Design and Simulation of DC-DC converters using open source tools

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Lecture – 05
Designing the rectifier capacitor filter circuit

Till now we have studied the rectifier circuit, capacitor circuit. We have seen it is wave forms, we have learnt how to simulate the rectifier capacitor filter circuit. We now have to do 1 important activity which is a designing the components you have only 2 types of components 1 is the diode rectifier diode and the other 1 is the capacitor. So, these 2 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.

However, the thermal stress calculation will be another course against that. 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 rectifier been trying to say; however, keep that in mind that these are aspects that you will have to consider when you are designing a practical circuit.

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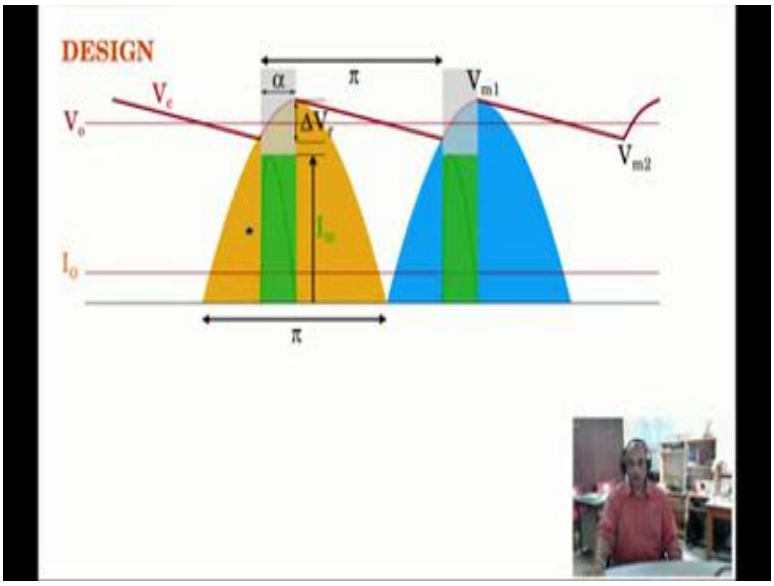

In this course now we will look at how to design for the thermal. How to design for handling the electrical stresses here, now that came to the white board where we have the wave forms we had seen this wave forms earlier this is the upper voltage wave form with the ripple Vc what we call Vc is the upper voltage wave form across the capacitance. I naught is the lower current we have shown the average value of the current they will be a small ripple, which will have the same similar shape as that of DC divided by r this green wave form is that of the current out 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 know this is half the wave shape of the full bridge rectifier. So, this must be having an angle of pi remember that this is whole 2 pi and this much is pi which means p 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 again repeats every cycle another variable to define is the peak to peak ripple. So, this is the peak to peak spring of the output voltage and therefore, we can call that 1 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 of the components there is not much that we would get by trying to calculate exactly the nature of this current because we need to anyway give some safety factors and we will normally be old rating the devices. If you take consider this rectangular green rectangular box, if the current wave shape were something like that if you design the components for this flat topped green rectangular box. Then definitely it will handle the inner shape the shaped pulse as it comes out of the capacitor filter rectifier.

So, therefore, normally in design practice what we do we use the 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 wave shape that we will assume for design only for design purposes not for any analysis.

Now, we shall define 1 more variable called V naught V naught is actually the average value of the output voltage Vc which you see at the capacitance node. So, if this is the peak value and this is the mean value of the ripple this plus this divide by 2 the average value will be V naught. So, this would be the average value of the current the average value of the voltage is given here 2 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 definitions we shall now calculate what would be the value of the capacitance and also what would be the value of the current that 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, that you will be able to follow me.

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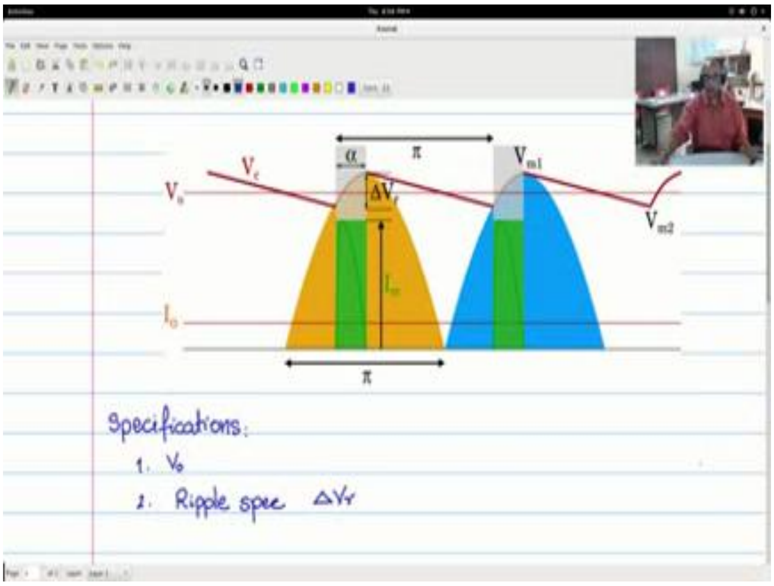

