**Indian Institute of Science**

**Design of Photovoltaic Systems**

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**NPTEL Online Certification Course**

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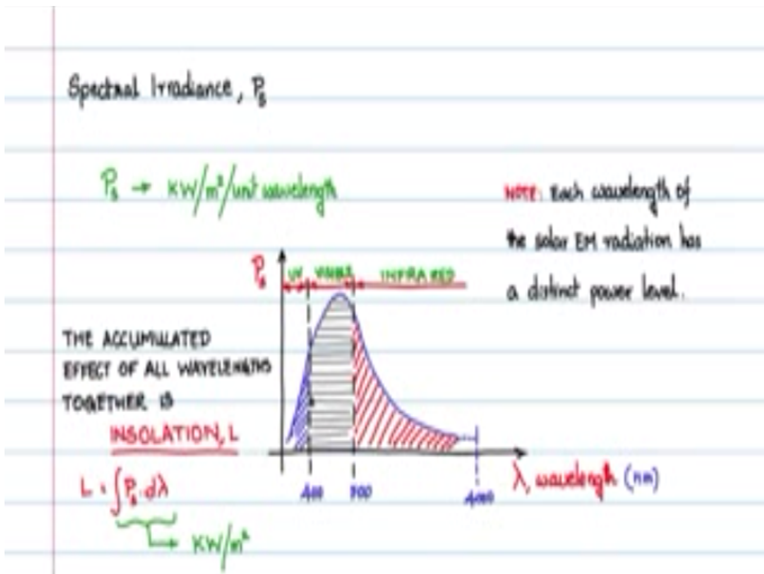


In order to estimate the energy from the Sun let us try to understand the sun's spectrum so let me introduce the term spectral irradiance $P_S$ the spectral irradiance has the units kilowatt per meter square per unit wavelength so generally the sun's of spectrum is given in terms of this spectral irradiance which is generally denoted kilowatt per meter square per nanometer or per micrometer depending upon the units used for measuring the wavelengths.

So typically the sun's spectrum will look like this you have a graph X and y-axis let the x-axis be denoted by $\lambda$, $\lambda$ is the symbol used to denote wavelength and the y-axis is the spectral irradiance as we see denoted by this unit the shape of the Sun spectrum is something like this it is an approximate I will later on show you a more exact spectrum but the general shape is in this fashion so we can denote it by three important regions so this first region is called the UV region this is a UV region and the second region is called the visible light region.

And the third region is called the infrared region now these regions are basically defined by the nature of the wavelength so if you take the UV region the UV region has wavelengths which are very small they are very high frequency the visible region have intermediate wavelengths and in the case of the infra infrared region the wavelengths are pretty long very large and the frequency is low.

So the Sun spectrum spans the ultraviolet to the infrared and the visible region portion of the wavelength is the one which is perceived by our eyes and we can see, see this light so visible light how our energy content is there with respect to other wavelengths also importantly note that now let us say that if I denote the wavelength as nanometer NM the UV region is approximately up to around 400 nanometers 400 nanometers to around 700 nanometers is the visible spectrum and beyond the 700 nanometers maybe up to around 4,000 nanometers you have the infrared spectrum.

So these are the thermal regions the visible and is the ultraviolet region so note that each wavelength in the spectrum has a distinct power level so solar radiation is an electromagnetic radiation and each wavelength has a distinct color now that he can be seen from this curvature and all these wavelengths all these wavelengths are, are held at the surface of the earth and it is a kind of a cumulative effect or accumulated effect of all the wavelengths put together.

So the accumulated effect of all wavelengths together is called insulation and the insulation is denoted by the symbol L and L is actually an accumulation of the spectral irradiance and therefore we can use the integral symbol the spectral radians and it is integrated with respect to the wavelength parameter Δ so which basically means that the area under this portion would indicate insulation of the ultraviolet region the wavelength.

The area under this portion of the spectrum all the wavelengths corresponding to this portion of the spectrum would give an accumulated effect and that is called the visible insulation likewise the accumulated effect of all the wavelengths in these parts of the spectrum would give you the infrared insulation the accumulated effect of all these put together is what we call as insulation and given by this LV the integral of TS.

We observe that PS here as the units of kilo watt per meter square per unit wavelength which is kilowatt per meter square per nanometer corresponding to this particular graph and L is an integral of P with respect to the lambda parameter and therefore the insulation has the units of kilowatt per meter square so remember this units we will be using insulation quite frequently in future.

Now this particular graph the spectrum that I have drawn by hand gives you a considerable amount of insight to the nature of the spectral energy from the Sun now I will show you an actual spectrum with real data and it will give you much better insight about the solar energy or the Sun energy for this I have collected real data and put them into a text file which I will call from within octave and plot the wavelength versus the spectral irradiance.

