Power Electronics with Wide Bandgap Devices
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Lecture-29
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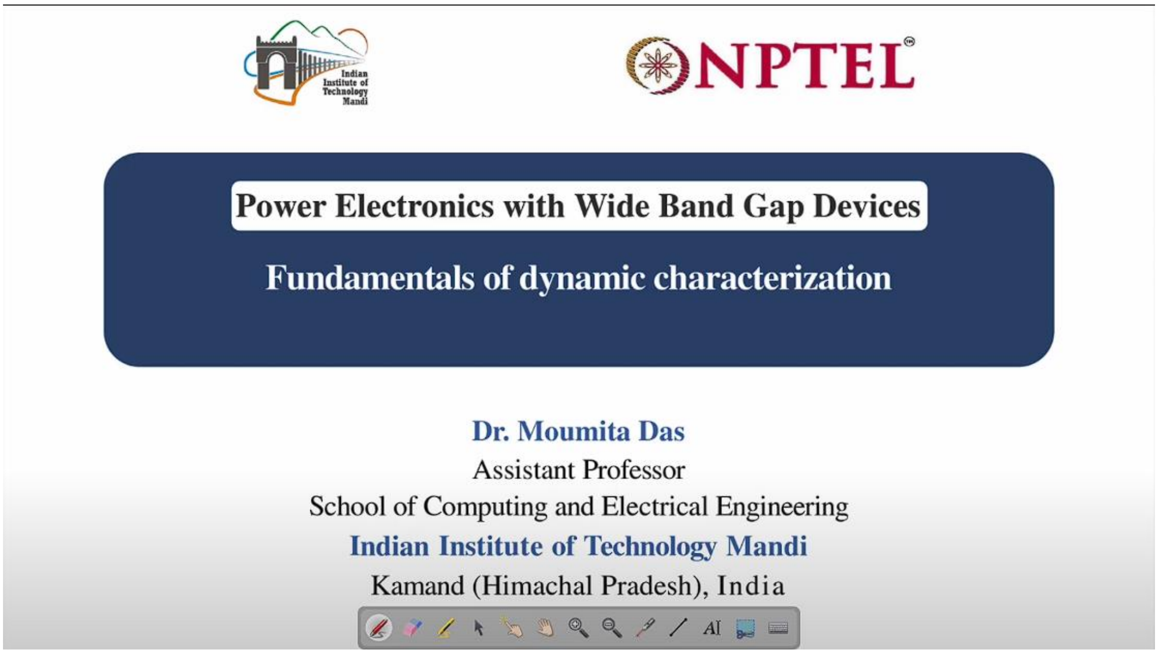

Welcome back to the course on power electronics with wide band gap devices. In the previous lecture, I have discussed about the double pulse test setup. So, in this lecture, we will see how to analyze DPT setup and what are the components required in order to dynamic characterization of any power electronics devices.

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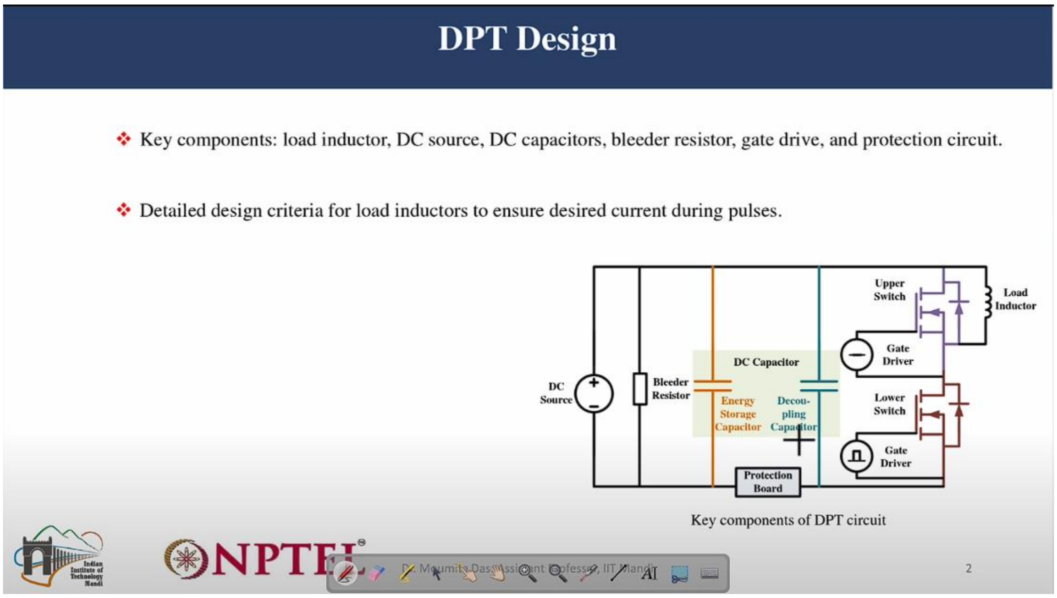

