Fundamental of Power Electronics

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Lecture - 12

Circuit Operation

So, till now we have studied the Rectifier circuit capacitor, Filter circuit. We have seen its waveforms; we have learnt how to simulate the rectifier capacitor, filter circuit. We now have to do one important activity which is designing the components, you have only two types of components; one is the diode, rectifier diode and the other one is the capacitor. So, these two components, you will have to rate such that they will be able to handle the electrical stresses and the thermal stresses. In this course, we will discuss about rating for the electrical stresses like the current and the voltage stresses; how was the thermal stress calculation will be another course in itself.

So, therefore, it is out of the scope as far as this course is concerned to calculate and rate the components for thermal stresses. There is another point which is also there while you are designing circuits that is to design for life. This is also out of the scope designing for a given MTTB MTT for MTPF mean time to say how work keep that in mind that these are aspects that you will have to consider when you are designing a practical circuit. In this course now, we will look at how to design for the thermal; how to design for handling the electrical stresses.

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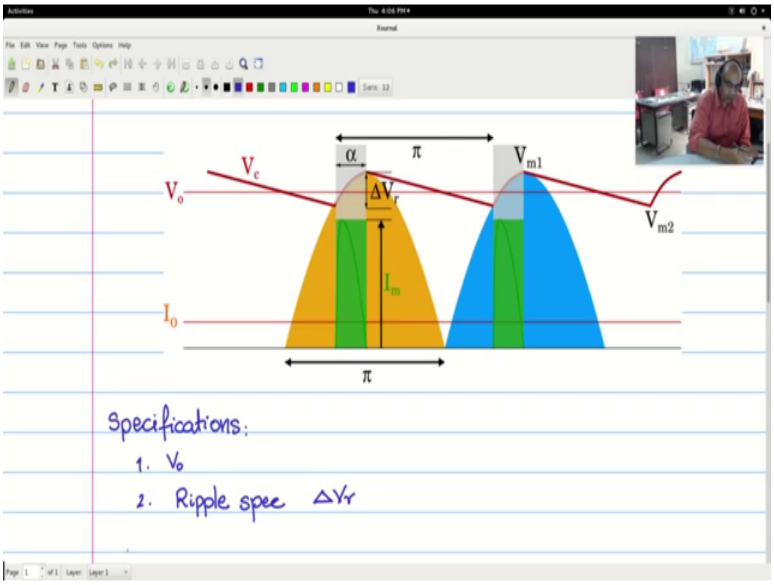

Here, now back again to the whiteboard where we have the waveforms, we have seen these waveforms earlier. This is the output voltage waveform with the ripple V c; what we call V c is the output voltage waveform across the capacitance. I naught is the load current. We have shown the average value of the current, there will be a small ripple which will have the same similar shape as that of V c divided by r. This green waveform is start of the current output of the rectifier as we saw and we need also to define few more parameters which we will do now in order to do the calculations for the values of the capacitance and the diode ratings.

Now, we have this is half the wave shape of the full sinusoid. So, this must be having an angle of pi. Remember that this is whole 2 pi and this much is pi which means T by 2; period by 2. Then, another parameter that we will define is the conduction period, the period for which the diode conducts and we will name it as alpha. Of course, from this point to this point is also pi, I can repeat every cycle. Another variable 25 is the peak to peak ripple. So, this is the peak to peak swing or the output voltage. Therefore, we can call that one as the peak to peak ripple.

This definition I m is the peak current that is flowing out of the rectifier as shown here. You see normally when we are rating or designing the components, there is not much that we would get by trying to calculate exactly the nature of this curve. Because we need to anyway give some safety factors that we will normally the over rating the devices. If you take consider this rectangular green rectangular box, if the current wave shape were something like that. If you design your components for this flat topped green rectangular pulse, then definitely it would handle the inner shape shaped pulse as it comes out of the capacitor filter rectifier.

