Power Electronics with Wide Bandgap Devices
Dr. Moumita das
School of Computing and Electrical Engineering
Indian Institute of Technology, Mandi

Lecture-5
FUNDAMENTALS OF DYNAMIC CHARACTERIZATION

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Hello welcome back to the course on power electronics with wide band gap devices. Today I am going to discuss about fundamentals of dynamic characterizations. So in the previous lectures I have discussed about static characterization. Now in this lecture I am going to focus on dynamic characterization.

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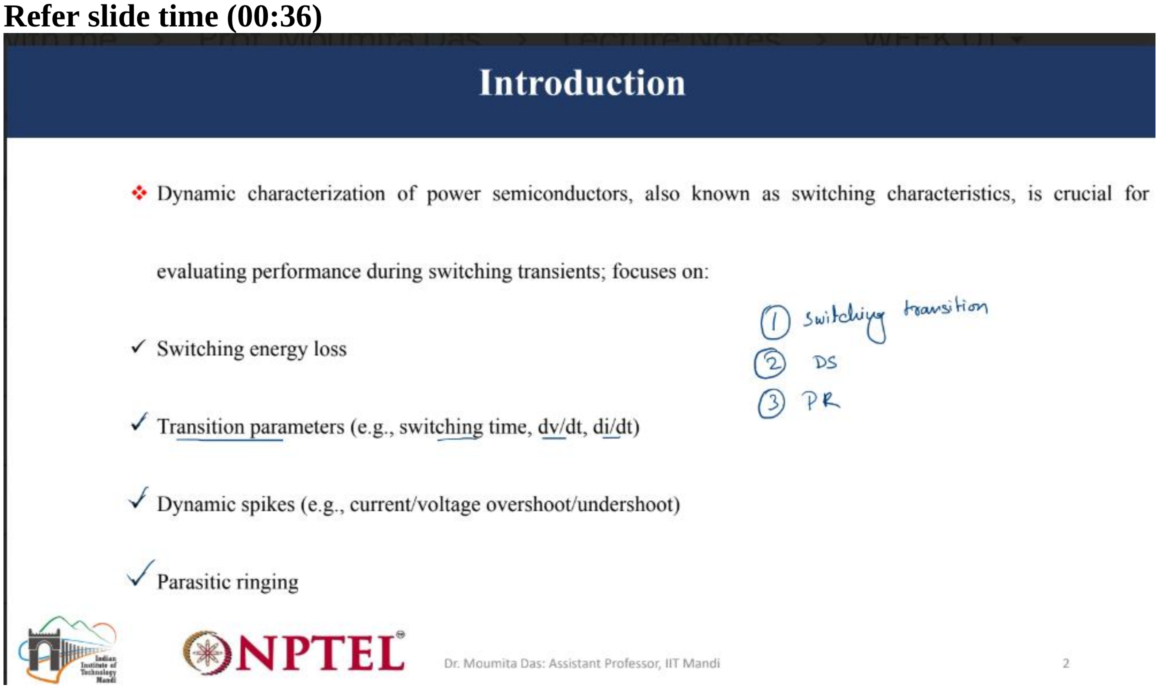

So when I say dynamic characterization so the thing generally comes to mind Whatever component is related to the dynamic time may be during switch on switch off time of the device so that comes under dynamic characterization so what we will be getting by this dynamic characterization so these are listed here so there are basically three components we will be getting by dynamic characterization one is it is also written here transition parameter so basically switching transition So, you know about switching transition. So, what are the components come in switching transition? Switching time, so basically delay time, rise time, fall time.

So, this comes under switching time and dv/dt and di/dt. So, these components will come under switching transition. Second thing is Dynamic spikes so dynamic spikes already given here dynamic spikes so this is having component of current and voltage overshoot and undershoot and third is basically the parasitic ringing So these three component are Comes under dynamic characterization so by using the dynamic characterization method we will be achieving these parameters.

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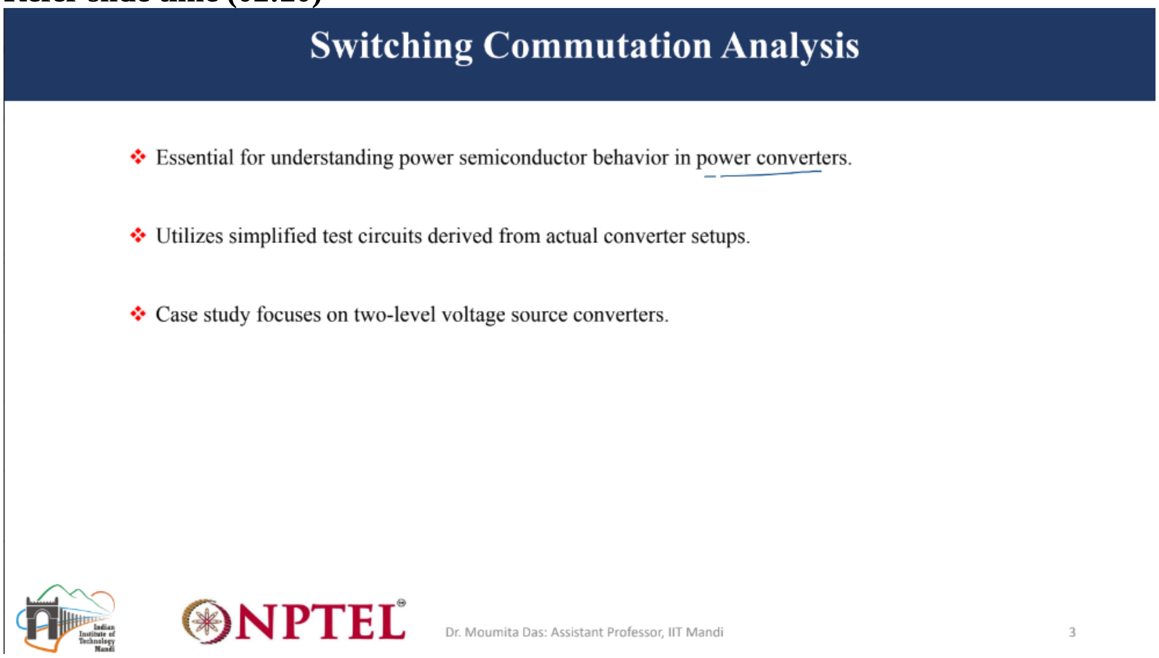