So, as you can see this particular slide, so here I have kept the DPT circuit which I have already discussed in the previous lecture. So, you can see here in this particular diagram, so the main components which are required for DPT circuit. So, they are two capacitors, one is decoupling capacitor, another is energy storage capacitors and then one bleeding resistor, one load inductor. These are the components required along with the DC source for characterization of power electronics devices for dynamic operation. So, now you can see there are two switches given one is written as upper switch another is lower switch. So, in this case we can replace upper switch with diode, but if you want to use switch that is also fine for this application. So, in this case we are actually characterizing the lower switch.

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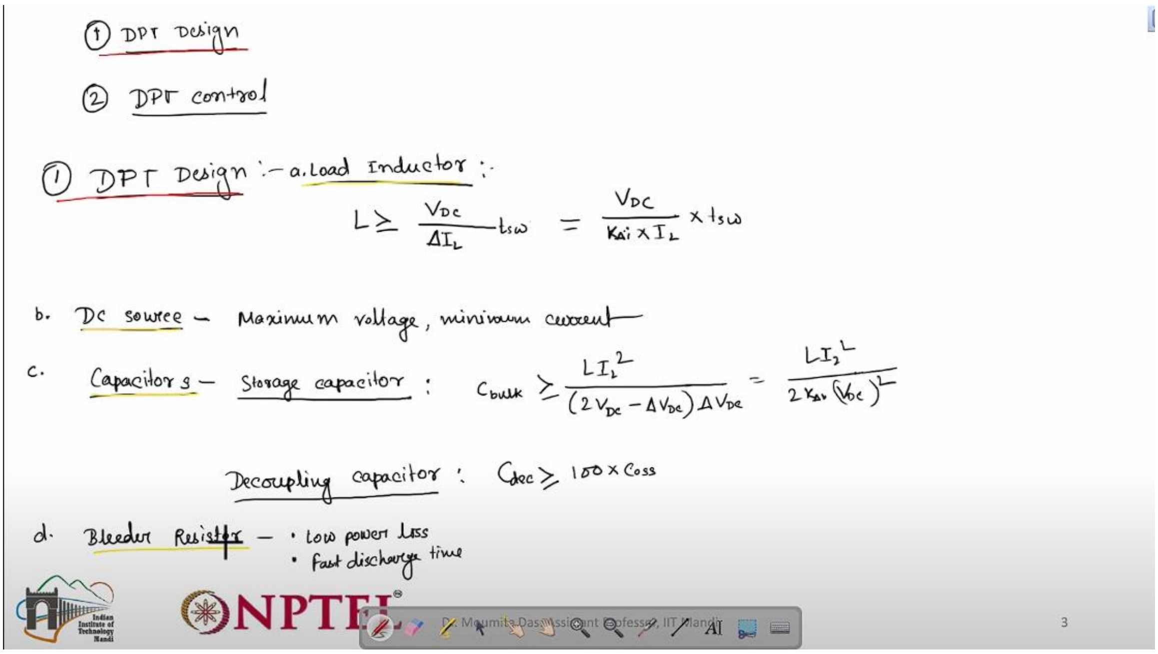

