

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 which is going to determine the output current let us say from a solar panel. So, the huge there is a huge difference between the output; so this is this is substantial. So how much output your solar cell is going to produce is dependent upon how much what is the sky condition or the cloud condition on that particular day. So, based on this absorption and so on and so forth there are two components of solar radiation.

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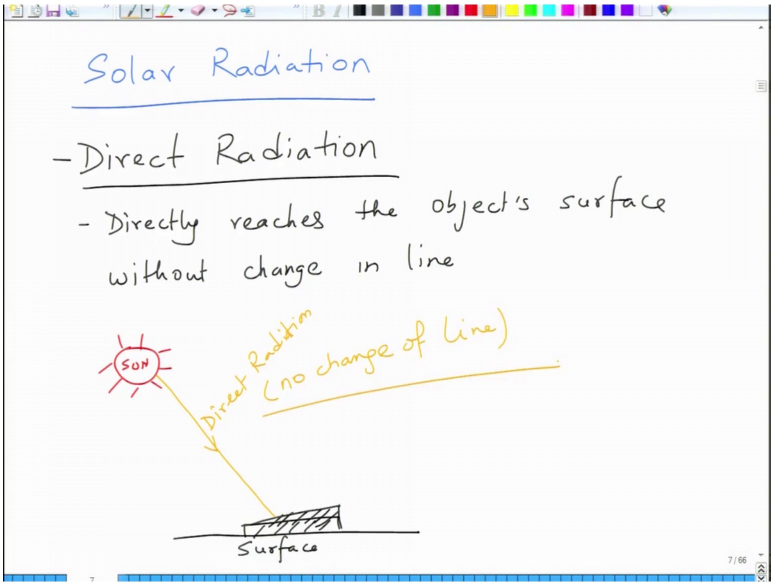

So, we can; so the first component of solar radiation is called as direct radiation. Direct radiation is the one which directly reaches the object surface let us say; without change in. If you have this as a horizontal surface and let us say somewhere here you have your panel ok; this panel may be inclined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

So, this is and this is somewhere you have your sun let us say; so this is sun. So, this is what is your direct radiation ok; without any change of line no change of line.

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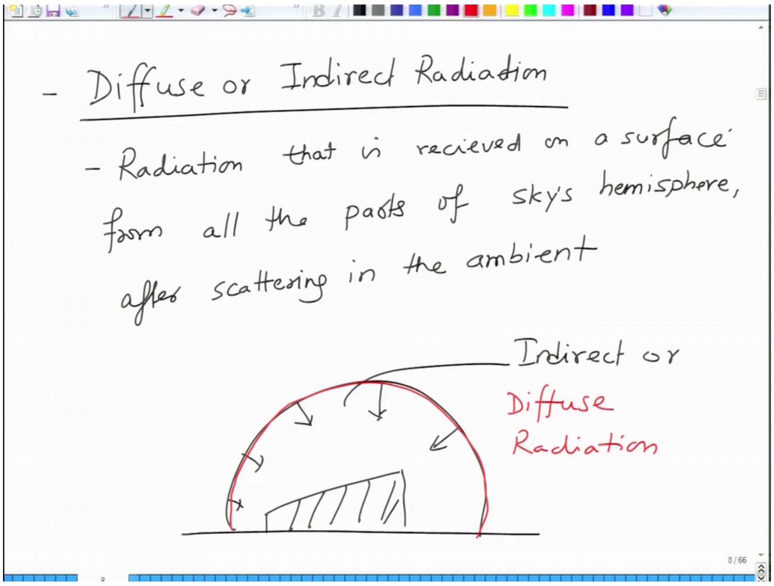

And the second component of this is called as, what we call that is diffuse or indirect radiation. This term we already introduced at certain place we will just elaborate on it. So, this is essentially the radiation that is received on a surface or let us say earth surface; object surface from all the parts of sky's hemisphere ok; essentially it is, you can say it is coming from all the sides; so right.