Now, in order to analyze these components, what we need to do? First, we need to know how the switches are behaving, switches are operates.

So, basically what we have to do? Commutation we have to analyze, how switches are commutating. So, that is possible if we consider any power converter and if we try to see that how this power converter switch is behaving during the turn on and turn off time. So, then what we can see, we can actually get all these parameters. So now any power converter when we are considering So most of the power converters are generally having two switches connected in series So let's consider simple voltage source inverter.

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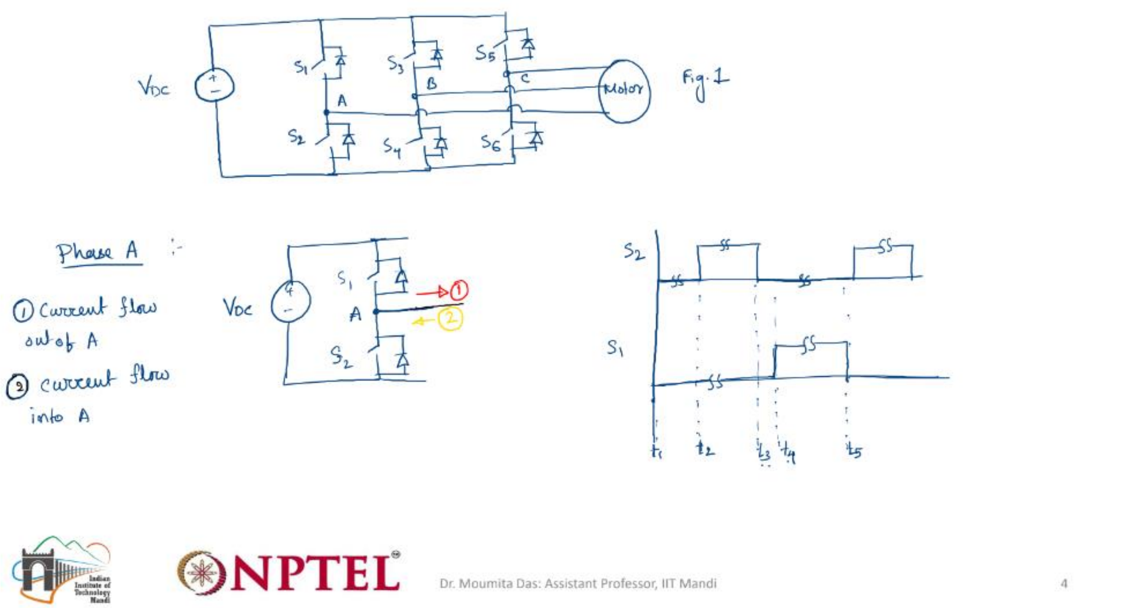

So let's consider one voltage source inverter which is having input DC voltage connected to it and in this case I am considering three phase voltage source inverter So it is having six different switches Generally all the switches are expected to have anti-parallel diode connected to it which can be body diode or may be there can be separate diode connected to the switch. So, like this there will be three different legs for three phase.

So, you can see here three different legs which are having similar types of switch and the connections are also similar. So, this is another last phase. So, if we consider any drives application, so these three different legs will be connected to the three phases of the motor terminal. This is VDC. Now, when we are considering these three different legs, so generally how the switches are connected? So, you can see here in each leg, two switches are connected to each other.

So, now S1, S2, similar way S3, S4, S5. Sorry S6. Now, positive or the drain point of one switch is connected to positive terminal of DC voltage source and negative of any switch or the source terminal of another switch is connected to the negative terminal of the DC voltage and the midpoint are connected to different phases of the motor. So, let us consider this is let us say phase A, this is phase B and this is phase C. So, each point is connected to motor.

Now in this actually if we consider any one phase other phases will have similar type of principle. So let's try to understand how switches are commutating in any particular phase. So let's consider the phase A. So if I try to draw phase A. and associated switches in this particular leg.