So, how we can calculate different values of this DPT circuit? So, DPT circuit when I am mentioning, so there are two different components. One is the DPT design. So, this DPT design where I will be calculating different components rating. So, one part is DPT design. So, design means what? As you know, so if we have any component in the circuit, so then we have to find out what should be the suitable value of different components whatever are the present in the circuit. Another thing is the DPT control. So DPT control means so how we are going to generate the switching pulses. So what should be the value of the pulse width? So that comes under DPT control. So basically we have to provide the PWM signal. So here in this case we will be providing two different pulses. So each having different pulse width. So what are the different factor which is going to affect this pulse width that we will see in today's lecture. So, first I will be discussing about DPT design, the first component is DPT design. So, as you have seen in the previous lecture, in design we will be calculating actually four different components. So, one is DC source, second is bleeder resistor, third is DC capacitor and then fourth is load inductor.

So let's start with load inductor. ok. So when I say load inductor. So how we can calculate the value of the load inductor. so the inductor should be such that it should be able to provide the required current required current. Means the current which we will be able to measure so then what are the factors actually is going to affect this inductor so the inductor value should be more than equal to the value which is required for this application, means like the value we can calculated it depends on input DC voltage and then the ripple in the inductor current and switching frequency. So, then how we can simplify this VDC multiplied by K delta I, so K is the constant, so that how much ripple we are going to provide for this particular test, multiplied by IL and then it is multiplied with the switching time. So, this is, this will be switching time not the frequency. So, this is switching time. So, now when we calculate the value of the inductor from these values.

$$\frac{V_{DC}}{K_{\Delta i} \times I_L} \times t_{sw}$$

So, what we have to do? We have to actually select a value which should be greater than the calculated value of the inductor. So, that is the first component which we need for this calculation. DPT test. Now second component is first let's say let's say second is second component will be the DC source. So what should be the value of DC source? So DC source actually should be such that it should be able to provide the required voltage. So let's say there is a voltage range which is given for this DPT test which vary from minimum to maximum. So we have to select a DC source which should be able to provide the maximum DC voltage. So the maximum DC voltage, let's say if it is 1000 volts so then we have to select a dc source it should be able to provide 1000 volt, means the voltage rating of the source should be more than 1000 volts and the amount of current it should be able to provide that depends on the minimum current rating of the device. Means if the device is able to carry 5 to 24 or this is the test setup, test condition given so then we have to select the minimum current. So the voltage source which should be able to provide maximum voltage and the minimum current so that kind of voltage source we need to select for this test. So maximum voltage and minimum current. So, the third component which we need in this case is the capacitors. So you have seen two components of capacitors are given. One is known as storage capacitor. I will just represent it as storage capacitor or bulk capacitor. So then this should be able to provide required current to the inductor. So how we can find out value of this capacitor? So this is also known as bulk capacitor. So this capacitor value should be more than equal to this particular equation**.**

$$C_{bulk} \geq \frac{L I_L^2}{(2V_{DC} - \Delta V_{DC})\Delta V_{DC}}$$

So, this we can also simplify in terms of L iL square into 2k delta V. So, amount of ripple we are going to allow in this capacitor, the amount of ripple voltage and then it multiplied with this multiplied with, so I will just remove the multiplication sign here. So, this multiplied with Vdc square.

$$C_{bulk} \geq \frac{L I_L^2}{(2V_{DC} - \Delta V_{DC})\Delta V_{DC}} = \frac{L I_L^2}{2 K_{\Delta V} (V_{DC})^2}$$

So, this will give us value of the required capacitor. So, whatever value we will be getting for this bulk capacitor we have to choose a value which should be more than that value. We can choose equal to that value, but it is always advisable to select a value which should be more than the calculated value. Now this is with respect to storage capacitor or the bulk capacitor. It is responsible to provide the required current to the inductor. Now there is another capacitor which is basically known as, so in the previous you can see here two capacitors are there. Energy storage capacitor, this I am representing as bulk capacitor and decoupling capacitor this let's represent as Cdec. So now decoupling capacitor.