So, therefore, normally in design practice what we do use engineering judgment here and say that for rating the devices, we will design the devices to handle this flat top complete flat top rectangular pulse much easier to design for that and if we design for that, it will definitely handle this shape of current. So, that is what we would be trying to do for. This is the current ratio that we will assume for design; only for design purposes not for any analysis. So, now, we shall define one more variable called V naught. V naught is actually the average value of the output voltage V c which you see at the capacitance node. So, if this is the peak value and this is the main value of the ripple, this plus this divided by two the average value will be V naught.

So, this would be the average value of current, the average value of the voltage is given here. Two more variables which is the peak value that the capacitor will take V m 1 and the minimum value it will discharge to V m 2 in the steady state. So, using these variables definition, we shall now calculate what should be the value of the capacitance and also what should be the value of the currents that should flow through the diodes and such. Now, for this to write down the equation, it is now better for me to use the writing board. So, I will go to the writing board and start writing the equations so that you will be able to follow me.

So, I have with me the same waveform figure with all the parameters named here with me and we shall use this for writing the equation; design equations. Now, first of let us calculate the value of the capacitance. Let us note down; write down, what is it that is given to you for design purposes the specifications. So, the specs that are given to you are the following. Specifications; one of the things that are given to you would be what is the value of V naught; Ripple spec, this will be given to you. It will be given to you as peak to peak ripple variation, delta V r as that as we have marked..

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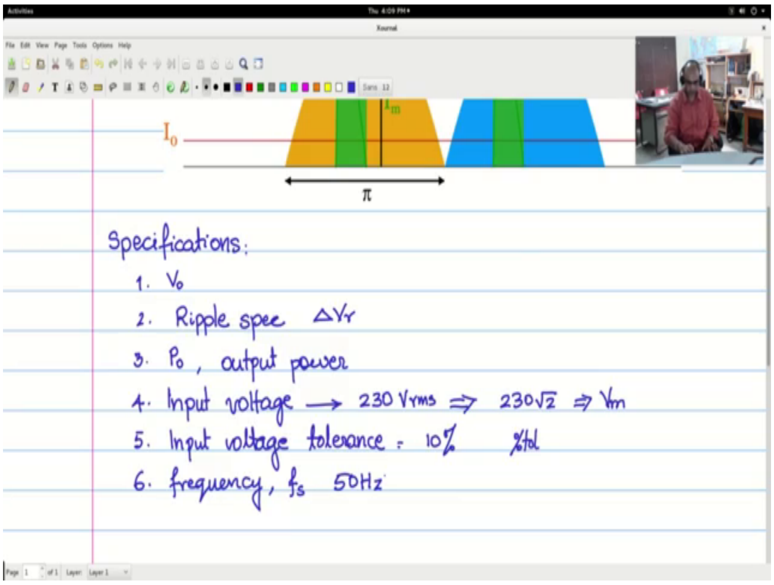

Then, what else that would be given is you will have the power P naught output power we also have the input spec. Now, the input voltage as two parts; one is see would have you would probably you have something like 230 Volt rms which implies 230 root 2 peak. This would be your V m, but it is not just that your input voltage will swing from place to place from minus from 180 degree 180 Volts to 270 volts. So, plus minus 20 percent, plus minus 30 percent; these kinds of swing you will find real voltage means great. So, you should also specify the input voltage tolerance. So, this is generally given like 10 percent or 15 percent of your nominal value. So, it will vary from minus 10 percent to 30 Volts rms to plus 10 percent to 30 Volts rms which means 230 Volt plus or minus 23 Volts things.

So, this tolerance has be given. So, let us say we call it has percent tol as the variable and then of course, you need to have frequency. The frequency supply frequency is known it is always 50 Hertz at least in our country (Refer Time: 11:13) bother much about that. So, these are the specs that are given to you; these are specs that are there with you, using these specs, we have to now arrive at the value of the capacitance C that is our first job. Let us start at this point. Let us see what is happening at this point or shall we come down here corresponding point. So, at this point, the capacitor has an energy half C V m 1 square and from here to here, the diodes are off; likewise here from here to here, the diodes are off capacitance is doing only the job of discharging into the load.

So, from here to here it has discharge and to the load, nowhere else and it has reached energy lower energy level of half C V m 2 square. So, what has happened to all this energy lost from here to here, it has gone to the load. So, that is our starting point that we will use.

