Indian Institute of Science

Design of Photovoltaic Systems

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We shall discuss now a very important topic that is of insulation with reference to earth, we have discussed about insulation and spectral irradiance of the Sun in a genetic manner where the sun spectrum does not change and the insulation of the sun's spectrum remains unchanged in whichever direction that you look at. However for a person on earth or a person with reference to the earth, the insulation is not constant, on earth during my time there is no solar radiation and therefore the insulation is zero, during noon the solar radiation is maximum and therefore the insulation is maximum.

During the morning dawn and during evening dusk, you will see insulation at a very low value all this is because the earth is rotating about its own axis, these are the diurnal changes and the earth is also revolving about the Sun in an elliptic orbit giving rise to seasonal changes and all these affect the insulation at a given locality on the earth. Therefore it is very important that we study insulation due to the Sun or due to the Sun spectrum with reference to the earth, so how do we correlate this Sun spectrum and arrive at insulation with reference to the earth is very important for sizing the solar PV panels and that would be the focus of the discussion now.

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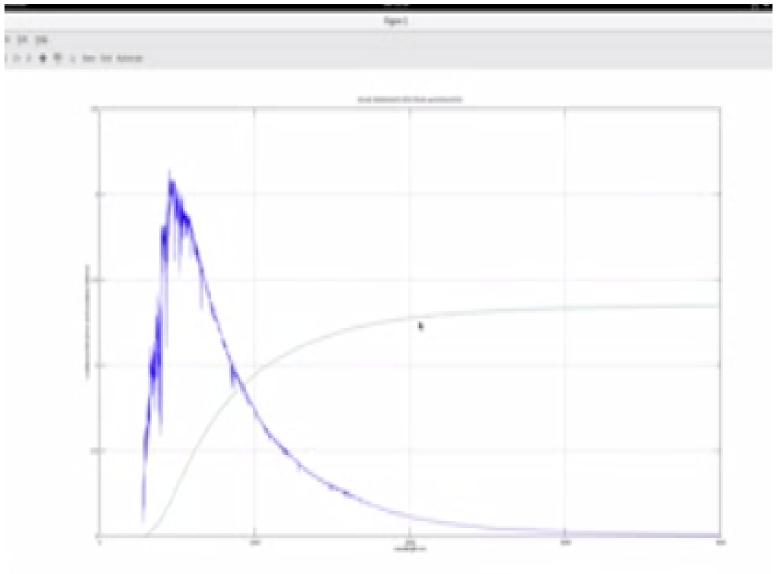

I would like to revisit the solar spectrum in again, so here you have the spectral irradiance and the insulation in kw/^{m2} this pictures this graph is with respect to the sun's spectrum, it is independent of time. However for a person situated at a point on the surface of the earth the insulation would vary with time, so the time of day is an important parameter that needs to be considered, for example if it is at night the insulation value would be 0 and it would be at a maximum value probably at noon.

So insulation value would probably be at a pretty low value at around 6 o clock in the morning and gradually increase to a peak at noon and then further decrease again to 0 by dusk. So how does one visualize this insulation with respect to time also, so let me introduce here in this graph a third dimension which is a third which is the time dimension and let us see how the insulation plot looks like.

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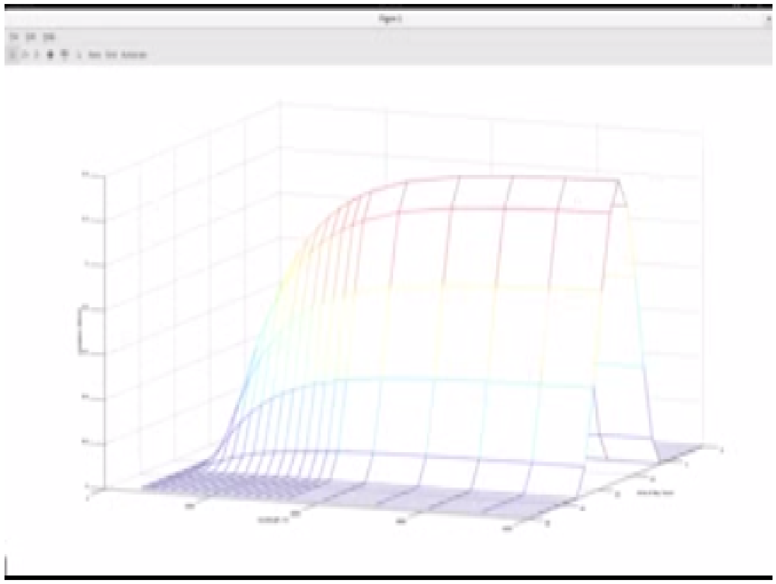

Here I have recomposed the insulation graph instead of the plot function I have used the mesh function and plotted the insulation using time as a parameter, so you see here a family of curve the x-axis of course is the wavelength and the y-axis is the insulation in kw/^{m2} this bottom line is at a pretty low insulation, which probably may be morning near 6 or 7 o'clock and then as the time increases in the day, you will see the insulation rising and rising further on as the time most words noon and probably at noon it may be at the max of the peak value and then further on it would again fall down and coming down to 0.

