Indian Institute of Science

Design of Photovoltaic Systems

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NPTEL Online Certification Course

It is time for some simulation some scripting we know how to evaluate the daily energy incident on a horizontal flat plate collector at any given latitude on the surface of the earth we also know how to evaluate the daily energy incident on a tilted flat plate collector located at any given latitude on any place on the surface of the earth, we have seen lot of equations we shall try to consolidate all these equations and put them in a form in sequence so that it will help you later on in design and sizing of the PV panels.

We shall use octave for scripting and try to run the simulation and see the plot outs of the kilowatt hour per meter square per day versus the day number so that you know how the available energy function is over the year.

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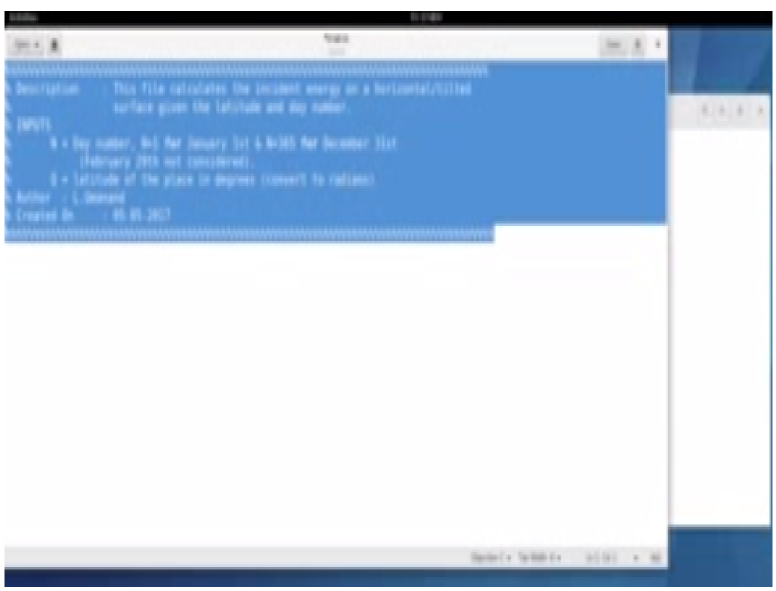

I have here a text file blank text file I am renaming it as IRRAT. M, IRRAT short for irradiation dot M it is an M file the script file which can be executed either in octave or MATLAB and then I am storing that file save that file in PV SIM it is a scratchpad folder. So now let us start to populate this file write the scripts first let us have the header comments, so these are all command files as you can see here this description is our to this file calculates the incident energy on a horizontal tilted surface given the latitude in the D number.

Where N real number and I am considering only the non leap years and I am using Q for the latitude instead of ϕ because I cannot type in ϕ and the ASCII in the text file it will be in degrees and we will later convert it into radians.

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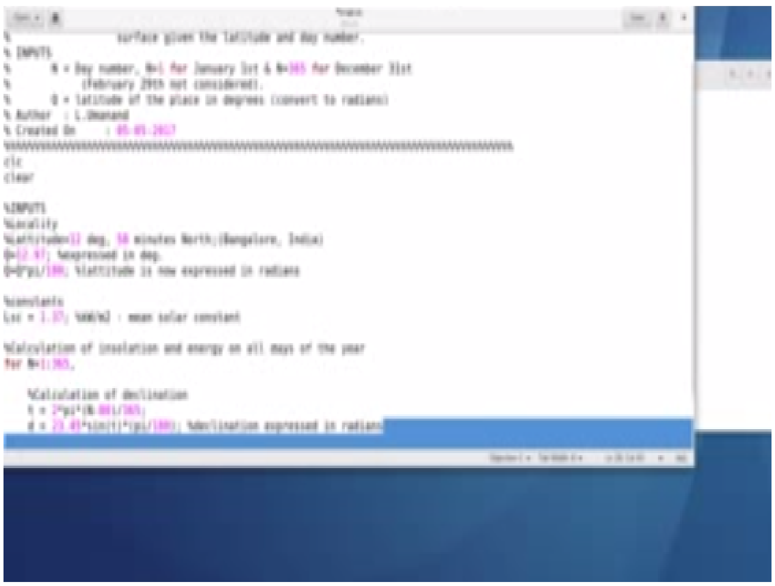