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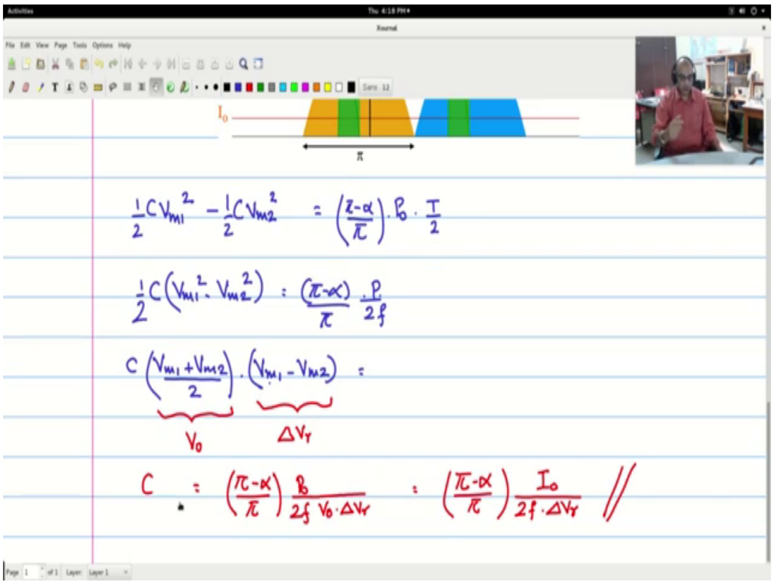

So, let me write mark; here it is half C V m 1 square and here it is half C V m 2 square; what is the difference? So, half C V sorry m 1 square minus half C V m 2 square goes to the load and it is actually not for the full pi period, it is for period of time pi minus alpha. So, for period of time pi minus alpha, capacitance only discharge to the load. So, with the duty ratio of pi minus alpha by pi P naught amount of power is been put.

So, during the time V naught into I naught that much amount of power is being put for a period of time T by 2. So, if you if you get this equation pi minus alpha by pi into T by 2 is the weighted period into P naught the power put. So, this is actually the energy Watts into time; Watt seconds. So, that is the energy the amount of energy that you see here half V half C V m 1 square minus half C V m square 2 square that is put into the load. So, let us simplify this half C V m 1 square minus V m 2 square which is pi minus alpha by pi P naught pi 2 f; f is the supply frequency.

Now, this can be split into C V m 1 plus V m 2 by 2 into V m 1 minus V m 2. So, this is actually a square minus b square form a plus b into a minus b. Now, this is nothing but let me move the screen up; this is nothing but V naught the average value. This is nothing but delta V r. So, therefore, we have C equals pi minus alpha by pi P naught by 2 f V naught delta V r coming in the denominator, but P naught itself is V naught into I naught. So, V naught and V naught cancel and therefore, you can write the value of C as pi minus alpha I naught by 2 times supply frequency into delta V r.

So, this is the value of the capacitor that you will have to put in order to get this particular ripple and for this particular load current. However, you should note that there are few other variations that can come into the picture; you should calculate for the max value of I naught. So, if you calculate the max value of I naught, the value of C would be sufficient to handle that. You should also calculate for the ripple that is minimum. So, the for the minimum ripple, I will get higher value of C. So, once you have taken care of the worst case condition for minimum ripple as for value of I naught, the value of C will hold good..

Another very important criteria that you will have to take into account while you are putting the value of C in a real circuit is when you buy an aluminum electrolytic capacitor, it has a very large tolerance minus 40 percent to even 100 percent those kind of tolerances.

So, normally what you calculate and then, what you buy and then actually measure can have very large and significant variation. So, normally what is done in practice is once you calculate that is the you get some 15 microfarad or 10 microfarads, you will take 3 times that value. So, 30 microfarads then put that value. So, that even if even the capacitor that you have bought is minus 40 percent down, it will be able to handle this kind of variations. So, this is how you calculate the value.

Let us now calculate the arms current that is flowing through the capacitance because that is one parameter which we that is one parameter which we need to calculate because that will indirectly affect the heating of the capacitor.

