Indian Institute of Science

Design of Photovoltaic Systems

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NPTEL Online Certification Course

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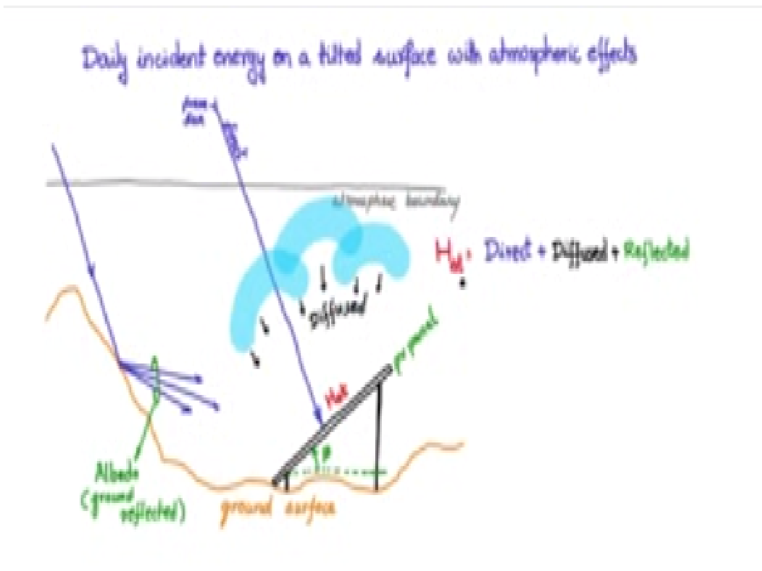

We need to estimate now the incident energy on a tilted surface with atmospheric effects so let us draw the real physical setting on how the collector is placed and what are the various radiation and atmospheric effects that comes into picture, so for that let me draw the ground profile this is a ground profile there is a hilly region here and then the valley region where probably we will place a flat plate collector at an angle and this basically is our ground surface now on this ground surface.

Let me place a flat plate collector and that flat plate collector is kept in inclined manner like this mounted on two struts and it is at an angle β to the horizon β is the δ angle so this could probably be a PV panel flat plate collector, now to this PV panel flat plate collector our objective of the goal is to find out what is the amount of insulation that is falling on it and to calculate the daily incident energy on this flat plate collector panel which includes all atmospheric effects now consider a line like this and this line is supposed to represent the outer atmosphere.

So we will call this as atmosphere boundary now from the distant Sun we will have an insulation vector falling onto the flat plate collector and this is called the direct insulation vector and this is coming directly from the Sun, so this is the direct incident radiation falling on to the panel apart from the direct incident radiation there are other forms of radiations subsidiary forms and one of them is let us say I take another parallel insulation line which is falling on the nearby neighboring Hill slope of the help.

So what happens after it falls on the ground gets reflected and it can get reflected in multiple direction and these reflected radiation can also go and fall on the flat plate collector and affect the amount of collected energy at the panel now this ground reflected radiations are called Albedo, the term Albedo is used for ground reflected radiations so you see that there is this direct insulation falling on the flat plate collector tilted and then there is this Albedo effect also ground reflected effect also coming on to the collector and apart from that there is one more important effect that comes into picture.

And that is the diffused radiation you will see that there is cloud flower and the insulation that is directed towards the flat plate collector will get scattered and we will also get diffused due to the cloud, and you will see that there are many insulation vectors indifferent directions pointing and many of them pointing towards the collector in this fashion and this is called the diffused radiation and it is our objective to find H_{at}, H_{at} is the energy incident on the flat plate collector which is tilted at an angle β including the atmospheric effects.

That is what H_{at} means and H_{at} is actually a composition of energy from direct radiation plus energy from diffused radiation like this plus energy from reflected ground reflected radiation.

Or the Albedo so all the three effects put together is what will be the H_{at} or the energy available at the tilted flat plate collector has position like this, now this is a practical and real situation how do we go about estimating this there are so many uncertainties in this unlike in the previous cases where we found HO and H_0 H_0T energy incident on a horizontal flat plate collector and energy incident on a tilted flat bed without the effect of that atmosphere that was much more idealistic and deterministic relation.

