Indian Institute of Science

Design of Photovoltaic Systems

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NPTEL Online Certification Course

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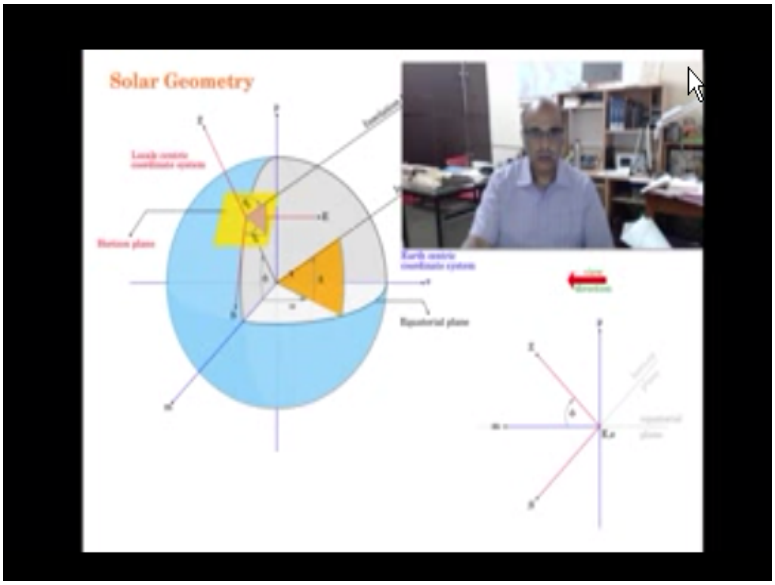

In order to estimate the insulation in kilowatt/m^2 and the hedge the energy in kilowatt hours/$m^{2/}$day at any given point on the surface of the earth we shall use the help of solar geometry solar geometry is nothing but the spherical coordinate system but if as it also involves the position of the Sun in relation to the earth it is generally referred to as solar geometry apparently the figure here looks complex but it is not as complex as it looks.

We shall reconstruct this coordinate system step by step and try to get insight into the various parameters that we have used in relation with the position of the sun and later use these parameters to estimate the insulation and the energy H in kilowatt/ hours/m^2/T at any given point on the surface of the earth

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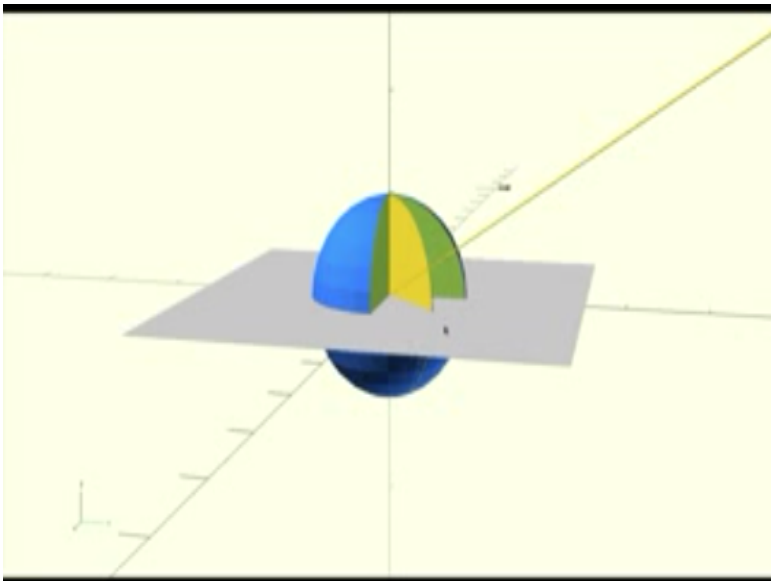

This is the coordinates of the 3d system X Y Z and you using open S CAD for building the 3d models let us build the earth centric coordinate system here and see how we can get the various solar geometric parameters first let us put in a globe and give it a blue color and this is a 3d sphere now we shall cut out a quarter and make that as our 3d coordinate space so after cutting with the quarter you will see something like this.

Now in this space only you will be trying to understand the X in this case is X Y Z portion and let us define the various parameters solar of the solar geometry and try to get our insulation estimate model now we shall try to connect the center of the earth to the center of the distant sun with a line and that line is something like this it is going on to the distant sun now I have cased it at an arbitrary angle you can see now with respect to this line connecting the center of the earth to centre of the Sun.

Let us see how the declination would up here I have now included an equatorial plane which cuts a right across through the globe at the equator as you can see now the equatorial plane will become the reference plane for us and we shall measure the angles electrical nation with respect to that I have now included a plane an original plane which goes in such a way that it just goes through the line which is connecting to the Sun.

This is this line can be called as the insulation line so this is the original plane which is going through the insulation line I shall now draw the angles that represents both declination and the other angle.