So, then it will look like the DC voltage source will be connected at the input as the previous diagram. This is let us consider this is as figure 1. Now, these two switches will be connected here. S1 and S2. So, I am drawing only this particular portion so that we can understand this switching operation properly.

If this leg we consider so there can be two different scenario. What are the two different scenarios? One in which the current can flow from the midpoint. So midpoint if I denote as A so current can flow current flow out of A. So, then if I try to represent this in different color, so 1 can be, current can flow out of A in 1. So, this I am representing as 1 and then second one, so let us represent this as current flow into A.

So then this can be represented as current flowing into N. So, there can be two different scenarios and in these two different scenarios the switches involved in the commutation process will also be different. So, let us consider the first case. So, current flow out of N. So, before that let me just draw the switching signal for these two switches.

So, how the switching signals will be So, generally what happens? So, there will be switches some one of the two switches will be on at a time otherwise there will be short circuit condition. So, let's consider switch S2 is on during this duration and switch S2 is off during this particular duration and again it is on in this particular duration. So I am giving this duty cycle can be anything. So I am not considering any particular duty cycle. Now, if switch S2 is on, so in that time switch S1 cannot be on, so then it has to be off.

So, this is not the only condition. So, when the switch S1 and S2 are turning on and off, so there has to be some dead time in between. Otherwise, as you know there can be problem of short circuit because you know due to the rise time and the fall time, So there can be a situation where both the switches can be on So in order to avoid that situation we need to provide proper dead time in between these two switches So that we can avoid any short circuit condition in the circuit So that is why there will be sufficient amount of gap in between So, now in this condition let us say switch S1 is on and in this condition switch S1 is off. So, now you can see here there is actually sufficient gap in between. Let us consider this as into different time steps.

So, this let us say consider T1 to T2. So, T1 to T2 this is actually dead time then T2 to T3 condition so in this time the switch S2 is on now T3 to T4 in this condition again we are providing some dead time before turning on switch S1 so now T4 to T5 this switch S1 is on. Again there will be repetition of the same time. So, we will try to see during this time durations how the switches are operating.

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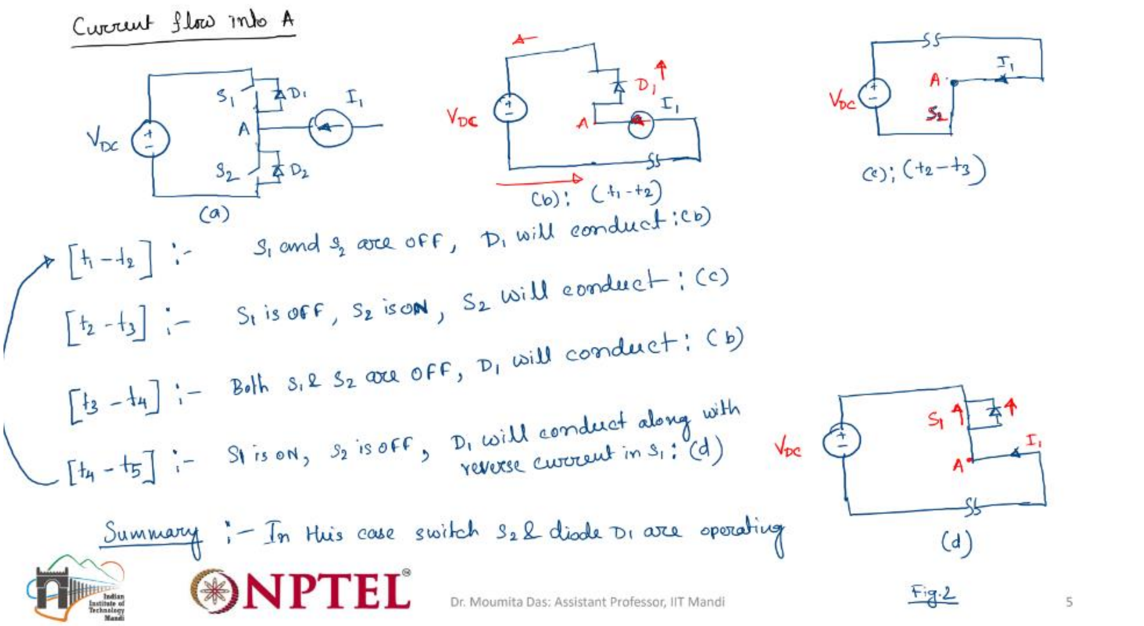

So, now if I try to draw a condition where basically the current is entering into the midpoint. So, Let's say this condition current flow into A. So as you know the circuit diagram remains same as this one. Two switches are there which is having anti-parallel diode So now these diodes can be body diodes for wide band gap devices. It can be body diode of silicon carbide. For GaN it doesn't have body diode but it provides reverse path.

So that will also work. So there will be no problem for that. For silicon, some of the silicon devices, it may have some reverse recovery problem with respect to the body diode of particular switch. Then we can either connect separate diode, any Schottky diode or any additional body diode of any switch which is having faster body diode for this test. So, now this current we can represent as current source entering into 0.

8. So, this is S1 and this is S2 in VDC. Now, how this current will look like? So, during t0 to t1 time. For time, so we have taken t1 to t2. the time first time so in this time so there is dead time provided so during this dead time what is happening so basically if it is dead time means both the switches are off both s1 and s2 are off now If both the switches are off, there has to be some path for this current.