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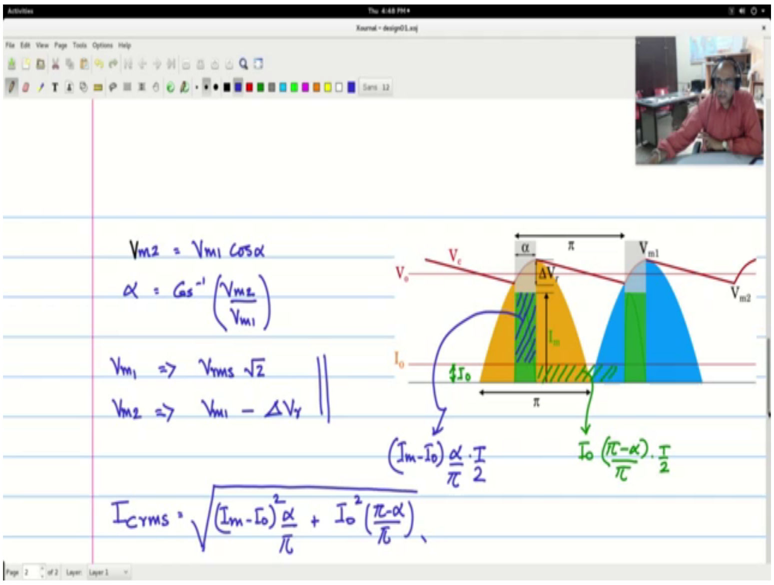

So, to do that let me go back again to this conduction period that is when the current is flowing. This alpha time is the period which during which the diodes are conducting; do we know this value of alpha, we know this value of peak V m 1. This is the cos wave from here. So, V m 1 cos of alpha will be V m 2. So, we know V m 1, we know the ripple, we know V m 2 and therefore, we should be able to know alpha.

So, how we can start this, like this V; I will use the blue ink V m 1 equals sorry V m 2 equals V m 1 cos alpha. Alpha equals cos inverse V m 2 by V m 1. V m 1 is known which is V rms value into root 2. V m 2 is known from the spec which is V m 1 minus delta V r. All these are coming from the input spec then once you know the value of alpha, you can calculate the current that is flowing through the capacitance. The current that is flowing through the capacitance now as I said we are going to make this rectangular approximation and you have to make use of the condition that the average value of the current to the capacitance is always 0 in the steady state.

So, this is the area that is that is the charge; charge up of the capacitor when it is conducting when diodes are conducting. When the diodes are not conducting capacitors, capacitor is discharging and the area is this. So, we know that this is I naught and therefore, this would be I naught into pi minus alpha by pi into T by 2 at is that area and this area of course is I m minus I naught alpha by pi into T by 2. So, this T by 2 is added. So, that this is the charge and this is the charge.

So, if you remove out the T by 2 just to find out the rms value of the current. So, I c rms I c rms is root mean square. So, for the positive area, I m minus I naught whole square with the duty cycle of alpha by pi plus I naught square pi minus alpha by pi this whole thing is. So, this would be rms r m s value of the current that flows through the through the capacitance that this rms current square into the esr value of the capacitor will give you the heating affect within the capacitor. So, this may be useful especially when you want to do thermal management then thermal design.

So, once you know this you will be able to specify the capacitance.

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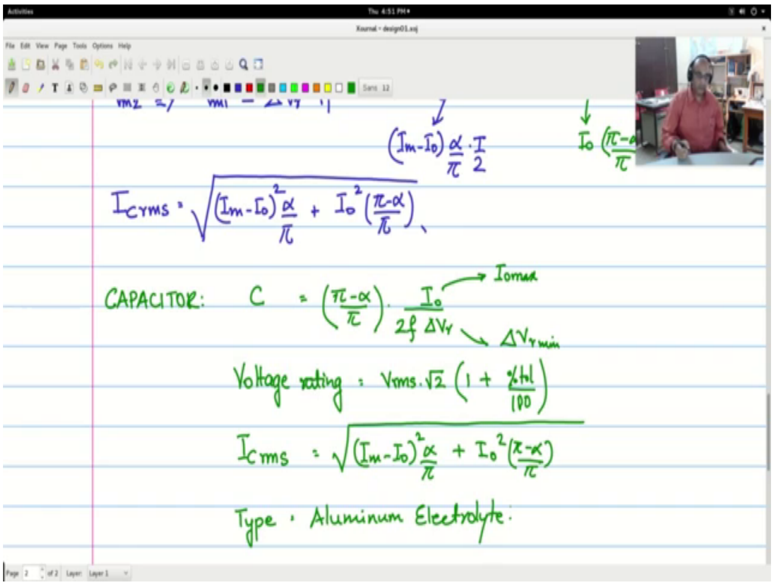