So the first commands would be clearing the screen and then clear all the variables and then now let us take inputs so to take inputs first we allow to mention the locality so the locality this again is the command file the latitude is 12 degree 58 minutes north of the Equator and this is the latitude of Bangalore that is Indian institute of Science Bangalore has this latitude so I just have taken that you can as well choose any other latitude or locality of your choice.
So Q = 12.97, 58 minutes is in decimals 0.97 and this is expressed in degrees we need to convert it into radians because it is always better to convert all degree units into Radian units the SI units and the system of equations that will follow and the result that will follow will be consistent. Next I have converted Q into radians q = Q x Π/80, Π/80 is the conversion actor from degrees to radians.

So next let me list out the constants there is only one constant part is right now that is LSC, LSC is the mean solar constant which is 1.37 kilo watt per meter square and that is what I have written and now let us begin the calculation of the insulation and energy on all days of the year, so we have to take one by one so let us say we take day number one n = 1 and calculate H0 then the day number two calculate H0 so on for all the 365 days we will calculate the H0 and put them in an array, so let us have a for loop and this for loop will do this job of calculating.

So if here if you see for n = 1 to 365 and n for of this day number loop within the loop what should come, so within the loop let us see what we can have first let us calculate the declination we know how to calculate the declination so let us say at T a variable t is equal to 2 Π n – 80/365 and then we use the declination the relationship which we have studied. D Delta was the declination but I cannot use Delta so I will use D for declination 23.45 Sin(t) or Sin (2 Π n-80/365) and this value is in degrees and therefore I want to convert it into radians and I am using this factor Π/180 the declination is now expressed in radians.

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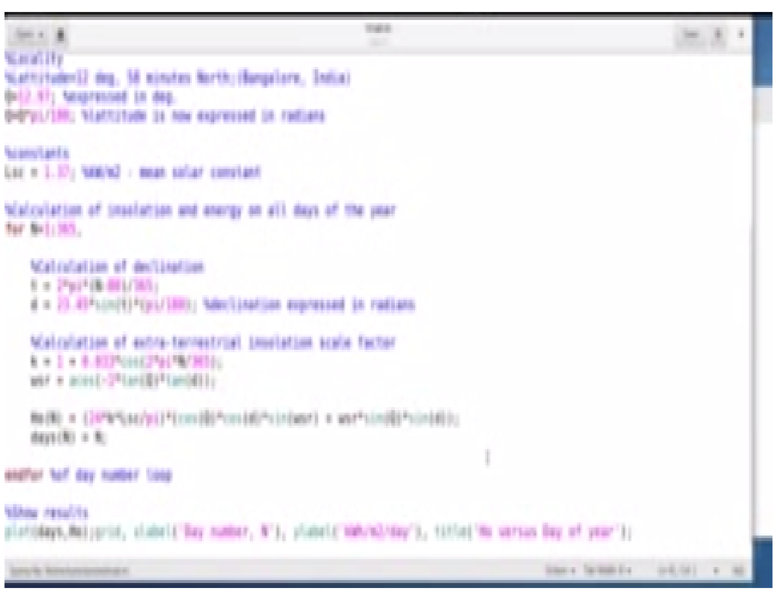

Next I will calculate the extra-terrestrial insulation scale factor KLSC we have LSC we need KLSC and that is calculated using 1 +0.033 Cos 2 Π n/365 I know n because n is an input that is it is an for loop input and we can calculate K then after that I will calculate the our angle so our angle is A Cos X Cos^{-1} – tan ϕ tan δ, so tan Q tank δ and you will get the our angle this is followed by calculation of H0.

H0 for the day number n so if it is 1 it will be H0 (1), H0(2) …. H0(365) this will be an array we use the equation well known to for 24 K LSC/ Π X Cos ϕ Cos δ Sin ωsr + ω sr Sin sr/ Sin δ, now this will give you the H0 in kilo watt hour per meter square per day we will also put into the day's variable another array the day number so that we can plot H0 as a function of the day number, then next we need to show the results and let us plot so what do we plot we will plot days versus H naught days on the x-axis H0 on the y axis and then we shall have the grid label the X label our Y label and the title.