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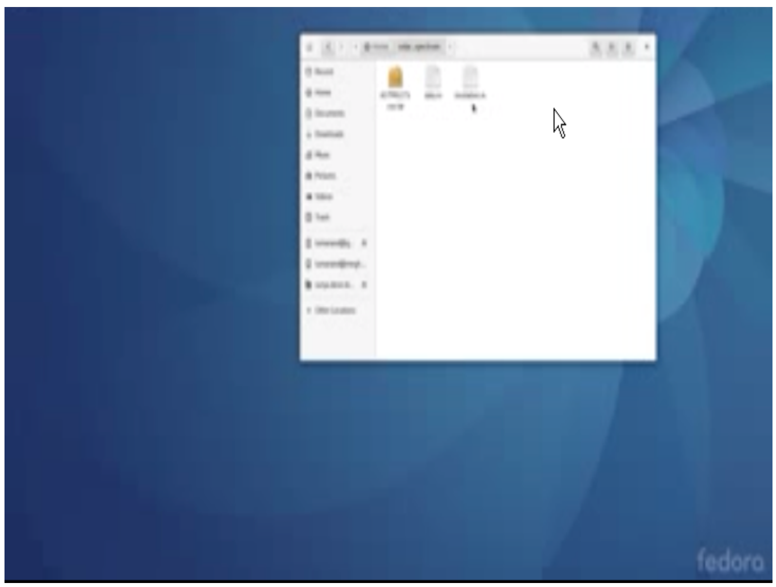


In order to understand the solar spectrum with real data let us go to Google and type in some keywords like solar spectrum data you will see lot of websites getting popped up something interesting is to see these images there are whole lot of images on the solar spectrum just along the lines that we discussed you can look at these images and get a lot of insight how do these are images these are pictures you cannot work with the data so we are looking at something.

Where we can work with the data where the data is available in numerical values there is one site one or one of the sides here where they have collated the data and made it available do downloadable form as an XLS file spreadsheet file also as compressed txt files which is compatible with PC UNIX and Mac and Macintosh let me download this UNIX version so a text file gets downloaded like this let me go and look at the folder where such a file has been downloaded.

And look within the compressed file so there is a CSV file let us see what is inside the CSV file so open the CSV file in a text editor and let us zoom the text you see that it has lot of data values comma separated data values there is a comma and then there is again data comma so you have in a row of four data values now the first data value is actually the wavelength in nanometer the second data value is the extra-terrestrial radiation in watts per meter square per nanometer.

So these two data values are the ones of interest to us we will only take those values and opt work on them now before we work on these data values let us convert this file let us edit this file into a MATLAB compatible or an octave compatible M file octave is an open source equivalent of MATLAB so what we do is that we just convert by simple Text Edit I will convert this first line into a comment line I will put a comment line here and introduce the website URL from where we took this file and I will make this as a comment line like this and introduce a variable called solve and put a Open bracket for the matrix what it basically means is that all.

These data values are put into a matrix what I will do I will go down right down to the bottom and put the clothes matrix brackets and that is it now you have a fully mat of compatible or an octave compatible file which can be worked with within the environment of octave or MATLAB so all these data are put into a matrix and they are named solve so solve will basically have four columns and as many rows as the data provided here what we have to now do is that change is dot CSV into dot m we will save this close and rename this as data dot en.

So now data dot m is a matter pile where you can call in mat lab and execute it so if you look at it now you will see that this is nothing but a regular MATLAB file with solve as the variable and solve is a matrix variable having column four columns of data and many rows and this is what we will be using and we will be using only the first two columns of solve the first column represents wavelength second column represents the spectral irradiance.

I know how another script file insulation dot M the job of this script file is to take the data values from within data dot m and then appropriately use them to plot our spectrum so data will be called by insulation and the spectral radiance of the spectrum will be plotted so let us see what is within this insulation dot M file quickly so I will double click that and let me increase the zoom in the text.

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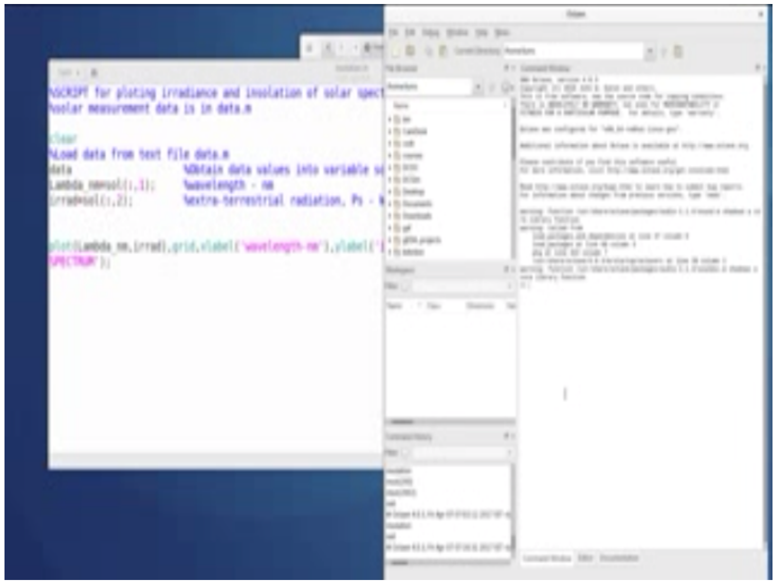


So quickly I will read through this is a very simple file descriptor plotting your radiance and solar insulation with the solar spectrum and the solar measurement data is in data dot M which we just now created so has to clear all the variables in the workspace load the data from the text file data by m by just calling data which we just created so it will put all the data values into the variable so on now λ a Newton meter will be taken from the first column of solve.