So, the capacitance can be specified as follows. We know the value. The C value is given by the equation that we just now derived I naught by 2 f into delta V r. So, this I naught; I naught you should take I naught max; maximum possible I naught that flows through that and minimum value of delta V r min. Under these condition what is the value of C that you would get? This variation why I am mentioning this variation is that the input voltage varies from a minimum value to a maximum value. So, find out the delta V r min or whatever the worst case condition and then plug these.

Now, the capacitor voltage rating; so, the max voltage that the capacitor will ever seen will be V rms into root 2. This is V m. Now, V m itself could be swinging to upper end because of the tolerance I say 1 plus percent tolerance value whatever 10 percent 20 percent by 100. So, this would be the maximum value that the capacitor will see. Of course, you also have the I c rms rating as we just now saw I m minus I naught whole square alpha by pi plus I naught square pi minus alpha by pi. So, this would be the rms value.

So, with this and then you can say the make type electrolyte type would be aluminum electrolyte. We do normally use tantalum. So, this would complete the electrical design of the capacitance.

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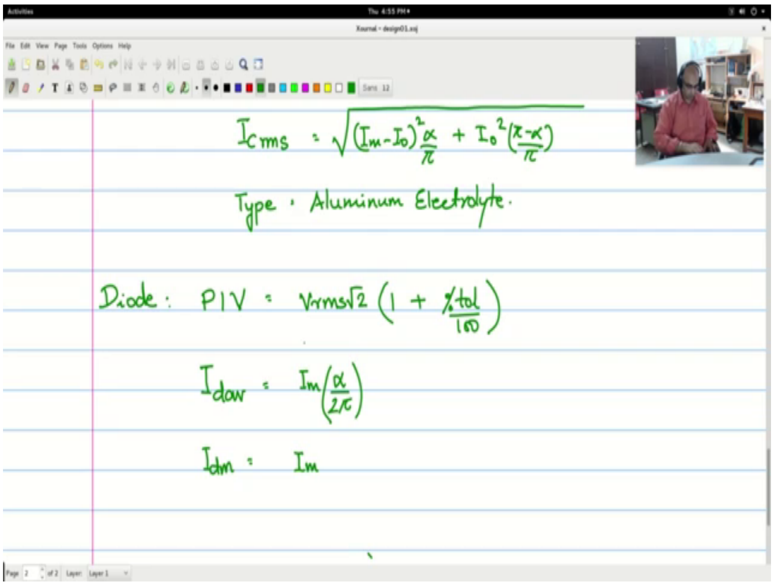

Now for the diode, the diode if you see when the diodes are off, they would see a maximum voltage the peak inverse voltage; peak inverse voltage would be V rms root 2. So, if it is 230, it would be 230 into root 2, 325 Volts to that you give the extra the tolerance swing for that particular place; this would be the max. So, when you choose a diode, you have to choose a diode which is definitely much having a peak inverse voltage rating much greater than what you would calculate using this formula. There are two other values that you need to calculate or the diode one is the average I d average and the I d maximum.

So, I d maximum is same as the current the my peak current that is flowing through gratifier. So, the I d maximum will be same as this. This is the I d maximum. I m average value through the diode will be you see that through every diode, it flows through alternate cycles. So, through d 1 and d 4, it will be through this d 1 and d 4 again, it will flow in the next yellow half cycle. d 2 and d 3, it flows here and d 3, d 2 and d 3 again flow in the next blue half cycle. So, therefore, the average for this is I m duty cycle will be alpha pi naught pi by alpha by 2 pi because this repeats every 2 pi. So, for the diode we can easily find the average in the following manner.