That we arrived at but here it is not so deterministic because we do not know the climatic condition at locality this would mean that we do not have the exact accurate model for predicting the cloud nature the nature of the water vapor and other the gaseous content in the vertical column above the collector all these all these knowledge is not available in any model form and we only have knowledge of history we only have statistical data and based on the statistical data only we can arrive at an approximate model which will try to give you an approximate value for these and give you an estimate of the energy that will become available at the flat plate collector so let us try to see how we can get as best a value for this H_{at} in the discussions to come further.

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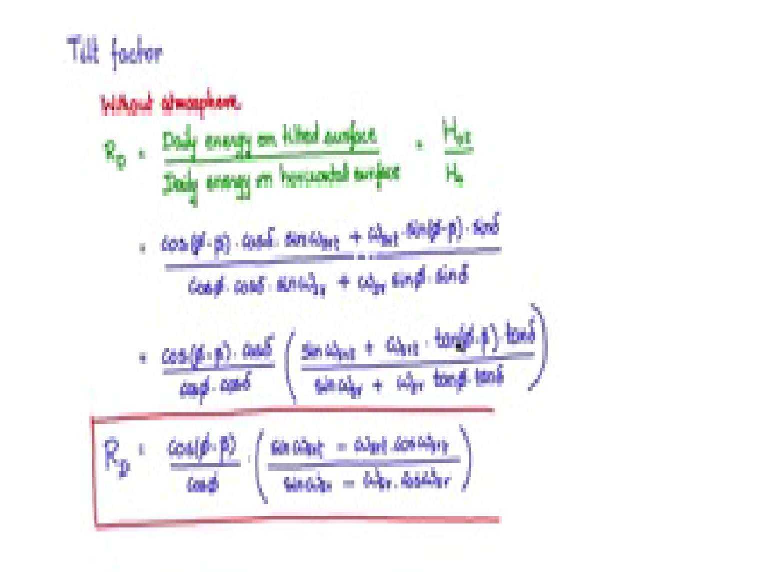

Let me now explain tilt factor the concept of chill factor we talk atmosphere you see we have already found out the energy that is incident on a horizontal surface and on a Tilt surface without atmosphere, so with respect to those energies let us define this term R_D R_D is called as the Tilt factor of the direct radiation R_D is called the tilt fact of the direct radiation and it is defined as the daily energy on Tilted surface to the daily energy on horizontal surface this without atmospheric effects.

And this is equal to we know how to calculate a daily energy on tilted surface they are seen that which is H_0T and on the organ service which is H_0 so if you write down the equations of these two and canceling the common terms you will get Cosϕ - βCos δ ω_{srt} sunrise angle of the Tilted surface + ωsrt Sinϕ – β Sin δ / Cosϕ Cos δ ωsrt + ω Sin / Sin δ, now we can simplify this slightly Cosϕ – β into Cos δ you take it out from the numerator Cosϕ and Cos δ

and Cos δ take out from the denominator and you will get in the numerator find ω* + ωsrt Tanϕ – β δ this because you are removed Cosϕ – β Cos δ it will get divided by Cosϕ – β.

And culture that will become tan piping likewise on the denominator side also you will get Sin ωs + ωsr Tanϕ Tan δ of course we can cancel out Cos δ here and ϕ Tan δ is nothing but – Cos ωsr Tanϕ – β Tan δ is equal minus Cos ωsrt substituting, this we can write it as Cosϕ – β Cosϕ Sin ωcr ωCR t - ω s R_T cos ω s R_T by sine ωsrt minus ωsrt cos ωsrt so this is defined as or tilt factor without that most fearing effects this is for the direct radiation without the atmospheric effect we will have another tilt factor coming with atmosphere effects, so or try to distinguish the tube consider the direct radiation there we will.