So all rows first column and from all rows second column of Solve you will obtain the spectral irradiance data now the spectral irradiance data is given in watts per meter square per nanometer so I will just comment it put a command there so that it is good for read ability now the last line here is a plot statement which plots λ that is the wavelength verses spectral irradiance and grid the X label y label and title are also included.

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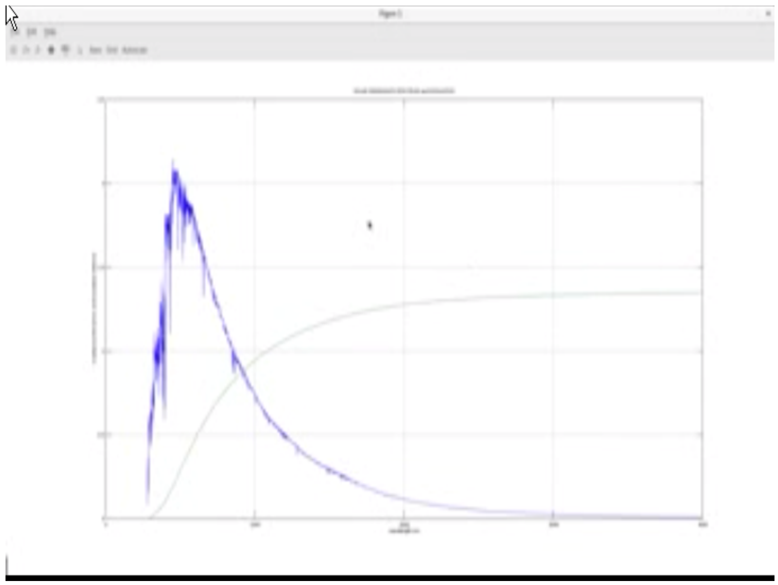

Now let us run this in octave and see what happens so let me open octave so this is the octave environment let me clear the workspace scream let me go in here into the appropriate force the folder the solar spectrum folder it has these files I have to run insulation script so let me type in insulation and it will plot the data values accordingly like this let me zoom this.

And you see that is the so a lot a radiant spectrum this is actually PS in watts per meter square per nanometer and the exactly the wavelength it goes up to 4000 nanometer up so here let me just use it as a marker episode art somewhere around here will be between 400 nanometers and 700nanometers and this is the visible spectrum what I have marked here in the rectangle to the left of it will be the ultraviolet region of the spectrum.

And to the right of this rectangle will be the infrared region of the spectrum let us now write few more lines in the insulation radium file such that we are able to integrate this pH curve and obtain the insulation curve also and super impose on this graph let me go back again into the insulation dot m file in the text editor let me introduce few more lines of code here so we have to integrate the irradiance call so integrate the spectral in the irradiance PS.

So that we may obtain yell the integration with respect to the lambda parameter I have used here a simple practice oral integration which is of this form and all these lines are basically integrating the spectral irradiance to obtain finally the insulation in the variable in Solve now the installation is also actually in watts per meter square because the data given is in watts per meter square per nanometer therefore insulation also is in watts per meter square.

However while displaying what I can do is let me display in this fashion plot λ that is the wavelength and the spectral irradiance wavelength and the insulation but insulation I am dividing by 1000 so that we can output the insulation in terms of kilowatt per meter square so the wavelength way label has irradiance in wax per meter square per Newton meter and insulation in four per meter square.

Because I have divided that by thousand so let us see the Volt plot statement power 3 so this would be the modified file let me save this and let us execute that so we go in here and let me type in insulation so when you type in insulation now you see that we see the graph of both the spectral radians the blue curve and there is this green curve which is the integrated value of the spectral irradiance along the λ axis now see it integrates to around, around 1.3 let me just zoom at that point then you will get the value.

So here you see that it has integrated to around 1.347 like that always remember that the solar insulation would integrate to between 1.33 kilowatt per meter square to 1.41 kilowatt per meter square and it depends upon the day of the year and this is because of the elliptic or orbit of the earth around the Sun so therefore this variation generally in the literature an average value the mean value between 1.2341and1.37 is taken as the solar constant.

So if you hear the term solar constant it means it is 1.37 kilowatt per meter square so always the insulation value L will integrate to a number between these two so that is the takeaway out of this figure so I will keep this data dot M file containing the data and the insulation dot T M containing the script for utilizing this data and plotting the radians and the insulation in the resource section so that you can download this source as a zip file and then you can run them operate on them and then gain some insight out of this.