So, I have with me the same wave form figure with all the parameters name here with me and we shall use this for writing the equations design equations. Now first of let us calculate the value of the capacitance. Let us note down write down what is it that is given to you for design purposes the specifications. So, the specs that are given to you are the following specifications 1 other things that are given to you what is the value of V naught ripple spec this will be given to you.

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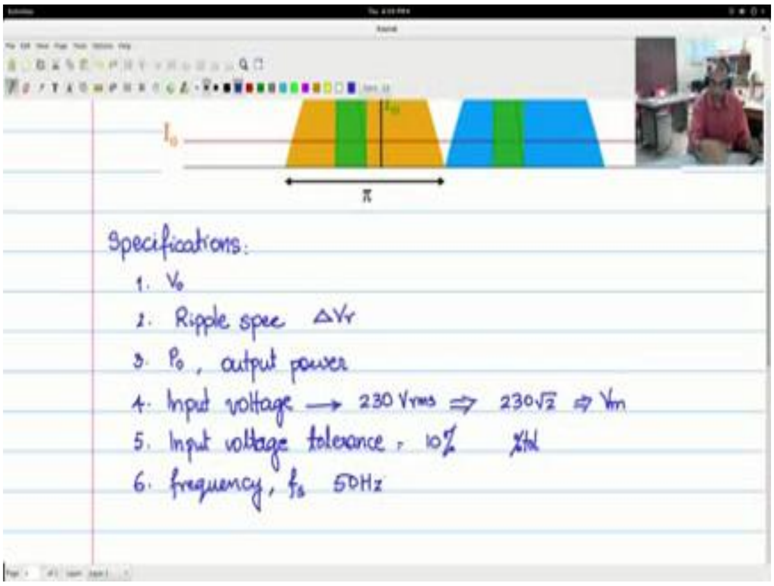

It will be given to you as peak to peak ripple variation delta V r as like as we have marked then, what else that would be given is, you will have the power p naught output power we also have the input spec. Now the input voltage has 2 parts; 1 is we would have you would probably have something like 230 volts RMS which implies 230 root 2 peak this would be your V m like 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 70 percent plus minus 30 percent this kind of swings you will find in a real voltage.

So, you should also specify the input voltage tolerance. So, this is generally given like 10 percent or 14 percent of your nominal value. So, it will vary from minus 10 percent to 30 volts RMS to plus ten percent to 30 volts RMS, it means 230 volts plus or minus 20 volts in tolerance. So, this tolerance has to be given. So, let us say we call it as percent at the varying 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. So, you need not bother much about that. So, these are the specs that are given to you these are the specs that are there with you using the specs we have now arrived at the value of the capacitance c that is our first job.

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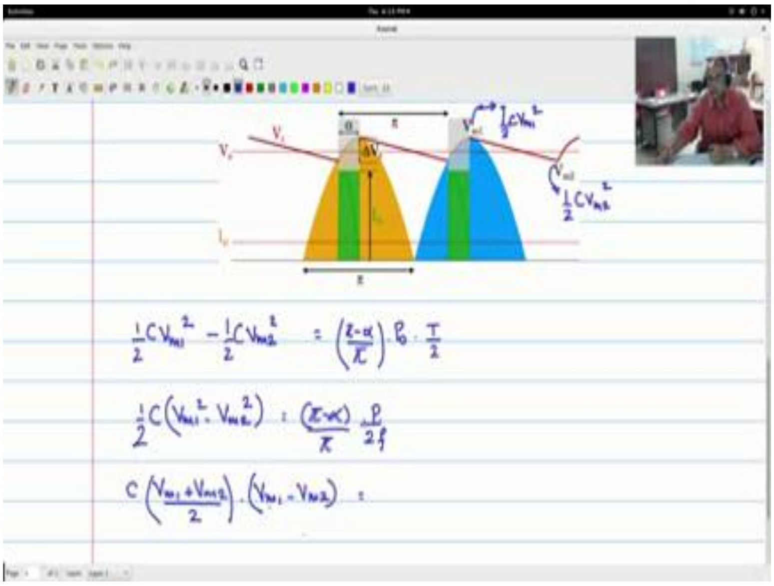