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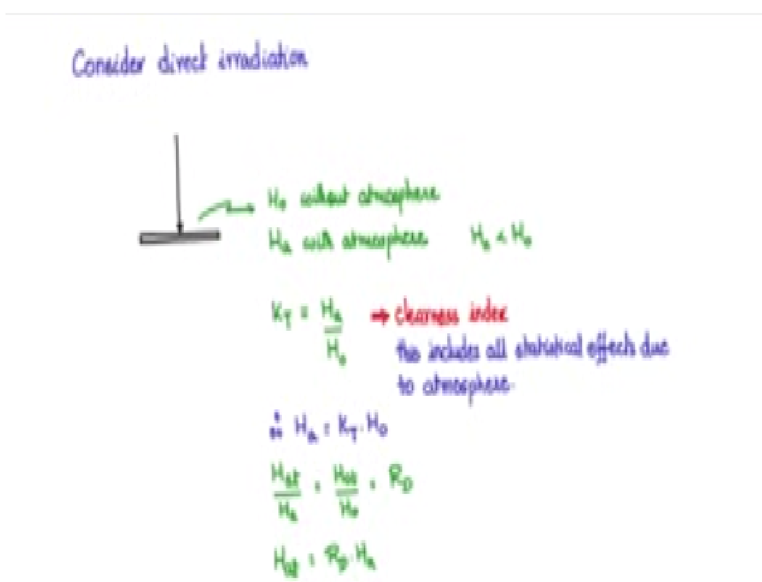

Consider a flat plate collector that is placed horizontally like this and normal to it there is the incident irradiance, now we know what H_0 naught is H_0 is actually the energy incident on this flat plate collector without atmosphere and Ha is the energy collected with atmospheric effects a cheer of course is smaller than H_0 because η is the attenuated value of H_0 after having gone through that mistake now let us define a term K_T, K_T is defined as H a the energy collector on a flat plate collector with atmospheric effects divided by H_0.

The energy incident on the flat plate collector without atmosphere or atmospheric effects and this is called clearness index this is a very, very important factor this clearness index because this consolidates all the uncertainties of the climate it includes because it is the ratio of energy instant on the same flat surface with atmosphere divided by one without atmosphere, so this ratio kind of encompasses all the uncertainties unpredictability z' and the statistical nature of the information that is present in the climate at a locality so this includes and incorporates all the statistical effects due to atmosphere so this is a pretty important parameter which we will use and we will discuss later how we will estimate this clearness index value from the previous historical data for.

Now let us conserve this as a variable and let us consider that this is estimated now once you have this clearness index then we can say that energy incident on a flat surface with atmospheric effects is equal to K_T clearness index into H_0 the energy that was incident in the flat surface without atmospheric effects, now what is a H_{at}, H_{at} is energy incident on the flat surface with atmospheric effects with a Title of an angle β and this can be obtained by this ratio Hat / Ha would be same as H_{ot} / H_0.

There are atmospheric effects in both these cases will cancel out and therefore at 4^{th} not would also approximately will actually be equal to the R_D which we just now calculated this is the title factor of the direct radiation therefore, I will now say Hat = Ha into R_D this is an important relationship.

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$K_T = \frac{H_a}{H_0}$ → clearness index

this includes all statistical effects due to atmosphere.

$\therefore H_a = K_T \cdot H_0$

$\frac{H_{at}}{H_a} = \frac{H_{ot}}{H_o} = R_D$

$H_{at} = R_D \cdot H_a = \underline{R_D \cdot K_T \cdot H_0}$

$$H_{at} = \underbrace{\left(H_a \cdot R_D - H_d \cdot R_D\right)}_{\text{direct}} + \underbrace{H_d \cdot \left(\frac{1+\cos\beta}{2}\right)}_{\text{diffuse}} + \underbrace{H_a \cdot \rho \cdot \left(\frac{1-\cos\beta}{2}\right)}_{\text{reflected}}$$

Now this relationship we shall now expand to include the diffused portion of the radiation and the reflected portion of the radiation that is as we defects but remember that both the diffused radiation and the Albedo are again very uncertain parameters varies from place to place very difficult to have a closed-form solution so we will only be using an empirical relationship so we shall expand this to include the empirical relationship of the diffuse and also the reflected components into H_{at}.