So, if I represent this in Cdec, so then this value should be more than equals **to 100 times of the output capacitor of the device.**

$$C_{dec} \geq 100 \times C_{oss}$$

So, this output capacitor is generally given in the data sheet. So, once we have the information about output capacitor, then we can actually select this decoupling capacitor required for the test. So, whatever we will be selecting, calculating it should be more than that particular value. So three components are there. So we have last component that is bleeder resistor. So, this is simple resistor. So, why we need this resistor? So, you can see in the previous slide. So, this is bleeder resistors which is connect across the DC source. So, we need this resistor after every test. So, let us say we are selecting certain voltage at that voltage we are going to perform this DPT. or certain condition we are selecting initially. Now we want to see the performance of the device in another condition. Then what we have to do? We have to restart the test. So if we are going to restart the test we have to consider a condition where all the capacitor will be in discharged condition initially. So that is why in order to discharge these capacitors we need some medium. So that medium is provided by this bleeder resistor. Now this bleeder resistor we have to select depending upon certain condition. So what are the condition? Although we are using it for like discharging the capacitor but we want the power loss in this resistor should be very less. So the first thing should be low power loss. This is when the test like certain condition related test is completed. After completion the test. So this is one condition and second condition is that, so when we are actually using this resistor so then it required some time in order to completely discharge the capacitor. So then that time should be fast. So means fast discharge time. So, we have to consider low power loss and fast discharge time. So, based on these two conditions we have to select required value of the bleeder resistor. Now these are related to DPT design. So the first thing is DPT design. So under this DPT design we have to consider four different conditions. So the four different conditions we are we have selected here, we have actually calculated here. They are load inductor, DC source, capacitors and bleeder resistor. So, these four different components are required in order to design the DPT circuit. Now, the next thing is to find out the control parameter.

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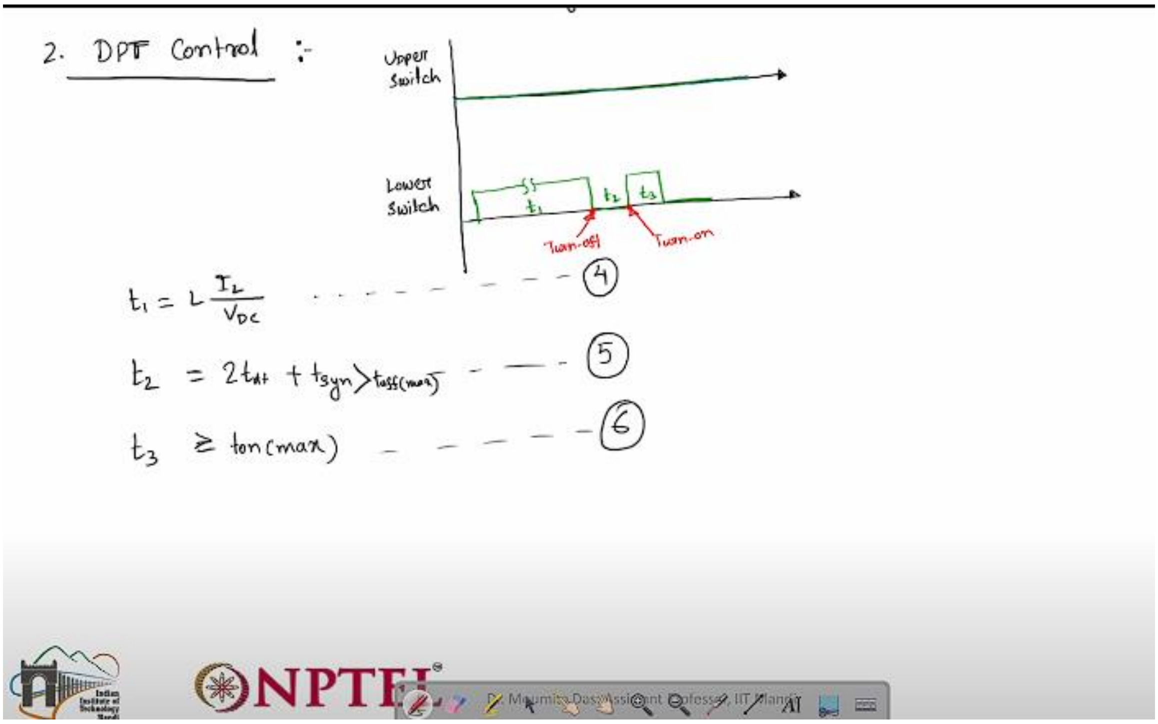

So, DPT control. So, now second thing is that DPT control. So, now control when I say so in this case you can see the circuit. So, here load inductor is connected across the upper switch that means the device which is under test so that is lower switch. So, this lower switch is basically, you can consider as device under test. Now, if this is the case then, how this switching signal should look like? The switching signal for this DPT control should look like.