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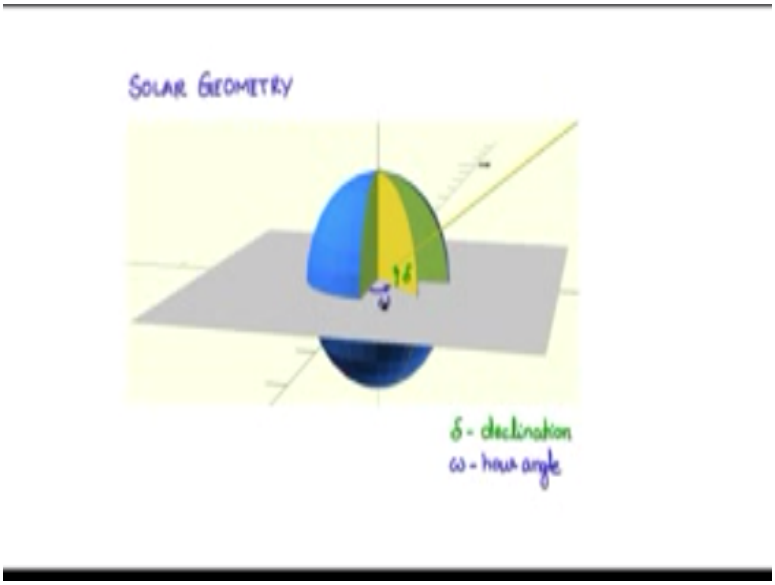

Consider this figure and consider this angle which are marked between the equatorial plane and the line joining the center of the earth to center of the Sun so this is termed δ and we know that δ from the eccentric view point is nothing but the declination there is another angle here I am going to introduce the angle between this coordinate axis and the point this meridional plane on which lies this line joining center to the center of the Sun.

May be the isolation line we call it ω and ω is called the hour angle the reason that it is called our angle is because it is directly related to the time of the day this insulation line will move from east to west till because earth is rotating about its polar axis and it'll appear as though this insulation line is moving from east to west every 4 minutes one meridional plane will be traversed or 1º longitude piece traversed every 4 minutes and the ω is an indication of that traversal.

So in this 3d coordinate system let me remove this insulation line and this original plane and define the axis of the coordinate system so I will remove those two items which is an original axis and the insulation line and we know how the plane quarter a system this axis we shall call the meridional axis the reason being that I would like to choose this longitude just meridian as the point of interest let me emphasize that by putting a marginal plane here.

I have now included this Meridian meridional plane this is the meridian of interest and the axis coordinate axis which is in line with this longitude is called M or the Meridian L axis this coordinate axis orthogonal to the meridional axis this axis will be called east of the meridian and the one going vertically up is called the polar axis P so this will be the polar axis P this will be E east of the meridian and this would be the original axis.

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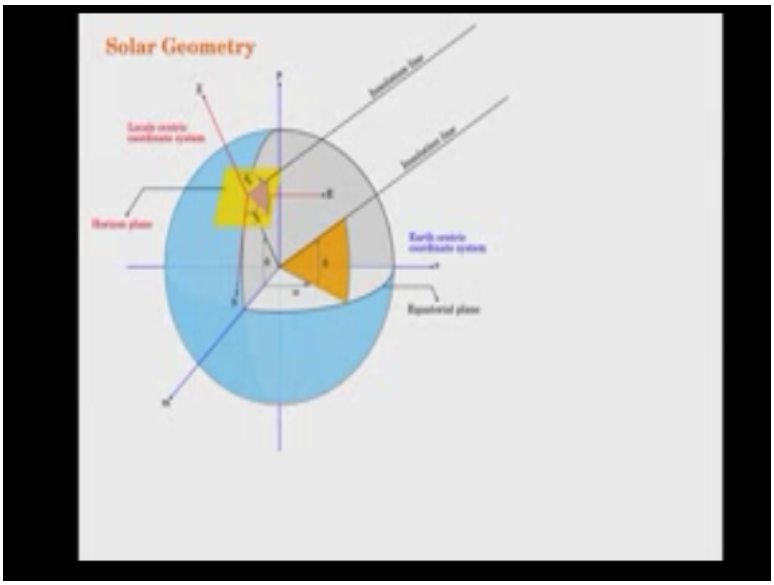

Let us now consider the solar geometry using a 2d graphic system I am using Ink space for 2d graphics the visualization that we just now had using the 3d graphic system will help you to visualize the entire solar geometry in a 2d graphics based system so we have these 3 axis here as shown the vertical axis is called P that is called the polar axis and earth is rotating about the polar axis.

Now this earth has been chopped off a quarter of the northern hemisphere has been chopped off as can be seen now a coordinate axis is shown here and this is going out of the page and that is orthogonal to both the other two axes but it is passing through this plane this meridional plane so when you want to consider a point of interest on the surface of the earth it will be associated with the latitude and the longitude the longitude is the meridian.