I m alpha by 2 pi this would be the average current that flows through the diode and when you chose the diode, it should have a rich current rating greater than this and I m itself is the peak current rating which is flowing or very small period, around alpha for this current kind of a pulse approximation. So, by this now you have the diode rating and you also have the capacitor electrically designed and these values can be you grading values for you to choose these devices. So, what you can do is that we can put these equations into a script file so that when you want to do an iterative you design you keep changing the specification then you check keep checking things out and probably you may not get a particular component and then, you may want to change things. So, it is good to put them in a script file like something like octave or metal.

So, we will be using octave script file and the run the script file repeatedly to see what are the designed values so that so that we do not have to manually calculate these values them and again which will lead to bold down. So, I will now show you how to put them into a script file and the others not automate the design courses. I shall show you know how to make a sample script for designing the designing the values of the components. So, this is our folder dialogue will go into DCDC folder, I have already created a sample here.

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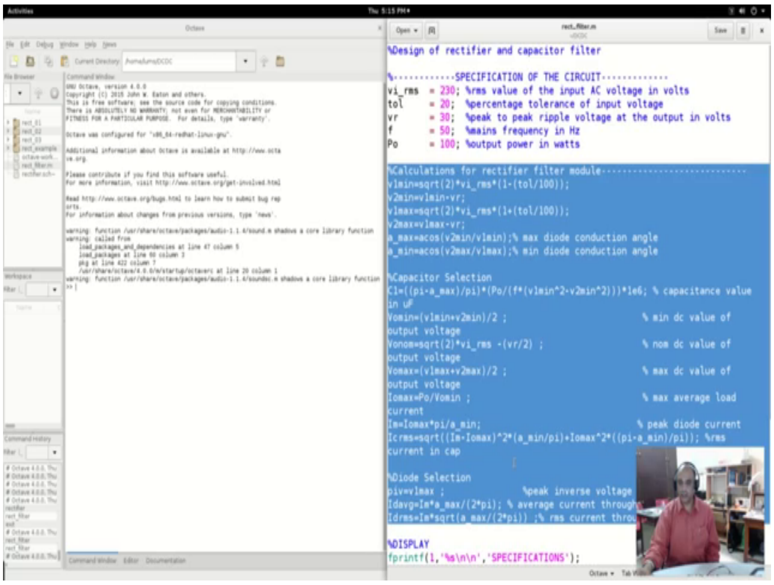

So, this is the m file, I will explain to you. I shall keep it on to one side, at the same time I would also like to open octave. I will open this octave. I shall keep this on to one side; maximize this place. So, I have the workspace here. So, it is like this. Let me go into the same folder here ok. The way you, I have already written it so that we do not waste too much time. You have to classify your script into 3 parts. This syntax is very similar to exactly similar to what you would do in Matlab; it is also having an extension dot m pi. You have the specification of the circuit written first then you proceed with the calculations all these are calculations and then, followed by display.

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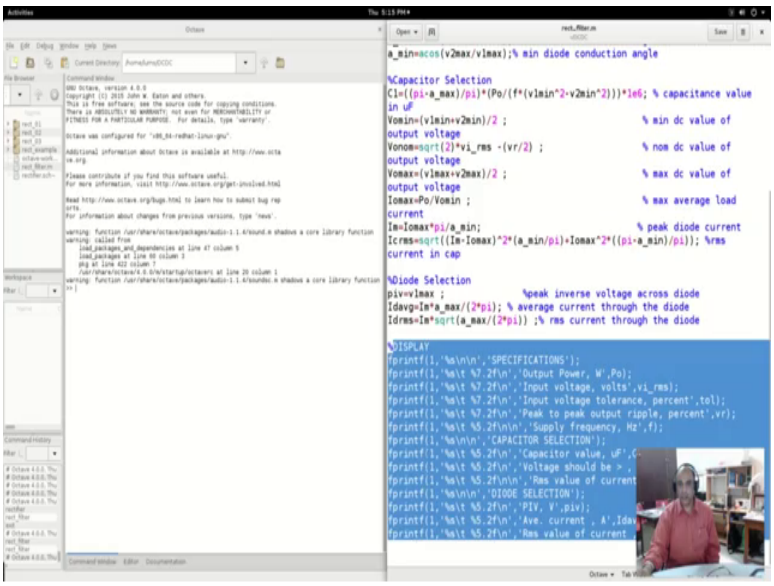