Let us start at this part, let us see what is happening at this point or shall we come down here corresponding point at this point the capacitor has an energy half CV m n 1 square and from here to here the diodes are off, likewise here from here to here the diodes are off capacitance is doing only the job of discharging into the load. So, from here to here it has discharged into the load nowhere else and it has reached the energy load energy level of half CVm 2 square. So, what has happened to all these energy lost from here to here it has gone to the load. So, that is our starting point that we would use. So, let me write mark here it is half CV m 1 square and here it is half CV m 2 square what is the difference. So, half CV sorry m 1 square minus half CV m 2 square goes to the load and it is actually not for the full pi period it is for a period of time pi minus alpha.

So, for a period of time pi minus alpha capacitors only discharge to the load. So, with a duty ratio of pi minus alpha by pi here are amount of power is being put. So, during that time V naught into I naught that much amount of power is being put for and for a period of time t by 2. So, if you look if you look at this equation pi minus alpha by pi into t by 2 is the weighted period into p naught the power put to. 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 CV m 1 square minus half CV m 2 square that is put into the load. So, let us simplify this half CV m 1 square minus V m 2 square which is pi minus alpha by pi p naught by 2 f. f is a frequency now this can be split into CV 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 from a plus b into a minus b now this is nothing, but let me move this screen up.

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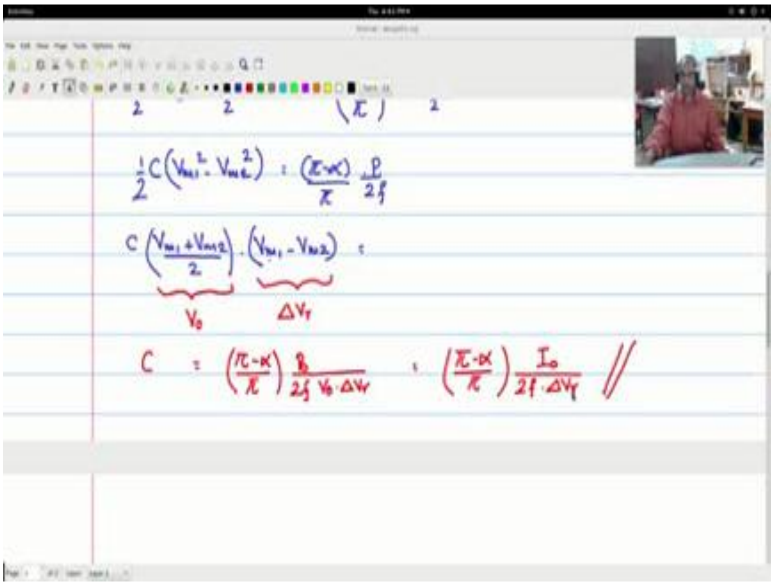

This is nothing, but V naught the average value this is nothing, but delta V r. So, therefore, we have c equals pi minus alpha by pi p naught by 2 f V naught delta V r coming in the denominator, but p naught itself is V naught into I naught. So, V naught and V naught will cancel and therefore, you can 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 like 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, that if you calculate for the max value of I naught the value of c would be sufficient to handle that you should also calculate for the report that is minimum. So, for the minimum ripple having it eigenvalue of c. So, once you have taken care of the worst case condition for minimum ripple as per 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 electrolyte capacitor it has a very large tolerance minus forty percent to even hundred percent those kind of tolerances. So, normally what you calculate and then what you buy and then actually measure can have a very large and significant variation. So, normally what is done in practice is once you calculated c you will get some 15 micro farads or 10 micro farads you will take three times that value, 30 micro farad you can put that value. So, that even if a, even the capacitor that you have bought is minus forty percent now it will be able to handle a these kind of variations. So, this is how you calculate the value of.

Let us now calculate the Hermes current that is going through the capacitance because that is 1 parameter, which we that what parameter which we need to calculate because that will indirectly affect the heating of the capacitor.