So as I use the mesh 3d I should be able to rotate it and just get a much better view of how it would look? So this now this position gives you a much better idea of what is happening and you see that the time axis is going down into the plane of the screen, so this is the time in a time in hours 2 to probably 24 somewhere here, this is usually the wavelength and this as usual is the isolation kw/^{m2} and you see that if I start here from 0 which is 0 hours midnight and this is a silo clock and probably at around 6 a.m. it starts to rise the insulation value and the insulation value would probably peak at around somewhere here noon 12 o'clock and then 13, 14, 15 so on it comes down and probably at 18 which is 6 p.m. it again goes down to 0 and then remains 40 during the night.

Of course this profile will change depending upon the latitude at the equator to be different had the northern latitudes, it will be different at the southern latitudes will be different but at a given longitude latitude point again at a given locale you will have a profile something like this over the day. So every day this profile will repeat. So this important takeaway that I would like to give you for the insulation at a point on the earth, I am assuming right now that our atmospheric condition but we will discuss that later.

But for now important thing that you should understand is for a person standing on the surface of the earth, at that locality the insulation is dependent on any dependent on the time of the day and this is the diurnal changes and this happens every day because of the day night effect because the earth is rotating on its own axis. I shall include for you also the script file which generates this I have made that in insulation underscore 3d and I will include that also in the resource start I would place for you there is a section.

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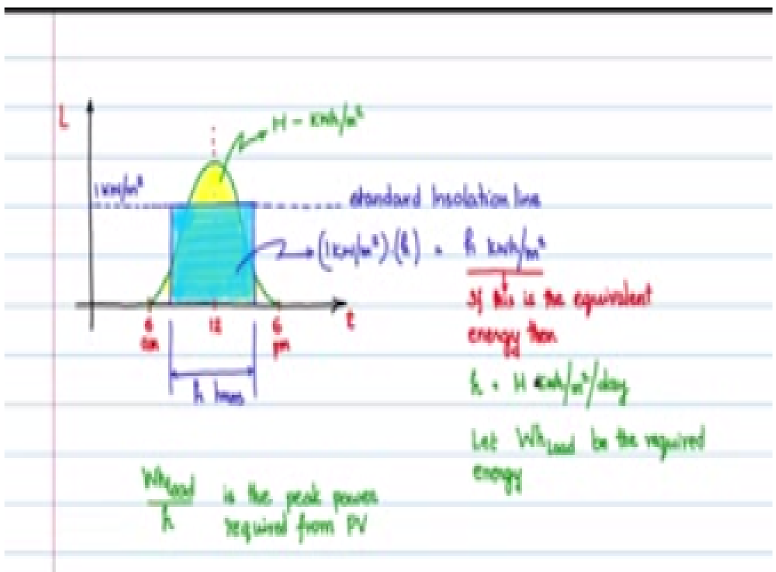

Once we know the daily insulation profile, we will be able to derive the solar photovoltaic panel requirement in terms of peak power. So let us put the insulation profile with respect to time that we just now saw on this screen, so we have the x-axis which is the time axis and the y axis which is the insulation in kw/^{m2} and we thought that this is the kind of profile that we get peak I have put it at our own known not necessary that it could be a more. Now if you take the region within this green insulation profile and take the area within this region it is nothing but the energy because it is the kw/$^{m2\ into}$ the time in hours will give you the energy in kilowatt hour's kw/^{m2} and let me denote that by uppercase H.

So if we make measurements let us say if we make either measurements or estimation at particular latitude, we will get this curve and the area under the curve should give us the energy per m^2 per day for that particular local latitude. Now this area can be approximated or can be represented equivalent in terms of the standard insulation, so if we consider the standard insulation line it is in this fashion, so this is a 1 $kw/^{m2}$ line and this is the standard insulation line. Now using the standard insulation line as the upper limit, we can draw a rectangle like this such that the area within the rectangle is matching the area H of the actual measurement or estimation.

So this width of the rectangle is let us say H hours, then what is the area of this rectangle? This is 1 $kw/^{m2}$ height into H hours. So this will give you H $kw/^{m2}$ per day. Now this is the energy that is contained within this left angle and if we make this energy equal to the energy the actual estimated energy at that place which is H, then we would know what is the equivalent hours of standard insulation time, so if the this energy is made equivalent to the actual energy of that place then the H hours of standard insulation time is equal to H $kw/^{m2\ per}$ day and this insulation can be used to derive the peak power requirement of the PV panel.

Now let us say that Wh_{load} is the required energy and Wh_{load} by H is the peak power requirement for the PV panel, so Wh_{load} is again energy in kilowatt hours and if let us say this Wh_{load} is the required energy daily energy for that day, now that would mean that the requirement is filling up has to fill up this rectangle. Now I know the hedge has been obtained if I am able to estimate head the uppercase H in $kw/^{m2}$ per day then that will directly give you the value of how many hours in a day with standard insulation, using here you will get the peak wattage required, now that would form the basis for you to select a PV panel with this peak power requirements. Now with data sheets and series parallel connection you can choose the number of panels that are needed for series connections and parallel connections.