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 and this comes from. So, if you 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 here here here here.

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

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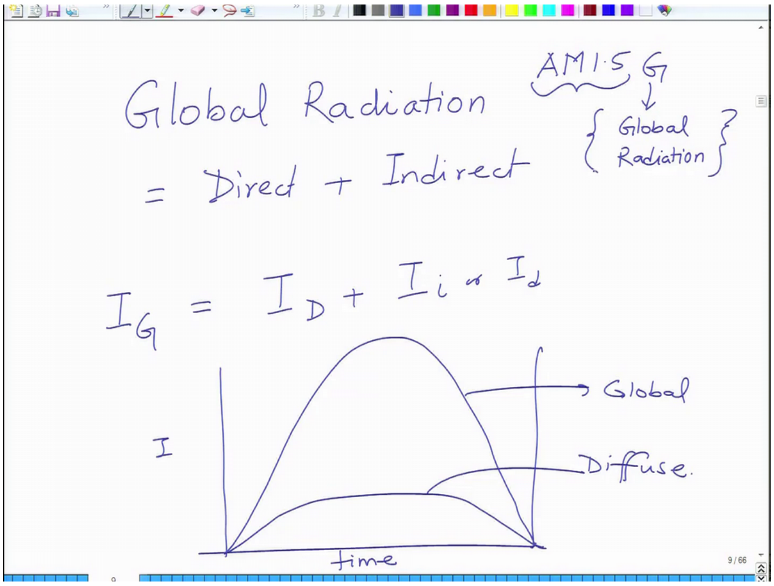

This is direct plus indirect. So, when you say I G which is the intensity of global radiation that is equal to I D plus I i or you can say I small d like that. So, global radiation is sum of these two. So, for a if we now plot I as a function of time; the diffuse radiation would be something like this and the global radiation would be; so this would be global and this would be diffuse.

Diffuse 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 something called as; so that is why this if you see the solar terminology, there is a term called as G.

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

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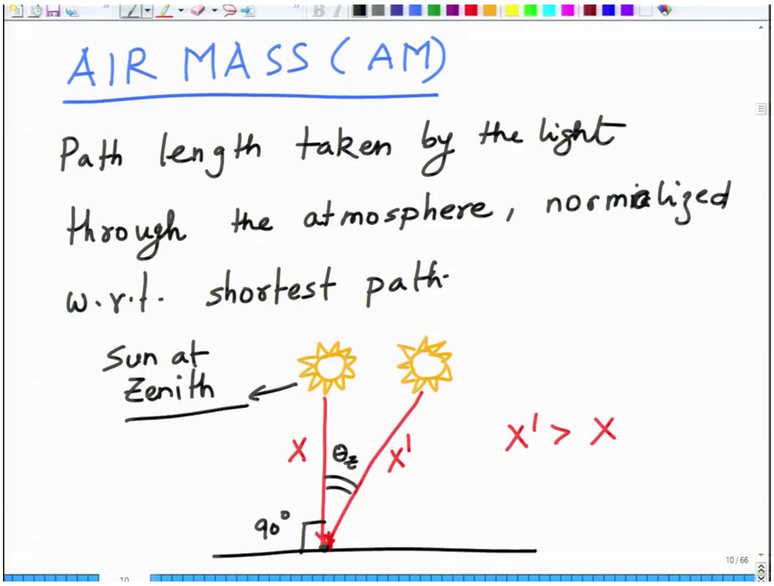

So, this air mass is basically the path length taken by the light through the atmosphere; which is normalized with respect to; with respect to the shortest path. So, shortest path would be; so if you have a horizontal surface, if you have a horizontal surface like this. And let us say we have sun at this point and then we have sun at this 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; so this is let us say X; this is X prime; so X prime is greater than X. So, this is this 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 theta Z; this is called a zenith angle and this theta z is the angle between the line vertical line and the line along which the beam is coming. So, naturally you can see that when the sun is not at zenith, when it is at a position which is away from zenith the light has to travel longer distance through the atmosphere to reach that particular point on the surface.