So this will complete our simple script file which will do the calculation of the energy incident daily energy incident on horizontal flat plate collector and we should be able to see the results of this value computed for every day of the year, so we shall now save this file and that's it and we have the script file ready to function.

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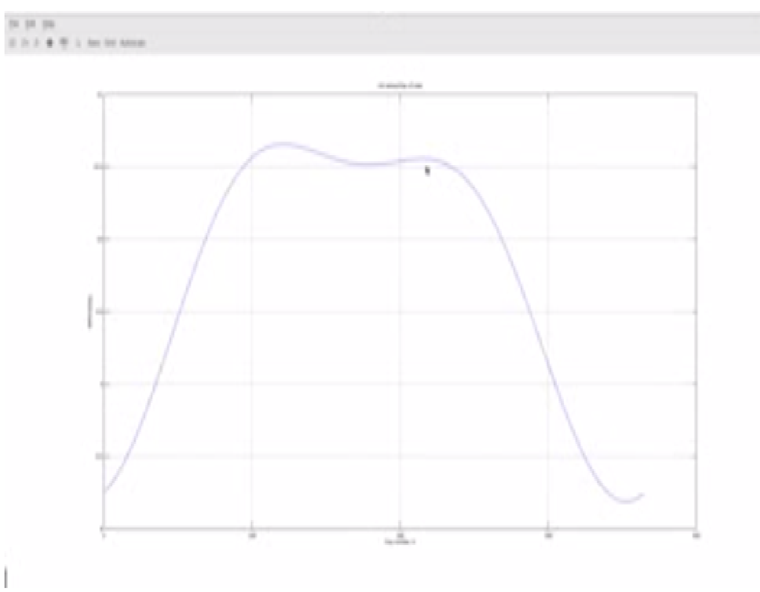

We will open now octave I will click on the octave, octave is open octave as open onto the screen I will clear up this workspace and move into the folder of interest so PVC this is where I have kept the files and I will call right, now it will execute the script file that we just wrote and we will get this, so you see that this is the H0 kilowatt hour per meter square per day computed for every day of the year where the x-axis the day number so the day number is one two three and somewhere here is eighty.

We had calculated for eighty remember that it is 10.54 and this is this is that one single calculation and so on at 100, 200, 300, 365 these are the values that you calculate for The H0 this is for horizontal flat plate collectors this is how it will look like, observe that this energy swings from around 8.25 to a max of around 10.7 or so, so this is a pretty large swing so you see that during January during November, December the available energy on the horizontal flat plate collector is low.

And during the mid year during March, June the summer solstice month you see that the energy that is available is high, however you should note that this calculation and plot of the energy available energy on horizontal flat plate collector is for a latitude and it is without atmospheric effects we will shortly discuss also the atmospheric effects.

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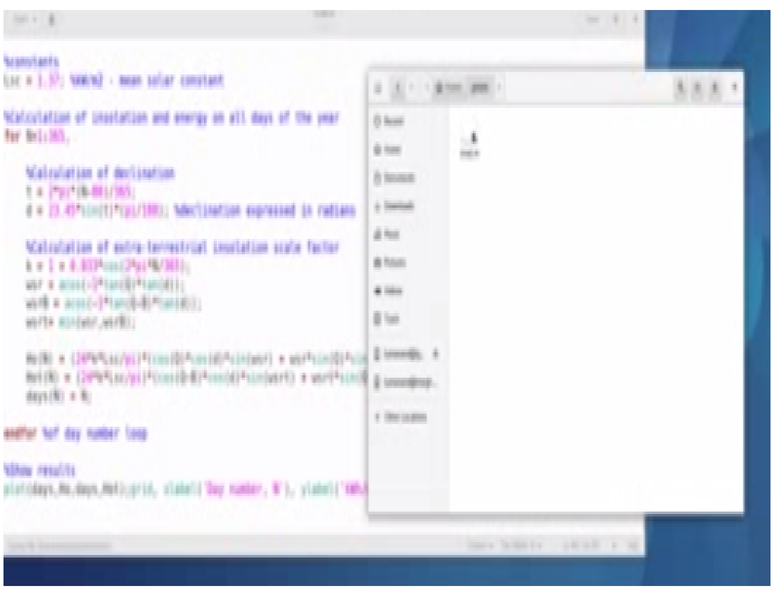

I shall long incorporate some changes in the script file so that we will be able to handle tilted surfaces two so that we will be able to evaluate the incident energy on a tilted surface so first let me incorporate this line so what I have done is set B = Q, what it means is that ß the tilt angle is set equal to ϕ the latitude angle, I am using B to represent ß the tilt angle tilt with respect to the horizon plane of the locality.