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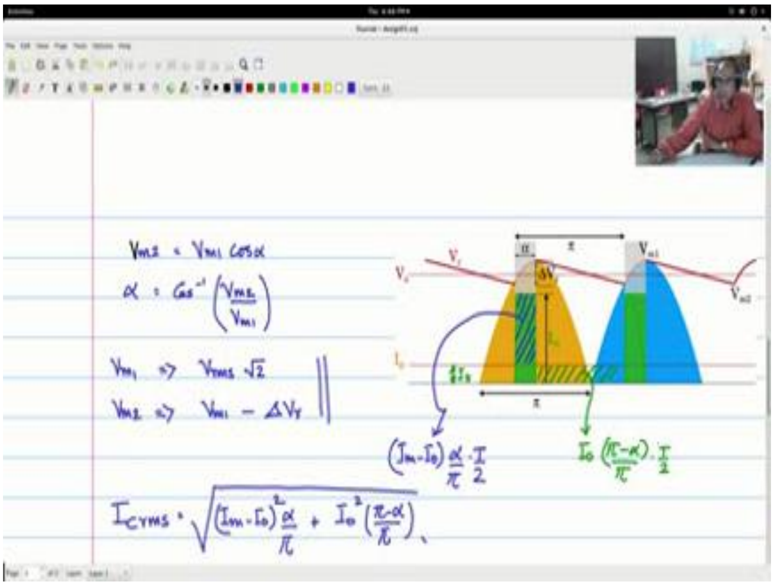

So, to do that let me go back again to this conduction period that is when the current is flowing this alpha time is the period which I believe which the diodes are conducting do we know this value of alpha we know this value of peak V m 1 this is from here. So, V m 1 cos of alpha will be V m 2. So, we know V m 1 we know the ripple we know V m 2 and therefore, we should be able to know the alpha. So, how we get that we will see that is 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 r m s value into root 2 V m 2 is known from this 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 through the capacitance is always 0 in the steady state. So, this is the area that is that is the charge charger of the capacitor then, it is conducting the diodes are conducting 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 will be I naught into pi minus alpha by pi into t by 2 and in 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 with the charge. So, if you remove all the t by 2 just to find out the r m s value of the current. So, I c r m s is the root min square, for the positive area I m minus I naught whole square. So, that cycles of alpha by pi plus I naught square pi minus alpha by pi. So, whole thing is the root. So, this could be the r m s where r m s value of the current that goes through the capacitance that this r m s current square into the e r s value of the capacitor will give you the heating effect with the capacitor. So, this may be useful especially when you want to do thermal management and thermal design. So, once you know this these you will be able to specify the capacitance.

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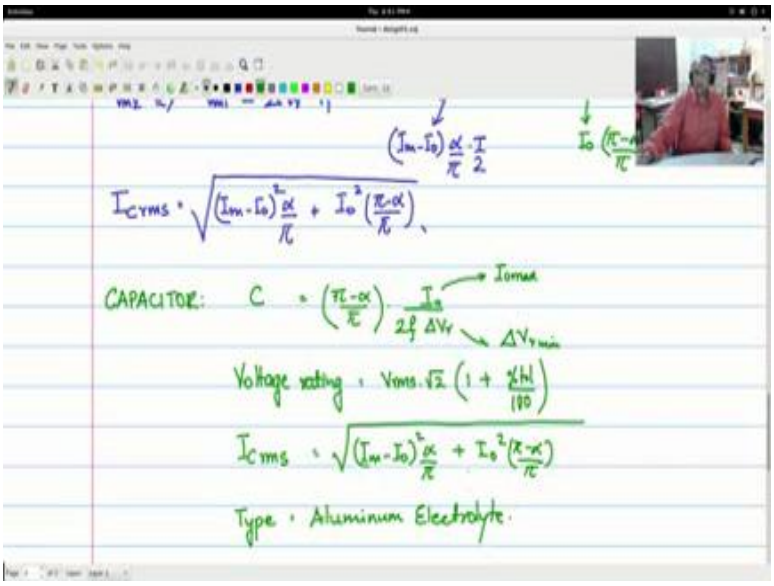

So, the capacitance can be specified as follows we know the value the CV value is given by the equation that we just now derived I naught by 2 f into delta V r. So, this I naught I naught you should take I naught max maximum possible I naught close to that and the minimum value of delta V r min under 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 new value to maximum value. So, find out the delta V r min what whatever the worse case condition and apply this in.