So, this is let's say upper switch. This one is lower switch. So, as you know that upper switch is basically connected across the inductor which also can be represented with diodes. So, then this the switching signal which we need to provide to the upper switch that is like this means the upper switch will always be in OFF condition. Now how this lower switch pulse looks like? So the lower switch pulse will be like this. So, we have to provide two different pulses.

So, let us say the pulse width for the first turn ON time for the lower switch that is t1 and for the second time that is when the switch is OFF that we can represent in terms of t2 and then third one we can represent in terms of t3. Now, we have to find out what should be the value of t1, t2 and t3. Now, t1, t2, t3 also depends on the device voltage rating. So, then for like different devices, let us say for silicon carbide, if it is for 1000 volts, then the t1 will be, we can calculate from that particular value. Now, if we are actually testing GaN device, it is having different voltage rating, let us say 600 volts, then t1 will be different than that of the silicon carbide. So, that is why it is important to calculate t1, t2 and t3. So, t1 how it is dependent on different factors?

$$t_1 = L \frac{I_L}{V_{DC}}$$

Already you know L in the previous page, so, here we are calculating inductor L. So, if I try to, if L represent it in terms of equation 1, storage capacitor this in terms of equation 2, this is 3. So, then from equation 1, we can take value of L.

Then IL will be given for particular test and then Vdc also will be provided. So, or Vdc we can actually take from the point B. So, the maximum voltage and the minimum. So, the maximum voltage we have to consider. So, that we have to use here in order to find out t1.

Now, let us represent this in terms of equation 4. Now, we know that how what should be the value of t1. Now, once we have value of t1, then we have to find out t2. So, now t2 is the OFF time. So, the if it is OFF time, so then how we can calculate t2? So, t2 should be such that the device should commuted properly.

Means the the device should turn off completely in this duration. So, the t2 should not be a time when device, let us say for device it takes time, let us say fall time it is having 10 nanosecond. So, now we have to provide t2 which should be more than 10 nanosecond. If we provide less than 10 nanosecond then the this test performance will not be acceptable. So, t2 depends upon the dead time. So, let us say this dead time can be represented in terms of two tdt. Dead time means during fall time, like during when the switch is turning off. So, that time also there will be some time required and when the switch is turning ON before that also some time is required. So, that is why generally for like this kind of switching configuration means if the switches are connected in one leg. So, there should be some dead time provided. In the previous lecture, I have already explained how much dead time we need to provide. So, we have to provide that much dead time here plus the T synchronous switch. t2 equal to 2 tdt plus t syn.

$$t_2 = 2t_{dt} + t_{syn}$$

So, in this case, since we are calculating t2 for the lower switch, we have to also consider, if there is a upper switch which if we are providing any signal to the upper side, upper side switch then we have to also provide that how much time is required for the upper switch to turn ON so that much time also we have to provide here so t synchronous represent the upper switch in this particular case. Because we are testing the device which is connected in place of lower switch.

Now we have to calculate value of t3. So, as you already know when the device is turning off means this particular point we actually find out the dynamic characteristic during the fall time and when the device is turning ON in the second time. So, then we find out dynamic characteristics of the device during the turn ON condition. So, this gives us turn OFF and this gives us turn ON conditions device characteristics. So, that is why we have to use t3 such that, the device will be completely ON. So basically t3 should be more than equal to ton(max).

$$t_3 \geq t_{on(max)}$$

This we can also represent the previous one. This should be equal to T of max. So, these are the different time required in order to implement pulses for DPT test. Okay? Now we have DPT related design parameters and we got the pulse width. So let's consider a condition or one example where we can find out all these parameters. And this same example can be referred in order to find out parameters for other devices. So let's consider so let's consider one example.