And right now I will just set it to a fixed angle Q which is the latitude angle, next I need to incorporate here couple of lines two lines to estimate the ωSR T the sunrise hour angle for the tilted surface so it is actually the minimum of the sunrise hour angle of the horizon and the sunrise hour angle of the tilted horizon, so let us incorporate these two these two lines so this line here is the sunrise hour angle of the tilted horizon ω SR ß which is equal to Cos^{-1} (- tan ϕ – ß x tan δ).
And this other line here is ωSRT the ω SRT is the tilted surface which is minimum of ω SR and ω SR ß, so that is what we will use to evaluate H_{ot}, now next we will try to incorporate H_{ot} we have H0 we will also obtain H_{ot} and that equation is like this H_{ot} =24 KLSC/ Π Cos ϕ - ß ± q – b Cos δ Sin ωSRT this is the sunrise our angle of the tilted surface ω SRT, Sin ϕ – ß written as Q – B to Sin δ.

Now this would give us the estimated evaluation of the energy incident on a tilted surface tilted with an angle beta then coming to the display results we have days versus H0 we will also need days versus H_{ot} and then we will change the title slightly as H0 and H_{ot}, so this would be our new edited file script file we will save it and then this would be the saved file here.

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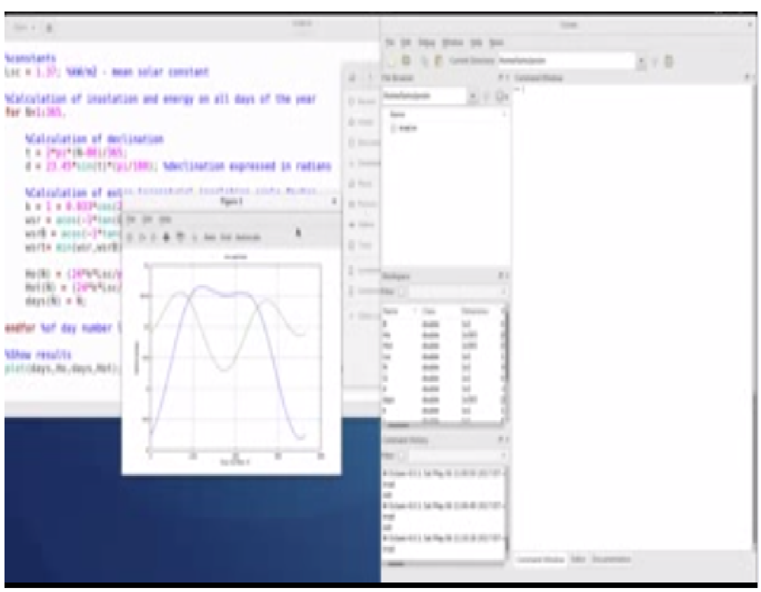

Now next we go to octave we will open octave I will clear up the octave workspace screen and then go to the PVSIM folder and that is where the IRRED.M is located we will now run the script file IRRID now that will result in this graph.

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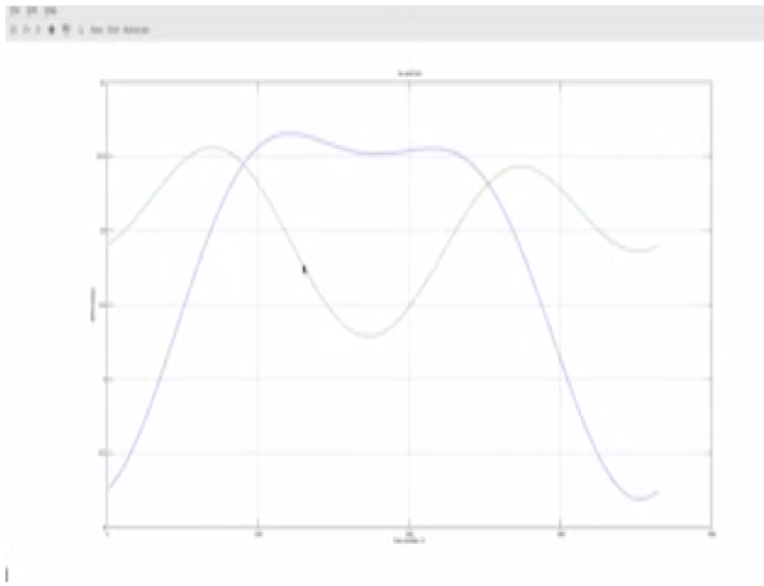