So now R_D into H_A can be expanded to K_T into H_0 now let me say T and H_{at} is composed of the direct component H_A into R_D now this H_A into R_D which is having KT into H_0 Ha is K_T into H not a part of the K_T investment is going off into the diffused radiation, so I will have to subtract from this the diffuse component and I will deal diffuse component separately as a separate term so let us remove the diffuse component from this so I will say - H_D let us say H_D is the diffused component of the air radiation and into R_D.

So this part I will remove H_D into R_D if you component and I will call this as a direct portion and the diffuse portion I will deal separately and I will call that one H_D into now here an empirical parameter Council which is dependent on the title angle so 1 + Cosβ / 2 this relationship is an empirical relationship which deals with the diffuse component plus let us improve the reflected component also, so it is a small fraction of Ha so in this row is called the reflection coefficient it is a value smaller much smaller than 1 and 1 - Cosβ / .

This is the reflected part and this is also an empirical relationship and it goes by this argument see when the Tilt is 0means when you keep the flat plate horizontal beta is 0 so 1 - 1 so there is no reflected component on a flat plate collector which is placed horizontally, so that is argument with which this empirical relationship has been brought about ∂ is a reflection coefficient it actually depends upon the terrain if it is a plain terrain if it is in the plains where there is not much possibility of reflection.

From the neighborhood ground surface then a ∂ is very small around point 1 and if you have a lot of mountains in the neighborhood let us say the collector is placed in a valley and there are a lot of nearby mountains and slopes which can reflect a lot of light onto the channel or if it is a snow-capped mountain which can reflect quite a significant amount of light onto the panel's collectors.

Then the reflection coefficient ∂ is 0.7 here so you see that there is lot of empirical mass which is brought in into this relationship but you cannot help it because of the uncertain nature of the locality and the climate however you should note that the direct portion is the dominant component of H_{at} of the total incident energy the diffuse and the reflected power component will be the subsidiary components which will supplement the direct component, so give lot of importance to this portion of the equation the other empirical portions of main equations are added to make H_{at} much more closer to the practical value much more accurate to the practical's measured values.

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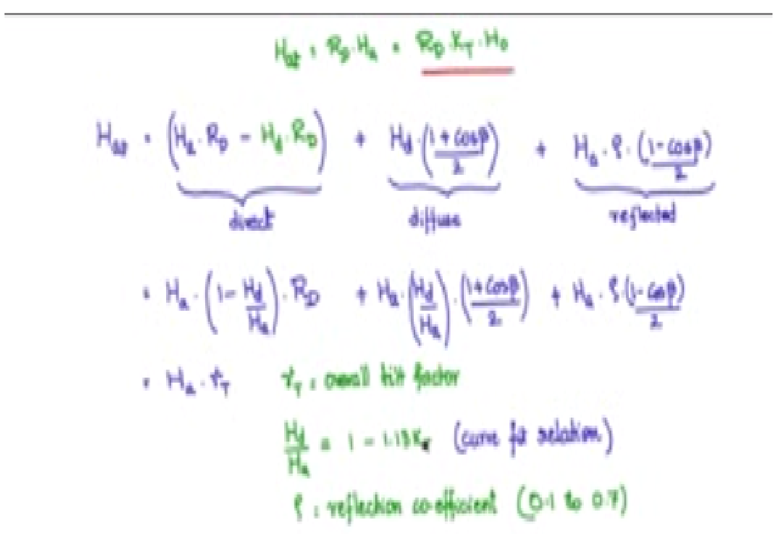

So then we can simplify this I will put it as 1- H_D by Ha into R_D at the direct portion plus I will put Ha into H_D by H_A 1 + Cosβ by 2 diffused portion + H_A into ∂1 – Cosβ / 2 by this is the reflected portion so I have HS common factors I can take out H as a common factor and say Ha into R_T now we have this R_T is the overall tilt factor taking everything into consideration and H_D by H_A the ratio of the diffuse to the energy with atmospheric effects on the horizontal surface is again an uncertain thing and it is also a carpet equation again obtained from previous statistical history and a perfect relationship is available.