And this is because of and this leads to losses in the in the intensity because if it has to travel a longer distance which means there will be more absorption because of atmospheric content; such as just and various 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 suns motion; so on a horizontal surface?

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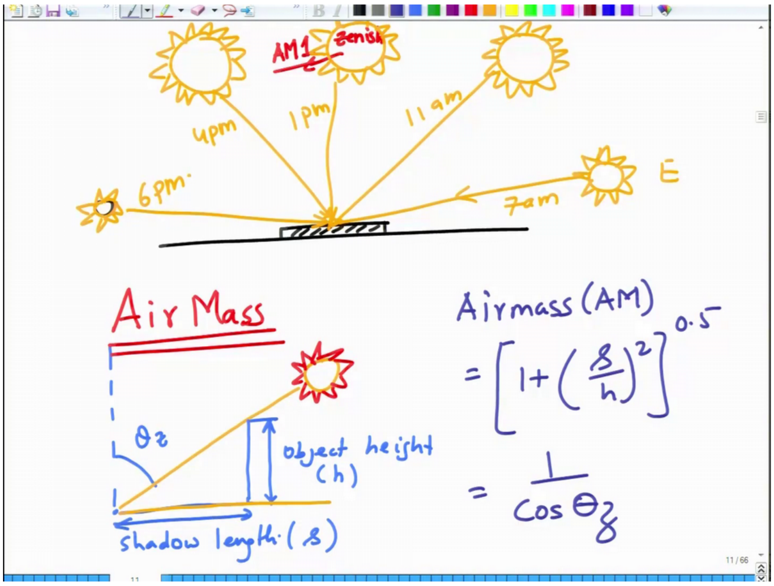

Let us say your solar panel is here. So, you are starting from this point; so your sun in the morning is somewhere here; let us say this is east sorry this is east. So, this is east it is coming in this direction right and then sun goes through this direction.

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 at the function of time. So, this is let us say 7 am; this is let us say about 11 am this is I know about 1 pm, this is about let us say 4 pm and this is let us say about 6 pm ok.

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 you need to normalize it. Because you can do one thing that your solar panel can remain vertical or solar can solar panel can remain at an angle; which is which gives you maximum absorption with respect to sun position all the time; which means you will have to as the sun moves you will have to make the solar panel move also that is one possibility.

If you cannot do that then you will have to position your solar panel such a fashion so that you average out the rotation of sun. So, that you position it 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 is that the way to quantify it is let us say you 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, let me just I think correct myself; so object length object 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 small s. So, air mass index and this is the angle if it was a zenith; this would be theta z right. And so air mass index is defined as AM is defined as 1 plus s divided by h square to the power 0.5. And this is equal to cos theta z 1 over cos theta z.

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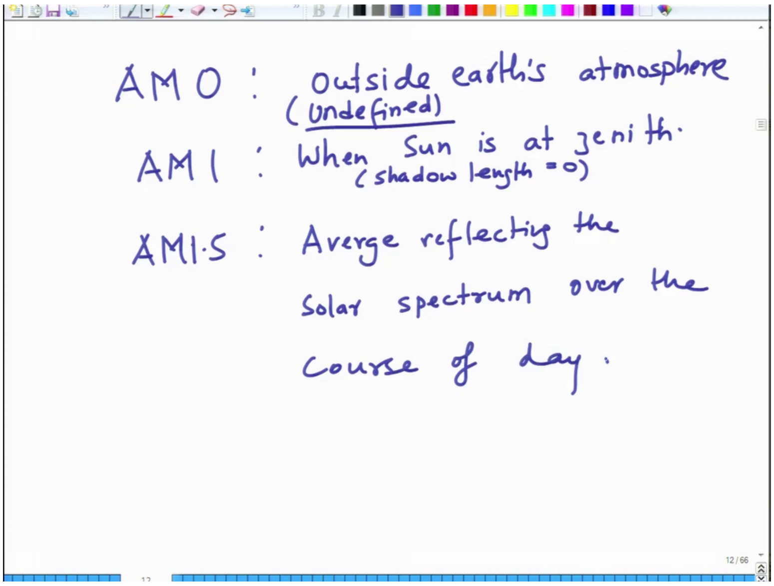