So I will open it up zoom it so this gives us two graphs the blue line and the Green Line so the blue curve you have already seen is representing H0 in kilo watt hours per meter square per day the green line is representing H_{OT} The energy incident on a tilted surface observe that the green curve H_{OT} is a better than the blue curve because H_{OT} is giving you over the entire year 1 to 365 day number 1 to 365 over the entire year a much more uniform incident energy on the flat plate collector which is tilted.

Compared to the blue line H_{OT} where the flat plate collector is placed horizontal so the max energy minus the min energy here the ripple that would be the δH ripple is large in the case of the horizontal flat plate collector compared to the max energy when the min energy of the tilted surface therefore it becomes essential that we need to tilt the surface appropriately at a proper angle such that you get the best collection of energy from the Sun.

We will see shortly what would be the best angle ß of tilt that we should provide for a given latitude.

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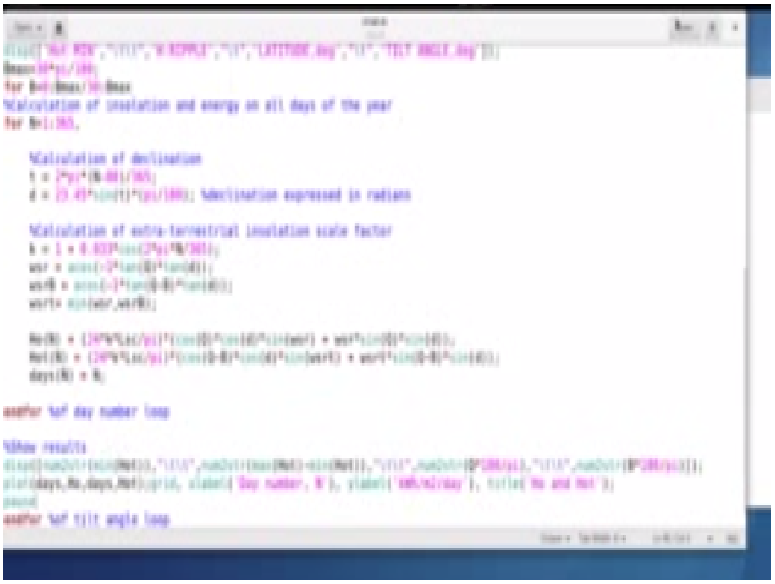

Let me further modify this script file so that we include a continuous variation in the tilt angle so that we try to find out which would be the optimal tip so now here what I will introduce is a line I have introduced B Max or ß max the tilt angle max has 30 degrees 30 x Π/180 radians this is just a limit here for this example you can set any limit which means that I would like to make the variation in the tilt angle from 0 degrees to 30 degrees.

In steps and see how the naught t varies with respect to H_{OT} so we will introduce one more for loop outer for loop for B ß tilt angles which is 0 to ß max with 30 degrees in this case would be any other value also and I have done that insteps of ß max/30which is one degree in this case so for every one degree zero one degree up to 30 degrees and let us have the ending of the for loop here so the end of the for loop end for the tilt angle.

And what we do in between for every value of ß every value of the tilt angles you will see although this I calculated as before H0 will be calculated H_{OT} will be calculated and it will be plotted and then the next value of tilt angle H0 and H_{OT} will be calculated and plotted and you will see that H0 is same does not vary and H_{OT} will vary with the tilt angle and we will be able to see how this H_{OT} moves and what would probably be the minimum value.

Now what I am introducing here is on the work piece screen we would like to see these parameters H_{OT} minimum value of H_{OT} important parameter to see what is the H ripple, ripple the maximum value of H_{OT} – the minimum value of H_{OT} what is a triple and we want to minimize that ripple so that it is as much as possible uniformed throughout the year let us type in the latitude value also and let us display the tilt angle what is changing and that is changing in steps of one degree.