Now, the capacitor voltage rating, the max voltage of the capacitor will ever see will be V r m s into root 2 this is V m now V m itself could be swinging to the upper end because, the tolerance I said 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 I c r m s rating as we just found. So, 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 we can say that may type, electrolyte type would be aluminum electrolyte we do not normally use. So, this would complete the electrical design of the capacitor.

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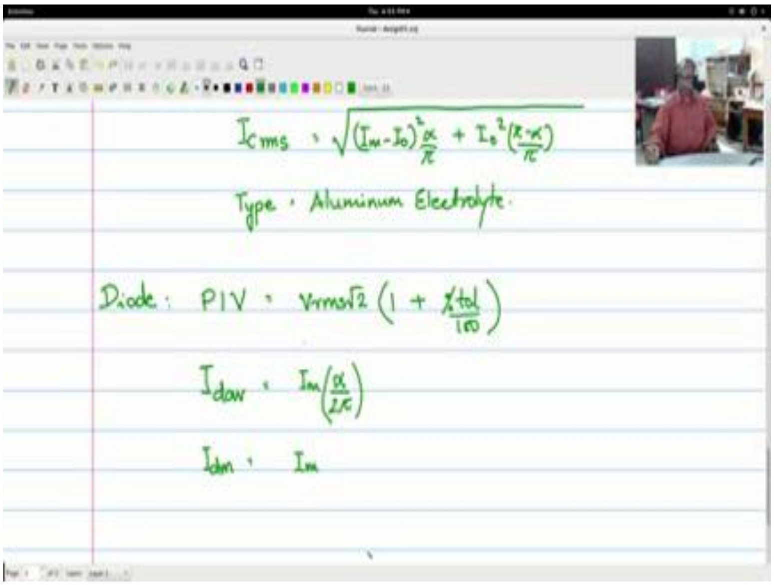

Now, for the diode the diode if you see when the diodes are off they would see a maximum voltage the peak inverse voltage peak inverse voltage would be V r m s root 2. So, if it is 230 it will be 230 into root 2, 325 volts to that you give the extra the tolerance swing for that particular place this 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 2 other layer value that you need to calculate from the diode 1 is the average I D average and the I D maximum. So, I D maximum is same as the current. The max current that is flowing through the rectifier, the I D maximum will be same as 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 to D 4 is D 1, D 4 again if you flow in the next yellow half cycle d D 2 and D 3. It flows here and D 3, D 2 and D 3 will 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, but 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 choose the diode it should have a rating greater than this and I m itself is the peak current rating which is flowing for a very small period than around alpha for this kind of a pulse approximation.

So, like this now you have the diode rating and you also have the capacitor electrically designed and these values can be your 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 design you keep changing this specifications and then you will check it keep checking things out and probably you may not get a particular component and then, maybe you want to change few things. So, it is good to put them into a script file the like something like octave or mat lab. So, we will be using an octave and script file and run the script file repeatedly to see what are the design values. So, that. So, that we do not have to finally, calculate these values time and again which will lead to boredom.

So, I will now show you how to put them into a script file and thus automatically design closes. I shall show you know how to make a sample script for designing the circular designing the values of the components. So, this is our folder dialogue we will go into DC, Dc folder I have already created a sample here. So, this is the m file I will explain to you I shall keep it on to 1 side at the same time I would also like to octave I will put on this octave I shall keep this on to 1 side maximize the space. So, I have the work space.

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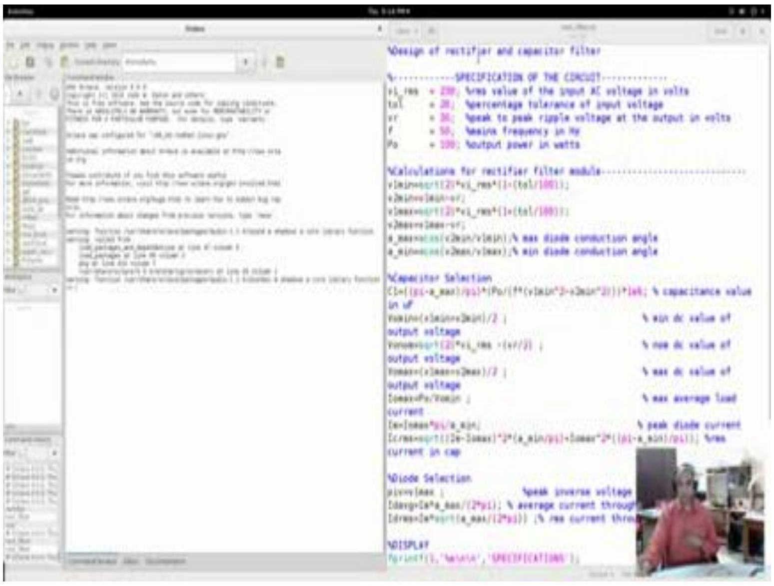