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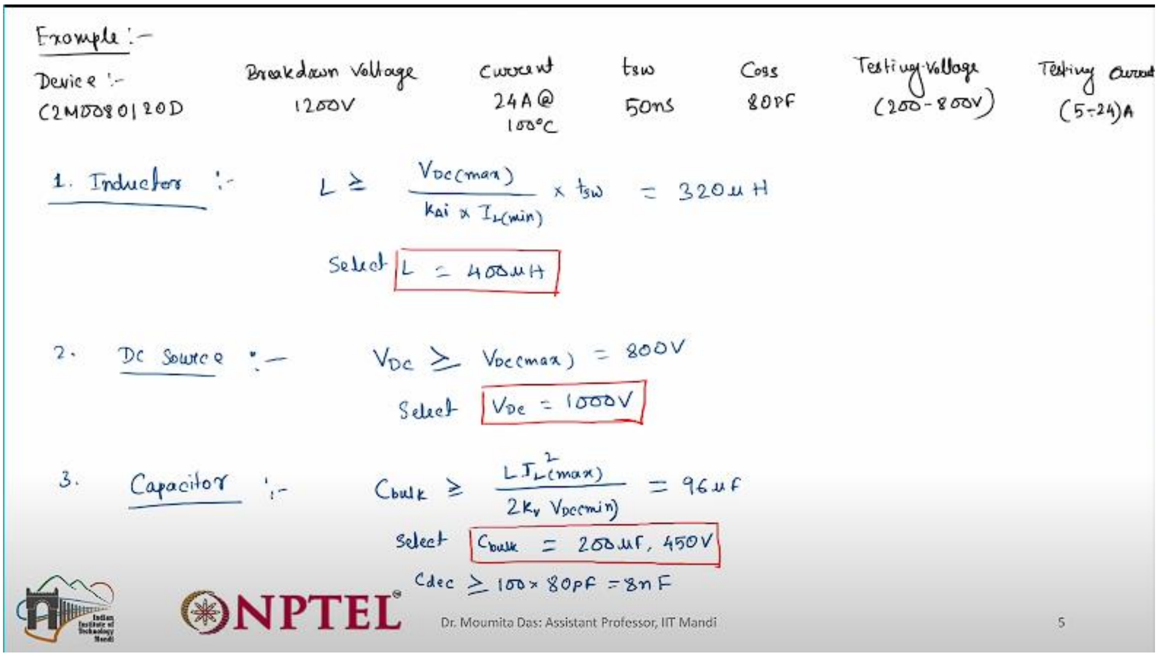

So, in this particular example, let's consider one device, silicon carbide device which is taken from CREE. So, the part number of the device is C2M0080120D, ok. Now breakdown voltage of this particular device 1200 volts, and the maximum current is 24 ampere at 100 degree Celsius.

Okay. Now in this particular, so there are like different components of the device will be given in the data sheet. So I am just writing the parameter which are required in order to implement the DPT. Okay. Now this switching time tsw is given here 50 nanosecond. 50 nanosecond is the switching time and then output capacitor value is given here 80 picofarad. Now test voltage is given 200 to 800 volts although the device breakdown voltage is 1200 volts but test voltage levels are much lesser than that of the breakdown voltage of the device. Now testing current is given 5 to 24 Ampere. So, any current level can be selected. Now, 5 is the minimum in order to get the required values. So, then so how we can select different components? So, what are the things we have to consider? So, we have to actually get different values of this parameters of the DPT. So, the first thing is the inductor. So, that I have already shown you the calculation in the previous slide. So, how you can calculate the inductor? So, inductor value you can calculate. So, first thing is the, so let me write it in different color. So, then it will be visible properly.

So, let us say first thing is the inductor. Okay. So, what was the formula for the inductor? You can go back to previous slide. So, you can see here. So, the VDC K delta I multiplied by IL into tsw. So, what we can do? We can actually write the same equation. So, basically same equation, in order to write that you need to also consider what should be the Vdc because you know here I am telling you that there are like testing voltage which is from 200 to 800 volts.