So you will see I am putting it in degree converting and putting it in degree so this would be the title line of the display I would like also put within the loop for every beta calculation display NUM to strain of the minimum H_{OT} the max H_{OT} – min H_{OT} that is the H ripple the latitude angle and the ß angle, okay. So this we can save and before we save let us pause for every tilt angle loop change so I will put a pause here so that you will be able to stop these script execution and observe the waveform, so this we can save and that would be the saved file.

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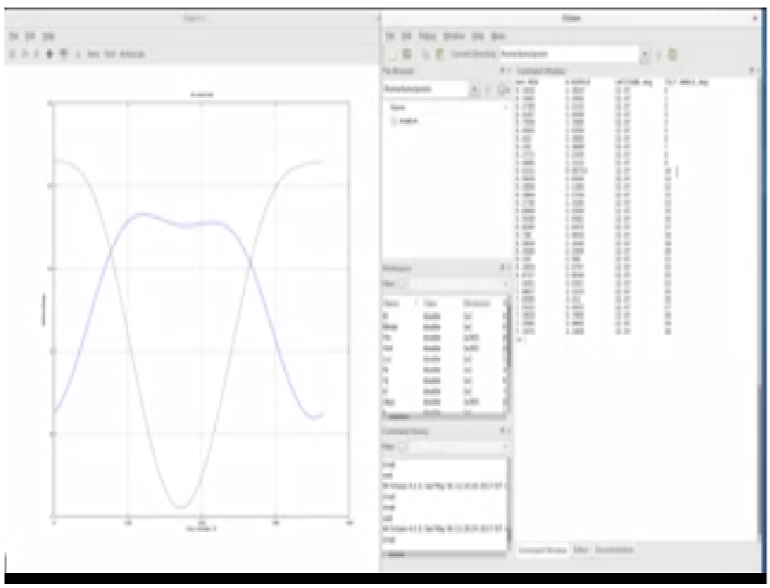

Let us now call upon octave open it and execute within octave so I will clear up the workspace screen let us go into our folder here and let us execute read and then you see we will get something like this I will now keep it side by side with the octave screen you keep observing here you see that there is a display which is appearing H, H_{OT} minimum which is this value the minimum value here the H ripple the max h minus the min H.

That ripple the latitude angle is 12.97 degrees and the tilt angle is zero it is starting with the first value of the for loop is zero and then next value also that this will keep putting up this values here in table and this also will change so you will see something like this and you and keep observing these two you see that as the tilt angle is increasing the ripple reduces to a minimum and then increase you see the ripple starts increasing beyond a particular value.

And you can see the values here in this fashion the tilt angle is changing from 0 to 30 like what we had set, so the tilt angle changing from 0 to 13 steps of one deals now what you could see is the h ripple and minimum h0 and you can probably see somewhere here at around 10 degree tilt at the 10 degree tilt value for this latitude a 10 degree tilt value you find that the ripple is minimum 0.99 and the value is close to the minimum the value of the minimum H_{OT} is 9.52 which is the maximum minimum value, so which is advantageous for us so that you can gain more out of this particular tilt angle from the solar PV panel.

So this would become the optimum value to place the panel at this particular latitude at a tilt angle of 10 degrees, now here again we have not had considered the atmospheric conditions we will consider that and get back again but the concept is like this you look for the difference between the max value of H, H_{OT} and the min value of H_{OT} that is one parameter which is important and also look at what is the H_{OT} min and the H_{OT} minimum must be as high as possible. So this at 10 degree tilt angle this is the most optimal and acceptable for us, in this way you can find the optimum tilt angle.