So let's say this is A. Now if I try to draw the equivalent circuit diagram for t1 to t2 duration, so then it will look like Because both the switches are off, the current it is flowing in this direction. So then it is having path through the body diode of switch S1. So I am representing body diode of switch S1 and S2 in terms of D1 and D2. So this body diode will provide path for the conduction of current. So obviously this point this return path will have some, from some like external path it will provide the return path.

So if I try to draw the complete circuit which will have additional component so then this will look like this. So the current will flow from So, this is point A, this is D1, this is VDC. So, the current flow path is like this. So, through D1, VDC and then it will provide like this. So, during T1 to T2 in this duration.

Now, D1 will conduct. Okay, now t2 to t3, so what was in that time? So, you can see in the previous slide, so t2 to t3 switch S2 is on, S1 is off. So, we can go to next slide, switch S1 is off, of S2 is on. So, S2 is on, so this is represented, we are representing this as B. So, this is like t1 to t2 duration, it is shown in B or maybe I can just write here in terms of time.

So, this is during t1 to t2. So, during t2 to t3, so then how the path will be? So, the path you can see here. So, S1 is off, our current is entering. So, obviously it can have path through S2. So, then it will look like So current will shift from D1 to S2. So then obviously there will be like additional path here.

So then the current which is entering here in this path. So then this will flow through S2. So S2 will be closed in that time. So you can see here so this is S2. so S2 through S2 the current will flow and then obviously there will be like similar path in the positive side which will try to complete the circuit.

Now you can see here so this is the point A as this is point A the current so let's represent this current as I or I1. So, I1 will flow through S2- VDC -S2 and so S2 will be on in this time S2 and then it will complete the path. So, this is the current flow path during the t2 to t3 time. So, in this time S2 will conduct. Now, let us consider the duration t3 to t4.

So, in this time what is happening? Again there will be dead time. So, dead time means both the switches both S1 and T2. S2 are off. Both are off. So, again the similar situation happened in case of T1 to T2.

So, D1 will conduct. This is similar to let's say figure, this is if I represent this as figure B, this is represent as figure C. Now, this is with respect to B, this is with respect to C and again this is with respect to B. Now, there will be situation when the complement switch will be on. The complement switch is Which one? S1. So, let's consider the duration when S1 is on.

So, T4 to T5. So, in this duration what happens? S1 is on. The upper switch is on and S2 is off. Lower switch is off. Now this time what will happen? So upper switch is on but switch is having drain connected to the positive terminal of the DC voltage and source connected to the midpoint. Now If the switch is on, ideally current should flow, forward current should flow from drain to source.

So, basically from VDC to A, but in this case already given current is entering into A. So, that means current can only flow from A to VDC. So, then how that is possible? So, again in this case D1 will conduct and current through S1 will conduct in the reverse direction if the switch is having capability to carry the current in the reverse direction. So, the current will be divided between D1 and S1. So, how this diagram will look like? So, this diagram I can draw here.

So you can see here So this diagram will look like So it is connected like this And D1 is conducting Obviously and the switch in this case So let me draw both switches and the diode Because you know current will flow through both the path If switch is capable If switch is not capable Then only the diode D1 will conduct So then in this case The current will be entering into A And then obviously the return path will have like additional network from the circuit. So you can see here this is A, this is VDC. And this is switch S1. So, in this case the same current which we are actually denoting as let's say I1. So, this will be flowing through both switch and the diode.

Switch, this current will divide. Here we conduct along with reverse current. in S1. Okay, so that means what? The current is flowing in the reverse direction. If we do not have switch, then also the current will flow. If our switch is on, then also the current will flow in the reverse direction.

So, there will be no difference with respect to turn on or turn off condition of S1. Only thing is that current will be divided. So, as you can see, so same thing will repeat from t5 again when the switch S2 will be on. So, again this process will repeat. So, basically from t4 to t5, the complete cycle is completing.

S1 on, S2 on and both are having dead time. So, after this again what will happen? This process will go back to t1. So like this the operation will happen. So this actually can be represented in C Sorry, this is I have already represented C. So this should be D So now you can actually relate this different switching time with respect to different current flowing path of the converter. So, what we can summarize from this particular operation? So, you can see here, so basically in this particular leg what is happening? In this particular leg if we are actually considering current flowing into the circuit so then the switch S2 and D1 are basically playing important role.

So basically these two devices are actually operating. In this case switch S2 and diode D1 are operating. So, then what is happening? In order to analyze this operation, if we connect switch S1 and diode D1, then we will be able to implement this particular operation. operation.