For that and I will write it down 1 - 1 point 1 3 times K_T it is note that it is dependent on clearness index K_T which means this is a term which will vary with the climate which will values the region which will vary with the atmospheric effects on the vertical column above the collector, so there are a lot of uncertainties in the relationship but it will serve the purpose for us for designing and sizing the PV panels so this is a curve fit relationship and also note that ∂the reflection coefficient is a value between 0.1 and 0.7 as we just now discussed

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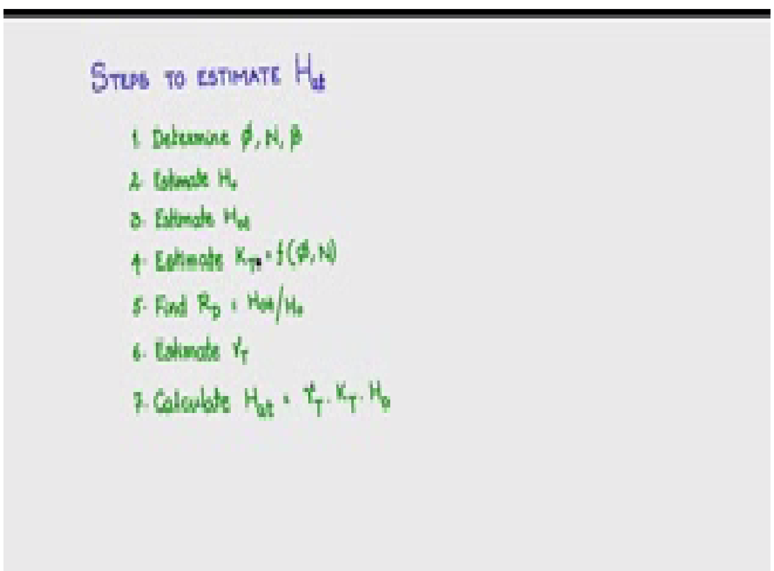

We have gone through a lot of steps to estimate the daily instant energy on a collector we have derived equations and we have formed relationships and we have also stated some empirical relationships in order to estimate the daily incident energy on a horizontal flat plate collector on a tilted flat plate collector and also on flat plate collectors tilted flat plate collectors with atmospheric ethics, now finally to size the photovoltaic panel you need this value HA the daily incident energy that a collector will collect a flat plate collector.

We collect without atmospheric effects and with tilt now this is the parameter that we need to determine and let us consolidate all the all the equations that, we have derived and discussed by listing out the steps that will lead to this calculation, so first we start with the inputs what you need determine the latitude at which the locality is placed and for which you want to calculate a H_{at} the day number the day of the year which you want to calculate H_{at} and β or the tilt angle now with this you can definitely estimate H_0.

Which we have seen we can also estimate H_{ot} because we know the tilt angle β and we need to estimate H_{at} K_T the clearness index this is the most important when you want to consider atmospheric effects and K_T is a function of latitude the day number the atmospheric of the climatic conditions at the day on that day at the place, so it is a kind of a figure that will give you all the statistics history which is based on all the statistical history of the place with respect to atmosphere.

So this is it to be formulated we need to discuss on this but for now consider that K_T, K_T can be estimated and it is a dominant function of latitude and the day number it can also be a function of latitude day number and water vapor but I will discuss that later but for now let us say K_T needs to be estimated from these values input values next if the maid or find out R_D the tilt factor for direct radiation which is H_{at} by H_0 we have this then we can find this then estimate R_T which is the overall tilt factor including the direct diffused and the reflected radiation.

And then finally you calculate the value of H_{at} the important value of H_{at} which is given by R_T* K_T into H^0 this we have seen just before shortly we discussed this one and we need to calculate this and this will be the value in kilowatt hours per meter square per day and this is what you will use to size the PV panels.

But before that we need to do one important job how do you find K_T we know how to find all other things in order to find H^0 we know how to find rd we know to find R_T and then this now this is the only parameter that we have not discussed this clearness index and how to find is clearness index this is a statistical phenomena and how does this clearness index factor encompass the entire climate of a particular locality we will shortly see that.