So, the way we define this air mass index now is; so what would AM 0 mean? Which means its outside earth's atmosphere; what would AM 1 mean? AM 1 would mean when sun is at zenith. So, if you look at AM 1 what would it mean? That s is equal to s by h is equal to 0 right and the shadow length will be equal to 0 when the sun it at the directly at the zenith.

So, this would mean that sun is. So, if you now go back to previous equation; so somewhere this would this is what will mean. So, if this is at zenith which means the shadow length will be equal to 0. So, this would give you AM 1 and when as I said AM 0 would mean; AM 0 would basically mean s by h is almost equal to you can say AM; AM 0 would mean that 1 over cos theta is like its undefined in the meaning of cos theta because cos theta can take values between 0 and 1.

So, you 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; so it is not it is not within the sun is not falling. 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 that the sun is outside earth's atmosphere; it does not reach you ok, the rays do not reach you.

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 alright. 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 at the only when sun it is at the zenith; the air mass is equal to 1.

So, this is the standard value 1; you need to calculate other values with respect to 1. So, basically the average value over the day; so of course, it 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.

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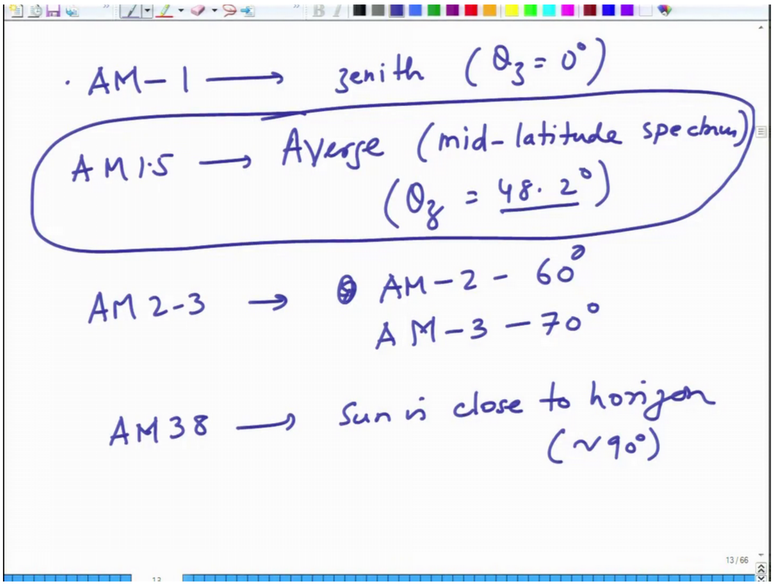

So basically you can say AM 1; when sun it has zenith. AM 1.5 you can say the average value which is basically the mid latitude spectrum. So, this means theta z is equal to 0; now this means theta z is equal to nearly 48.2 degree AM 1.5. AM 2 to 3 is about theta; so AM 2 is about you can see that cos theta will be equal to 60 degrees which means it will be equal to 1 by 2. So, AM will be; so 60 degrees not percentage I am sorry; so it 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 it 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 intensity 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 ok. This is what it means it goes from 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, we that is why we make the measurements based this average intensity taken at AM 1.5; is that clear to everyone ok? So, this part we have covered now here; in the next class what we will do is that we will do we 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; you see that we will see concepts like time.

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 you have 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 that those things in next couple of lectures.

Thank you very much.