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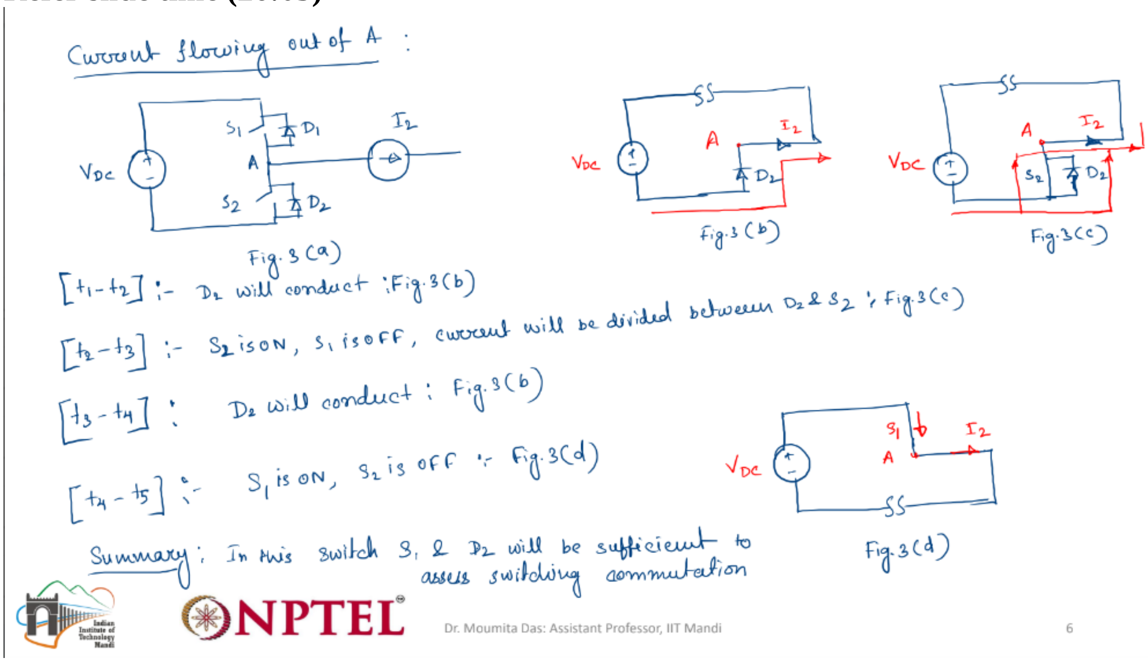

Now, next similar thing I will be discussing when the current is flowing out of the phase 1, sorry phase A. So, now if I draw the similar circuit, current flowing So, in the previous case you have seen flow into, so this will be flow out of A.

So, then how this circuit diagram will look like? This circuit diagram you can see here. So, VDC will, it will be similar to the previous case. S1 also will be there as the previous case. S2 will also be there. S1, S2 and then both are having body diode as the previous case D1 and D2.

Now, in this case current is flowing out of point A. So, this current let's represent it as I2. This is VDC, same VDC as the previous case. Okay, so now how the operation will be for similar time duration. So, similar time duration if I consider, so then again, so this I am considering as, so the previous, let's say this is with respect to figure, different figures are there.

So, same figure I can represent as figure 2. So, this a, b, c, d are with respect to figure 2,b , c, d like this. Now, in the next case let's represent this as figure 3a. So, now during t1 to t2. In this duration, what we have observed? We have observed the dead time is given. So, if you forget about this, so you can just go back to the previous slide or you can draw this switching diagram in your notebook and then try to relate this switching diagram during the converter operation discussion.

So, t1 to t2 you can see similarly the dead time is given, t2 to t3 S2 is on, t3 to t4 dead time again and t4 to t5 S1 is on. Similar thing we will be using for this case also. So, dead time is given in this case. So, dead time is given means what? So, then you can see here as the diodes are connected this way.

So, then the diode D2 will conduct in this case. This we can represent, this I can actually show you in the similar diagram. So, V dc will be here and then this network obviously will be completing through another part and then this current will be flowing through diode D2. Switch will be off. Both the S2 and S1 switches are off.

So, then the current flow will be like this. So, this current is I2. This is VDC and this is the current flow path. You can see here this is the current flow path. Now, this let's represent this in terms of figure 3b.

So, this is given in figure 3b. 3b. Now consider the situation when t2 to t3. So what was the situation in t2 to t3? S2 was on. You can see here. So T2 to T3, S2 was on. So then in this case S2 is on, S1 is off So, obviously if S2 is on the condition is such that that current cannot flow from A to the ground.

So, current is in the opposite direction. So, this will be the similar situation in case of previous discussion. So, what is happening? in t4 to t5 means this current will be divided between, current will be divided, will be divided between D2 and S2. So, basically if the device can carry reverse current, so then this current will flow through the device in the reverse direction, otherwise it will only flow through diode D2. So, this will look like, similarly in the previous case, so the current flow will be, so this is having the path as I have shown in the previous case. plus minus and then here this current will be divided between switch and the diode D2, D2 and the switch S2 and this current will be going out of A.

So, you can see here, so this is I2, this is point A, this is VDC and this current will be divided in two part, one will flow in diode D2, another if possible flow through the switch in the reverse direction and then this will go out of point A. So, this is how the current flow path will be in this case. Now, consider the situation t3 to t4, again the dead time is coming. So, in this case, so this, okay, let us represent this as figure 3c.

So, this can be represented in figure 3c. So, now t3 to t4, so what is happening? In this case, dead time is there. So, it will be similar to t1 to t2. So, only D2 will conduct.

So, this figure will be similar to figure 3b. Okay. Now, consider the situation t4 to t5. So, what is happening in this case? Switch S1 is on. S1 is on now. Now, S2 is off.