So, in this case what you have to do Vdc you have to select Vdc maximum. that is 800 volts. So, that you have to select from the test condition. So, Vdc maximum and then you have one like parameter K delta I multiplied by IL into TSW.

$$L = \frac{V_{DC(max)}}{k_{\Delta i} \times I_{L(min)}} \times t_{sw}$$

So, IL what we have to select? IL we have to select as minimum. So, IL should be minimum IL and then tsw, anyway it is given as 50 nanosecond. Now, K delta I how much we have to select? So, we have to select some percentage of like this current whatever we are selecting right. So, we can select that how much ripple we are going to allow in this particular case. So, that depends on like like particular any like factor we can select. So, in this case what we are selecting we are actually considering this K delta I equals to 25 percent.

So, then if we consider all this parameter 25 percent K delta I we are selecting. So, then Vdc maximum we are considering as 800 volts and IL minimum we are considering 5 amperes and tsw is the 50 nanosecond. So, then what we get we get, we get value equal to 320 micro-henry.

Now, what was the condition? Condition was L should be greater than equal to this particular value.

So, now let us consider, select L. So, it is always advisable to select the parameter which should be more than the calculated value. So, the select L equals to let us say 400 micro-henry.

So now we got the value of L. So this is our L. So you got one parameter. Now second is, what was second parameter? So second parameter was DC source. So, what should be DC source? So, DC source should be the voltage of the DC source, voltage VDC should be more than equal to the maximum DC voltage. So, maximum DC voltage, how much is given for this test? So, that is 800 volts. So, at least we have to select 800 volts for this.

So, select VDC which should be more than that. So, select one source. equals to let's say 1000 volts. So we got second parameter. Okay. Now what are the other components? Now third is capacitor.

So, two different capacitors are there. First is storage or the bulk capacitor. So, C bulk, you already know the formula of C bulk. You can go back and check the previous slide. So, there the C bulk formula is given. So, the same formula I am writing here. So**,** L IL here we have to select maximum inductor current square divided by 2 into KV into VDC minimum.

$$C_{bulk} = \frac{L I_{L(max)}^2}{2 K_v V_{DC(min)}}$$

Okay, so now we have to select here KV that is selected as 3 percent ripple is considered in this case. So, now this IL maximum is given as 24 ampere, 24 ampere maximum current we can use for this test. And now L already we can select L from this inductor calculation, that is 400 micro Henry and then we can calculate the value of the bulk capacitor. So, the bulk capacitor it is coming around, so, you can do the calculation you can check whether it is matching or not 96 microfarad. Now we have to select bulk capacitor which is more than this 96 microfarad. So let's select C bulk equals to, so, here we are considering minimum DC voltage. So, then we can consider minimum DC, the DC minimum DC voltage is given 200 volts. So, we can consider C bulk which will be let us say around 200 microfarad and it should be capable of handling 450 volts. So, the voltage rating should be minimum voltage whatever is given it should be more than that and the capacitor value it should be more than the calculated value. Now, another component of the capacitor that is C decoupling capacitor that is more than equal to 100 times of COSS. So, you can see here COSS is given 80. It is given as 80 picofarad. So, now you can calculate from here. So, what should be the decoupling capacitor required? So, the decoupling capacitor it is coming 8 nanofarad. So, we have to select a value which is more than this 8 nanofarad. So, now you can select any capacitor. So, like it should be ceramic capacitor. So, based on this calculation you can select any value. Now, let us go to next page.