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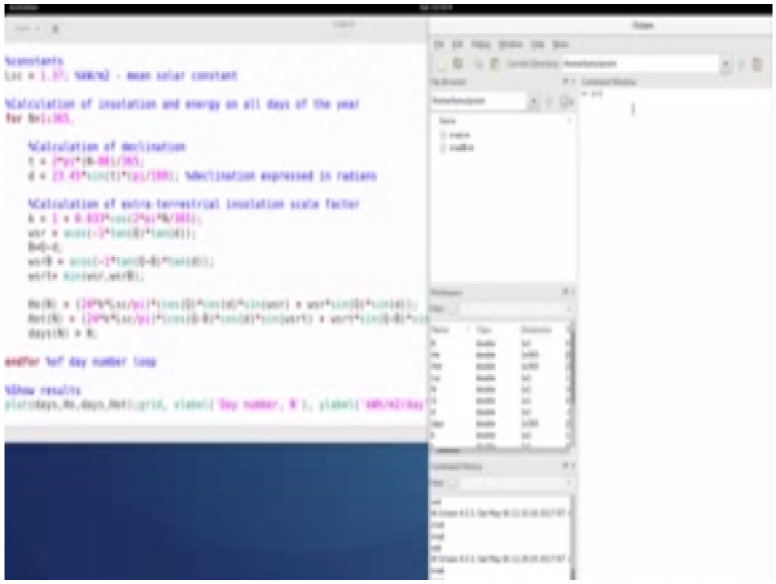

We have seen the result for a success tilt angle throughout the year but if you change the tilt angle every day such that it faces the Sun optimally that is you link it up with the declination Delta then you will get a much better incident energy on the tilted face so what I have done past these that save that previous file as IRRADD.M which means that it is a fixed beta M file I will put it up in the resource so that you can study that and then use it.

And I will make one more modification in the IRRAD file here means I will remove the for loop for the tilt and I have included here one-line beta R the tilt angle is equal to $\Pi - \delta$, Q - D here then the δ is equal to the latitude which means the insulation line is such that it is passing through the latitude of the location then $\phi - \delta$ will be 0 at that place at that time the tilt can be 0 that is it can be horizontal.

Because the Sun will be directly overhead and at any other declination let the panel track the Sun so making this modification and keeping all the equations same let us see what you will get when you run the script in octave, so I have saved that and then let us run IRRAD.

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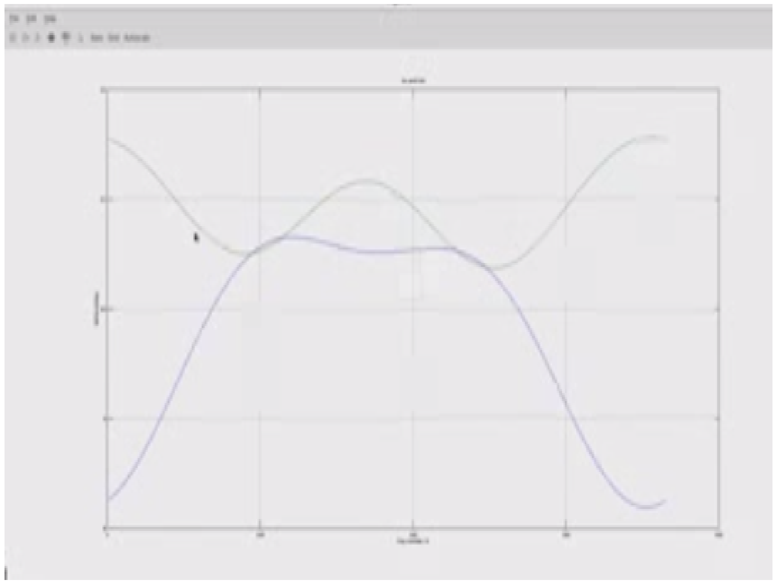

And when I zoom it up so you see two curves the blue curve representing H0 and the green curve representing H_{OT} the energy incident a tilted surface however here the tilt angle is changing every day on day number one you have one tilt angle Day number two another tilt angle so on day number 365 another tilt angle so it is tracking the Sun throughout and you observe the improvement in the energy curve and you see that it is really much higher than H0.

And the previous six at tilt angle and you see that the minimum the minimum H_{OT} itself is much higher than 10 kilowatt hour per meter square per day, so this is the benefit you would get by tracking it on a daily basis but it is cumbersome to track because you need to fit up motors and the mechanical Arrangements where you have to pay for that so in order to keep it sync simple people generally have a fixed set angle tilt and try to optimize on the fixed angle tilt which you would place.

The other option is to have a seasonal tilt so every season let us say three times or two times in a year you can change the tilt angle and keep it and maximize the energy that you connect over the year.