So, now what will happen? The current will shift from D2 to S1. So, how it will be? So, in this case the current flow will be. So, the current flow will be plus minus this is. So, the switch S1 is on obviously the current will flow like this and it will go out of point A.

So, you can see here. So, this is this is S1, it is on. So, current is flowing in this direction and then this is point A. So, this current is going out of point, this is I2 and this is VDC. So, now you can understand completely how the operation is happening in any particular leg with respect to two different scenarios.

So, this is figure 3d. This is figure 3d. So, summary of this. particular operation is So if we have to consider a situation where current is flowing out of point A or any phase any particular phase So then what is happening? So then again similarly in the previous case we can consider only one switch and one diode But this time the switch and diode will be complement to the previous case So in this case in this switch S1 and diode D2 will be sufficient to Get the behavior of the switch. Switching commutation. Now, why we are actually looking into all these things? So, basically this switching commutation is very important to actually understand the switches operation, how the switches are operating and in order to optimize the operation of the power converter. In order to design also, we need this switching commutation behavior. Until and unless we have this commutation behavior, we cannot have the complete knowledge of rise time, fall time and also what should be the frequency of operation.

So, that is why this is very important to design any power converter and also how we can optimize. So, this dead time whatever I have shown here, so this dead time how much it should be, how much we need to optimize for particular operation or whether we can avoid this dead time. So, this all this information will come from the switching commutation behavior and this information we need before actually designing any converter. So, that is why this information we have to provide before using particular switch any power converter.

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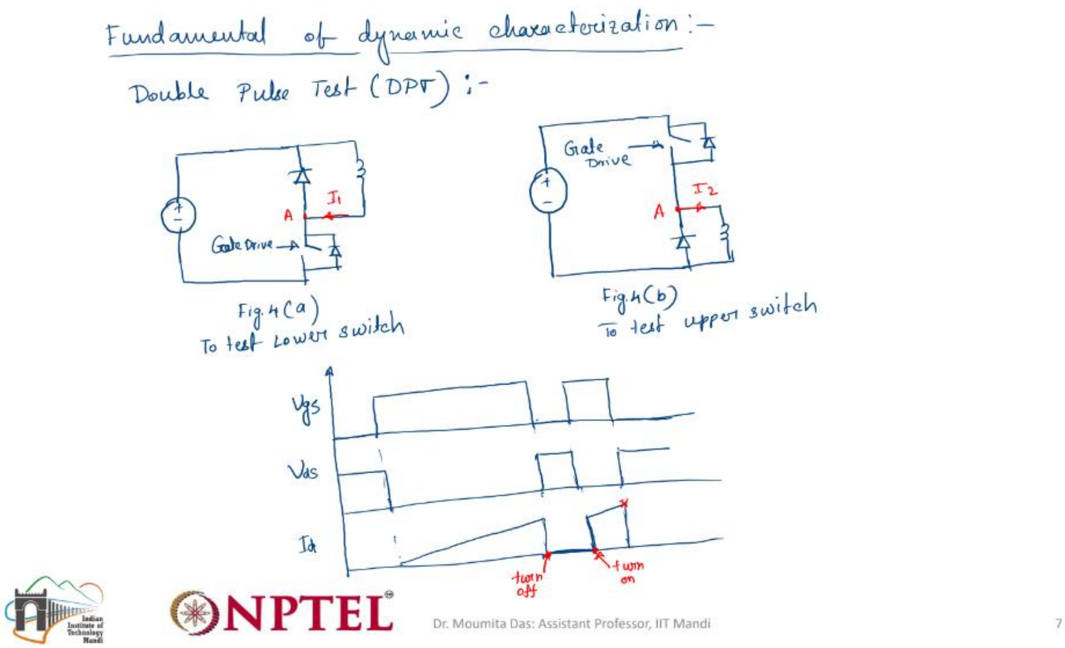

So, now this is basically the fundamental thing which is required for dynamic characterization. So, this is also known as fundamentals of dynamic characterization. So what we need in order to have these fundamentals of dynamic characterization? As I have explained in the previous slides, we are actually considering two different pulses. So In one pulse, one of the switches, either upper or lower switch is on and in another pulse, the complementary switch is on. So, basically we need two different pulses. So, that is why we need a setup where we can provide two different pulses to get the complete switching commutation.

So, this is known as double pulse. Just a minute. Double pulse test setup or DPT. So DPT is very important in order to get dynamic characterization of any particular device. So how this will look like? So it can have either combination of one switch on diode or we can have two different switches. So we can actually get commutation of any particular switch either upper switch or the lower switch depending upon how we are providing the current. So, then we can have two different configuration the current we can actually replace in with inductor. So, how this setup will look like? So, we have to provide DC source obviously in order to test the device principle we have to provide the supply and now this will be if we are actually considering the lower switch which is like device under test.

So, then upper we can Consider diode, so this diode can be first diode and then there will be inductor which is connected in parallel to the diode which acts as current source. Now this will be connected to the lower switch which we have represented here as S2. Now lower switch also will have anti-parallel diode but that is not a problem. So here we can provide gate drive. So this gate drive will have two signal okay so this is when we are considering so this is let's say figure 4(a) if we are considering lower switch and figure 4b, if we are considering upper switch.