So in this way you can arrive at the size of the path, but the difficulty here is how to get this H because this Edge has many uncertainties are as I said the daily the seasonal, the water vapor content in, the atmosphere, the clouds, the weather conditions, climate conditions all these are going to affect this H, that is the incident energy falling at that particular locality or particular latitude. So if we are able to get this with reasonable accuracy then you would be able to size the panel appropriately, so our whole focus is to see that we get $kw/^{m2}$ per day that is the energy per meter square per day as accurately as possible.

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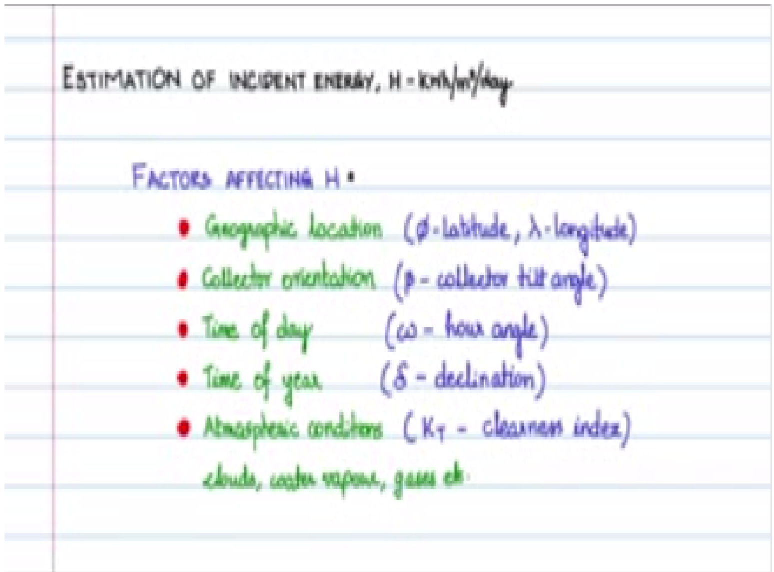

Estimations the incident solar energy hedge in kw/^{m2} per day is an important activity that we have to now take up, if we have to appropriately size and rate the solar PV panel for any given application. However this instant solar energy is dependent on many factors and many parameters, so it is important that we have a look at these factors that affect the solar incident solar energy H. A note of caution this hedge I am calling as the incident solar energy in kw/^{m2} per day in literature you will find the solar energy is also referred to as irradiance as solar irradiance, we have used the term spectral irradiance, so distinguished spectral irradiance and solar irradiance, the units are different.

Spectral irradiance has the units of kw/^{m2} per nanometer solar energy are the solar irradiance has the unit kilowatt hour energy per meter square per day so keep this distinction in mind but as far as my discussions here I will not be using the term irradiance for this I will just use incident solar energy, so that it reflects closely to the units of the energy that we keep writing for H. So be cautious about this particular variable it is also called solar irradiance in the literature but note the unit is one of the important obvious factors that affect the incident energy is the geographic location. So geographic location is represented by two parameters two variables one is ϕ latitude represents the latitude and other is γ representing the longitude at a given place.

Another factor that affects significantly this value of H is the collector orientation by collector; I mean here the solar PV panels. Solar PV panels are always flat they are flat collectors however in the thermal applications the collectors need not be flat you will see parabolic and cylindrical purple lights being used as collectors and they have different concentration profiles. However for the solar photovoltaic applications the collectors are always flat and I am always meaning the flat plate collectors and the orientation of the flat plate collectors to the horizon plane or the horizontal plane, so that is the angle which we which we understand here by collector orientation.

And that angle is denoted by the symbol β so this is also called the collector tilt, the tilt angle. Another very important factor is the time of day this is something that we have discussed already and we saw how the insulation is affected by the time of the day and we use the symbol ω for our angle ω the hour angler presents the time of the day and which also represents the diurnal changes and diurnal effects. Another effect is time of year this is another factor which seriously affects the value of the incident solar energy. We represent this by symbol δ and it is called declination. I will explain later what declination is but this is an important parameter this actually represents the seasonal variations and the seasonal effects on the incident solar energy.

All these parameters which I have listed or fairly deterministic however the one that I am going to now say, which is the atmospheric effects is the one which is most difficult to estimate, the atmospheric conditions like cloud conditions, water vapor content in the atmosphere gases present in the atmosphere etc all these things affect the instant solar energy. Now all these are not deterministic at on a given day we do not know what the condition is and what are the effects probably in the statistical values for all these.

This is represented by a variable called KT and it is called clearness index and this probably is the most difficult to estimate due to the uncertainties in that atmospheric conditions, so we will look at all these parameters and variables and see how we go about obtaining these parameters and then once we have these parameters, how we get integrated into the estimate equation for H.