So consider that particular meridian which is related to the point of interest as the meridian of interest and let this axis cut through that particular meridian and we will call this axis as M the meridional axis so it is actually the meridional axis of the meridian of interest so whichever is the

meridian of interest let a line be drawn from the center of the earth along the equatorial plane cutting the meridian of interest and coming out of the page like this and that is the meridional axis.

The third axis orthogonal to both the medial axis and the polar axis is basically east of this meridian and as it is just east of this meridian we just named it as e representing east of the meridian now let us draw a line joining the center of the earth to the center of the Sun this line is eventually going to the center of the distant Sun and that is the insulation line which represents the incident radiation from the Sun any vector or any line is now considered with respect to this plane.

This plane is called the equatorial plane so the equatorial plane the three coordinate axis that is the polar axis maternal axis and the Eastern Meridian axis together form the earth centric coordinate system with the origin positioned at the center of the earth now from the insulation line let me draw an arc like this and it is actually a projection onto the equatorial plane and you have two important angle one of the angle is this.

And this we have known the angle of the insulation line with respect to the equatorial plane is δ which is the declination the other is on the equatorial plane the angle from the meridian so the angle from this medial axis up to the projection of the insulation line on the equatorial plane and that is called ω or the our angle.

Moving back to the 3d visualization now let us drink this meridional plane so that it is in line with the earth radius so like this now that is the meridian of interest and restoring all the other parts we know how the system like this now let us consider a point of interest on this meridional plane let us say some point like this as pointed by at the cursor let me draw a line from central that the right through the point of interest like this.

You see that this line goes to the point of interest here on the surface of the earth and that line continues down to the center of the earth the coordinate system that we have been discussing till now is with respect to this as 000 the cursor is pointing to the origin this is the earth centric coordinate system where you had the pole axis the east of the meridian and the meridian axis now this is the local point which we are interested now someone is standing here.

Now the line passing through the local point and the center of the earth intersecting at specific latitude and longitude here will become the 00 origin for the local coordinate system now let us say we place a tangential plane here we play the tangential plane here to indicate the coordinate system at the locality and you see that we have placed clean here at the locality the locality point as the origin tangentially to the meridional plane.

So to get a better visualization if I move it like this now you see that this plane here is tangential to the meridional plane and it is tangential to that line passing through the through the locality so this angle probably would give you a better visualization probably if I move it in this fashion you will get a visualization of this plane now this plane is called the horizon plane important node you see that this is the equatorial plane and this plane is called the horizon plane.

This plane is the horizon planes specific to this latitude it is orthogonal to this line which is joining this latitude point to the centre of the earth and the coordinate system for that latitude is referred with respect to this reference plane which is the horizon plane now let us write down the coordinate system for this latitude and we call this one as local centric coordinate system remember this coordinate system which we have written down is the earth centric co-ordinate system.

Now you have another coordinate system which is focused in this horizon plane and related to this horizon plane and is called the local centric coordinate system.

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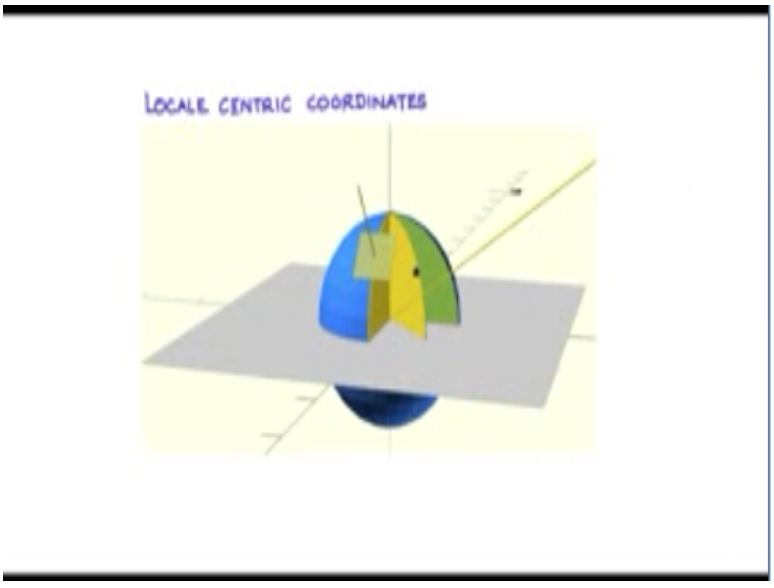

Let us define the coordinate axis of this locality with reference to this horizon plane first this axis the one which is normal to the horizon plane going right from the centre of the earth through the locality and straight up the vertical line we shall call that as Z representing zenith so this is the zenith axis which is just going normal to the horizon plane as going vertically up so that is one axis the other axis is along the meridian tangential to the meridian going down south.