So, similar type of setup will be there. Only thing is that whatever device we will be considering, so that we have to consider the other one, other device in series to that can be represented, can be replaced with diode or we can provide switch also. The problem with providing switch, we have to provide the gate drive. So, that is the thing we have to consider. So now here this inductor will be connected here.

So now this is the device which is under test. So here we have to provide gate drive. So in case of upper switch there the gate drive will be provided. So this is to test lower switch. This one to test lower switch and this one to test upper switch so you can see here so the commutation will be such that so basically in case of when we are considering the lower switch so basically current is flowing into the system so this is the path of the current I1 and then when we are considering the upper switch, so then current is flowing out of the system, this is I2. So, similarly we can also consider the same point A here. This is how we can represent double pulse test circuit So now how the pulses will look like So the pulses will be such that We can have sufficient amount of time So that inductor current can flow And it can reach to a value where we can measure the current But also inductor should not saturate So double pulse from the name you can actually understand it will be having two different pulses.

So, the pulse width will be such that the first pulse width will be significantly higher, width it is having higher width and then second pulse will be having lower width. So, then we will be measuring two different components Vds and Id. So, Vds Ideally, when the switch is on, the VDS will be appearing across the switch and when the switch is off, VDS will be appearing across the switch and the switch is on, so that time ID current can flow into the device. So, Id will look like, basically Id I am representing in terms of I1 or I2.

So, this current will look like this. So, just let me draw it properly. So, two lines are there. So, let me draw it in one line. So, now during this time it will be off. The current will be zero. And then again the current will start from wherever it was in the previous duty cycle.

So, this is the time. Now, there are two important point here is that this point and this point. You can see here. So, this point will tell us about the turn off duration. And this point will tell us about the turn on duration. So, these are the two different points which we will be analyzing for this dynamic characterization.

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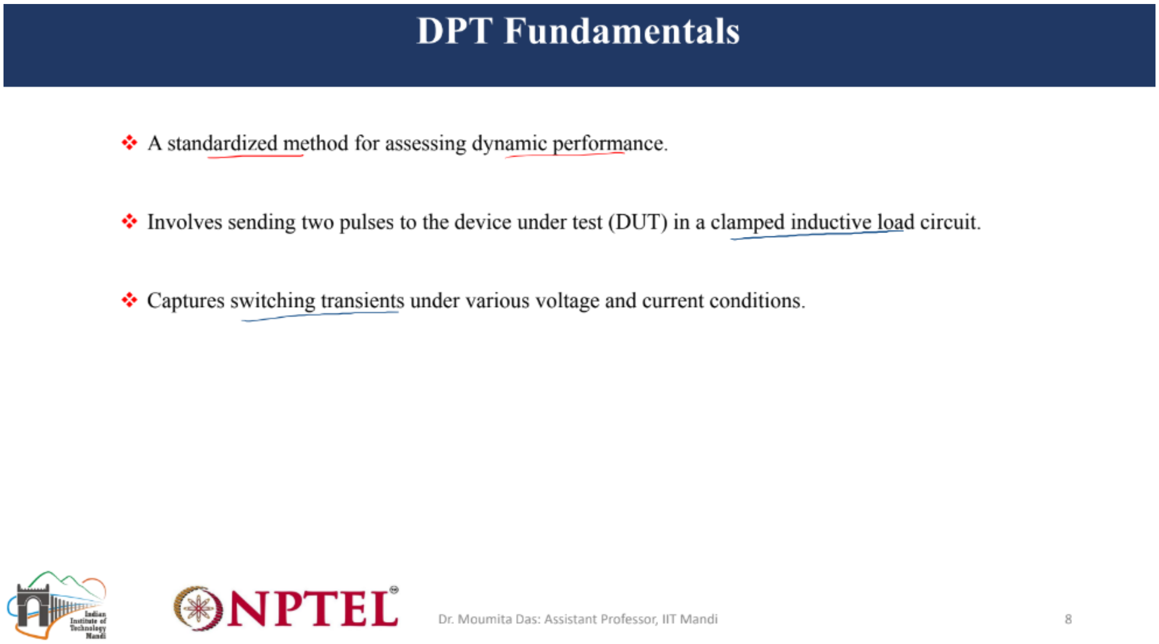

So, this is the network or the circuit which is required for double pulse test. So, you can see here, so basically DPT we need, this is a standardized method It is not something new which we are using for wide band gap devices We are using, it is for wide band gap device dynamic characterization But this is the same thing which is probably used for silicon device also So, this is standardized method for dynamic performance characterization. So, this involves sending two different pulses so that is why it is known as DPT and which provided to the device under test and where inductor load so basically inductor is clamped in the circuit to provide the required current. So, this captures two switching transient under various voltage and current conditions. So, this is the fundamentals of the DPT. Now, what are the components involved in DPT testing? So, the components which are involved in DPT board, so basically if we try to actually analyze the circuit, so then what will happen? For practical implementation, this DPT board consists several components.