This is what you would like to display at the end of the day after you finish the calculation. So, keep it into these three parts. So, for the specification, what is it? This is where you will change for doing iterations; all these calculations are based on these variables. We have specified the I have used appropriate variables here because I cannot use subscripts and superscripts. So, V I rms is the input voltage, the tolerance 20 percent tolerance. V r is the peak ripple voltage of the output means supply frequency and the power V naught and the calculations you first try to calculate what is the minimum value and the maximum minimum value of the peaks have the maximum value of the peaks. So, that you can get the worst case condition; go through these equations just like we discussed, but I have now used the tolerance values also.

Similarly, you will get two values for alpha; alpha min alpha max. Choose the max value of alpha for calculating the value of C, then here to calculate the voltage that the C will see the output current max, output current the capacitor rms value and then, the diode selection peak inverse voltage value, I d average and the rms value. Then finally, the display have used the f print of statement; one I have used. So, that it is put on to the display standard output. You could put it to a file also and this is just like your C syntax specifications, output power capacitive selection values and diode. So, these are the parameters that you would like to. So, this I will also upload it in Google drive. So, that you can have a look at it and then try to make a your design script files along these files.

So, we go into the octave word space, what you would do is just run the script file. So, we know that the name is red underscore filter dot m which as to that that underscore filters. Do not give the dot m h extension just run it. So, you will see that this gets executed. So, probably may be good to clear the screen before you to save that.

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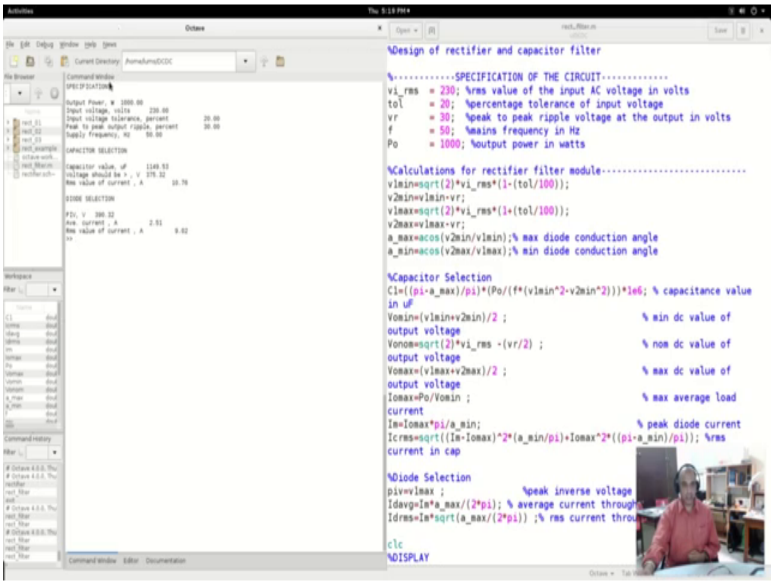

So, let me do that execution once again. So, the specifications this is the output power all those things and capacitor selection values 100 and 114.95 microfarads so on and so forth. The diode selection have the (Refer Time: 35:22). I have multiplied here by 1e6 so that I can express it in microfarads rather than having a very long floating point number here.

So, this way you can keep doing the iterations any number of time change the power value make it 1000 Watts and then rerun the script. So, you will see things changing and then, you can keep experimenting with it and then go back to the simulation plug-in the values and see what are the values that you would get. So, this could give you a lot of insight into the rectifier circuit; rectifier filter circuit in such. So, this is how you would do about analyzing and designing. The two important components in the rectifier filter circuit is the diode and the capacitor.