So this line which goes tangential to the meridional plane going down south along the horizon plane will be denoted as S. The s coordinate system representing salt the third coordinate axis is shown east as e uppercase E to distinguish between the lowercase e which we used for the earth coordinate system and this is East remember that this East uppercase each of the local coordinate system and the east of the earth coordinate system are parallel and the point to the same direction. So this forms the coordinate system of the locality.

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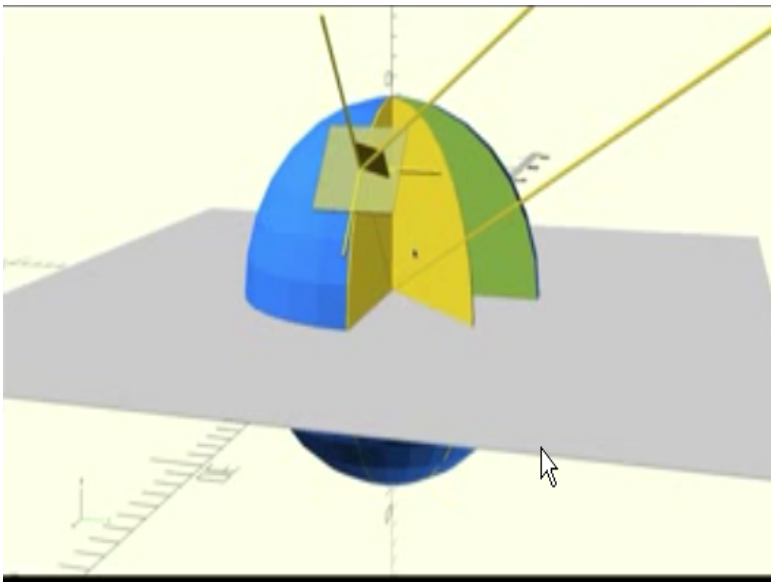

Let me give you a 3d visualization I am looking down from the North Pole polar axis straight down you see the horizon plane here located at tangential to the local point latitude this is the zenith taxes as pointed by the arrow this axis is pointing south on the horizon plane and this axis is pointing East on the horizon plane we could probably take another view something that is something that is much more familiar to us.

We have written this kind of a viewpoint on the paper this is the Zenith axis this is the axis pointing south on the horizon plane this is the axis pointing East on the horizon plane this is the insulation line joining the local point to the center of the Sun now observe that three important parameters this angle here is the latitude angle because this line joining center of the earth to the local point here makes a angle equivalent to the latitude angle.

And this is the insulation line and the angle that insulation line makes with the Linnet axis is called the zenith angle and if you take a point of insulation line project it down and projection line makes an angle with respect to the south axis on the northern plane and this angle is called the zenith angle these are the important angles that you must keep in mind with respect to the local geometry.

So you see that in this figure there are two important coordinate systems the odd centric coordinate system and the local centric coordinate system so these two coordinate system of the important ones that we need to analyze and try to estimate the insulation at the local point so let us see how we go about doing that but first let us try to consolidate this two coordinate system on a 2d graphic system.

Let us go back to the 2d graphics let us draw a line from the center of the earth to the locality of interest this line will make an angle Φ to the equatorial plane and this angle is the latitude angle now from this point the locality point you draw you extend the line straight up vertically up and at the surface of the earth let us how a plane which is tangential to the Meridian are shown like this and this plane is exactly horizontal and the locality is called the horizon plane.

Now on this horizon plane will be the new coordinate system which is the local centric coordinate system remember the art centric coordinate system which was with respect to the equatorial plane you had the people our axis the east and the meridional axis now at the locality here with respect to the horizon plane this axis exactly vertical up is called the zenith axis Z and so going south exactly south on the horizon plane.

We will call it as axis yes and going east this axis is called just East to distinguish from the earth centric coordinate system I will use upper case for the local centric coordinate system let us now draw the insulation line from the locality point to the center of the Sun extends to the center of

the Sun so this insulation line will make an angle to the vertical axis or the Senate axis now this angle is called θ Z and this is called the zenith angle.

The angle that the insulation line makes with the vertical axis at the locality the zenith taxes at the locality is called the zenith angle there is one more term so you consider a point on the insulation line drop a vertical projection onto the heart of the horizon plane and this line on the horizon plane connecting the projected point to the local centre and the south axis so this angle is called the azimuth angle γ S.

So these are all the variables that you will use in estimating the insulation at this locality point remember there are two coordinate systems our central coordinate system and the local centric coordinate system in the earth centric coordinate system the important variables all δ the declination the our angle ω and in the case of the local central coordinate system two important angles are the zenith angle θ z and the ultimate angle gamma is.