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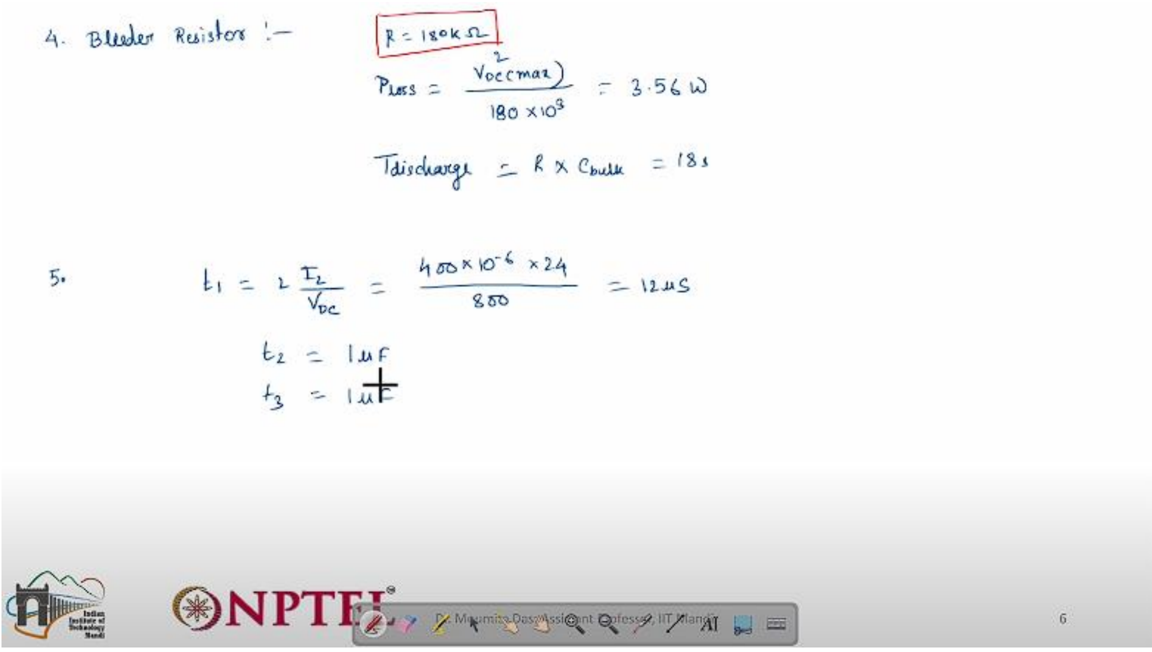

Now the fourth component is bleeder resistor. The two conditions I have written, one is the low power loss and the fast discharge time. So, we can select a resistor which will be a very high value, then the power loss will be very less.

So, then let us consider a resistance of 180 kilo-ohm. Now if we try to find out power loss in this resistor then how much we can get? We can get the power loss VDC, let's say maximum square by R is the, let's say 180 kilo ohm. We will get power loss around 3.56 watts. So, this is low loss we can select this resistance then we can find the discharge time. How we can find discharge time? So, we can actually multiply this R bleeder R with this C bulk.

It is coming around 18 seconds. So we can select this resistance. Okay. So now we have all the components which are required for this DPT implementation. So let's consider see decoupling, I haven't selected anything let's consider select, okay now we have all the component now one important thing is that we have to consider this decoupling capacitor, so because you know like if we have initially the voltage level, if we don't consider, so then what will happen with respect to the selection of the capacitor, the voltage spike will reduce down. See if we have very low value of the capacitor, so the voltage will be very high. So, that can come from the capacitor. So, the initial high voltage requirement or if there is any transient condition that can come from the capacitor.

If we do not have the capacitor that will directly affect the DC source. If we have the capacitor that component will come from the capacitor. So now, With respect to the time, so then how we can calculate the time? So, then time calculation let us say this is the fifth component. So, we can calculate t1, t2 and t3.

So, how we can calculate t1? So, t1 already you remember.

$$t_1 = L\frac{I_L}{V_{DC}}$$

So then this we have to consider the maximum current, that is 24 ampere and the DC voltage also should be maximum 800 volts. From this, we can calculate so then you will get time of 12 microsecond. Now, for the selection of t2 and t3, so both the condition should be that t2 should be more than equals to the turn OFF time and t3 should be more than equal to the turn ON time. So, the switching time, it is given for this particular device it is 50 nanoseconds. So, if we can choose a time which is more than that means, if we choose 1 microfarad So, that should be sufficient enough to implement this DPT circuit.

So, then we have all the design parameters which are required for the implementation and also we have the timings, which is required for implementation or providing pulses for this DPT circuit. So, then by using all these different parameters and the timing, we can actually characterize the device for dynamic operation. So, this is very important in order to find out the turn ON and turn OFF dynamic characteristics of the device. So, this is I have taken example of silicon carbide device, you can also use the same method in order to get different parameter for gallium nitride or any other devices. Okay, this is all for today. Thank you.