So, it is like this let me go into the same folder here, I have already written it. So, that we do not waste too much time you have to classify your script into 3 parts , this syntax is very similar to exactly a similar to what you would do in mat lab it is already having an extension dot m at you have the specification of the circuit written first. Then you precede with the calculations all these are calculations and then followed by display this is what you would like to display at the end of the day after you finish the calculation.

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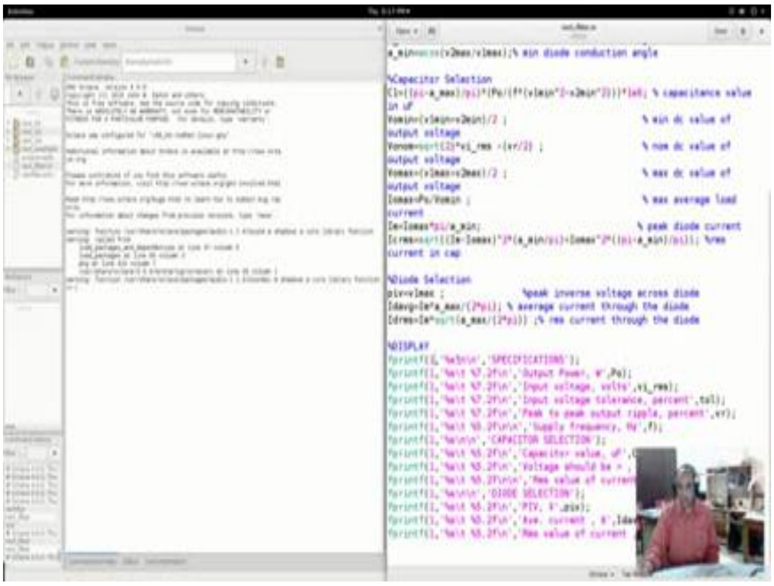

So, keep it into these 3 parts. So, for the specification what is it this is where you will change for doing iterations all these calculations are based on these variables we have specified the I, I appropriate the variables here because I cannot do subsequent sums of the scripts. So, V I RMS is the input voltage the tolerance I made twenty percent tolerance V r is the peak ripple voltage of the output main supply frequency at the power p naught and the calculations, you first try to calculate what is the minimum value and the maximum.

Minimum value of the peaks and the maximum value of the peaks, that you can get over the worst case condition go through these equations just like we discussed, but I am now using the problems values also similarly you will get 2 values for alpha alpha min alpha max choose a the max value of alpha for calculating the value of c then here you have to calculate the voltage that this you 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 RMR value. Then finally, the display I use the f print of statement 1 I used. So, that if is put onto the display standard output you could put into a file also and this is just like your c syntax specifications output power capacitor selection values and diodes. So, these are the parameters that you would like to.

So, this I will also upload into Google drive. So, that you can have a look at it and then try to make your design script files along these likes. So, we go into the octave space. What you would do is just run the script file. So, we know that the name is erect underscore filter dot m which has to write erect underscore filter do not give the dot m extension just run it. So, you will see that this gets executed, probably maybe good to clear the screen before you. So, save that. So, let me do that execution once again. So, yeah the specifications this is the output power all those things and capacitors selection values 110 114.95 micro farads. So, once you put the diode selection at this level I am multiplying here by 1 e 6, that I can express it in micro farads rather than having a very long 14 point number gap.

So, this way you can keep doing the iterations any number of time change the power value make it 1000 watts and then re run this script. So, you will see things are changing and you can keep experimenting with it and then go back to the simulation plug in the values as you wanted the values that you can. So, this would give you a lot of insight into the rectifier circuit rectifier filter circuit itself. So, this is how you would do about analyzing and designing the 2 important components in the rectifier filter circuit is the diode and the capacitor.