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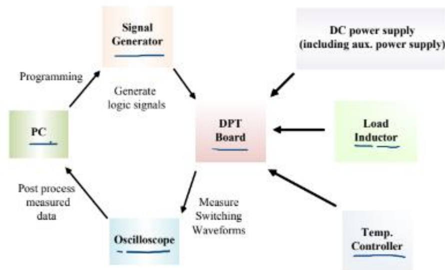
Practical Implementation

- DPT board includes DC capacitor bank, gate drive, protection circuit, and interfaces.
- Double-pulse signals generated by microcontroller or function generator.
- Switching waveforms measured and data processed by a PC.



Physical implementation of DPT

So, you can see here, so this DPT board, it is connected, DPT board means like where these two switches and this network will be there. and but this network is not the only thing which probably we need to get the characteristics but this DPT board will be connected to the signal generator which will provide two pulses and this signal generator can either be a microcontroller or maybe this waveform generator which generally you get to see in the lab so whatever is suitable for you to use for generating two pulses and this if it is microcontroller then we need to program it by using PC so then this PC will program the microcontroller or the signal generator for signal generator we don't need pc then it will be provided to the DPT board now DPT board whatever signal will be capturing that will go to the oscilloscope Again the oscilloscope data will be analyzing in PC. So these are the components which are required to analyze the characteristics.

Now for DPT testing we need different components. One is the DC power supply. Main DC power supply which I have shown as VDC. So that is required to provide the supply voltage. And one auxiliary power supply is also required to provide the supply voltage to the gate signal. and then obviously load inductor is required externally so that it can provide the required current and then temperature controller temperature controller is very important thing because you know like whenever you see any data sheet they test the device under certain conditions certain temperature condition so that is why we have to provide this temperature control so that we can maintain the device in a particular temperature if we don't provide that then the temperature in the device if it vary for some reason then the characteristics what we will be getting that may not be suitable for any particular temperature operation so that is why this temperature controller is very important so these are the different components for practical implementation.

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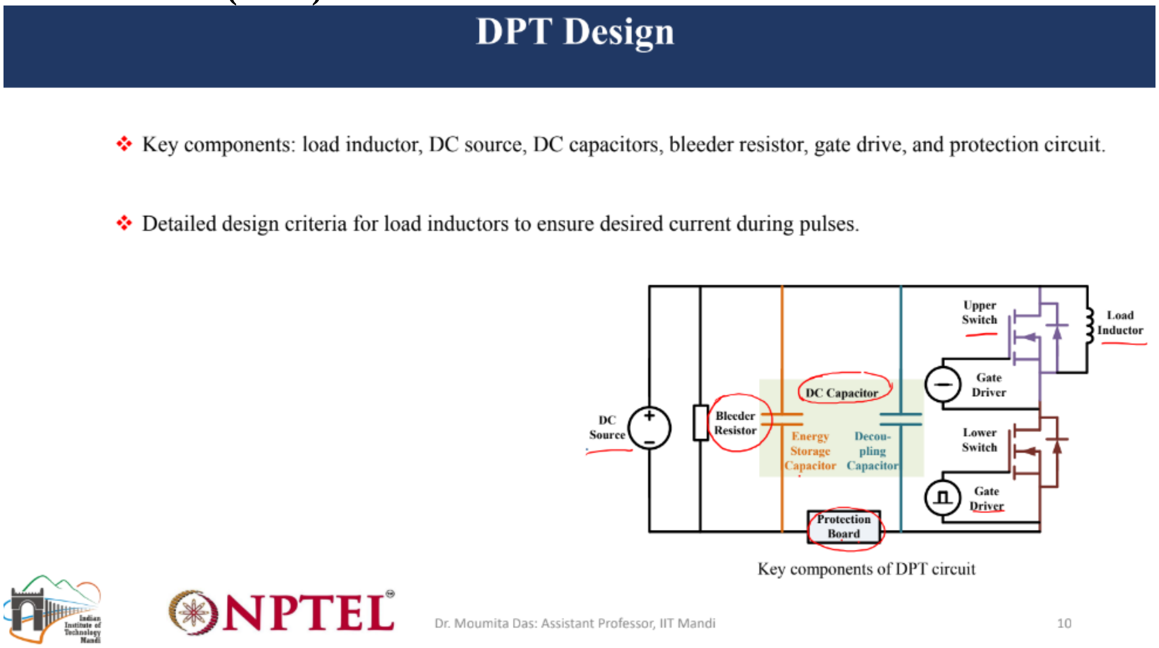

So now This is the design, DPT circuit and the key components of the DPT circuit. So, till now whatever I have shown you, so there are like DC source, then two switches, are there along with gate drive, load inductor.

But here what are the additional thing you are seeing? Additional thing what you are seeing is the bleeder resistor, DC capacitor which are having two different component, energy storage capacitor and decoupling capacitor. And then There is actually protection board also there. So these components are additional which you are seeing here. As I told you like we can either connect two switches or one switch and one diode. So generally like people connect one switch and one diode but if you want to extend the same DPT for practical application let's say for synchronous buck converter or maybe you can extend this work for implementation of inverter.

So, then you can use two different switches. The same circuit you can use for characterization, eventually you can use for practical application. So, different components here whatever present here, so this DC capacitor are having two different components, energy storage and decoupling. So, energy storage capacitor obviously it stores energy and provide constant DC supply to the DPT board. Now decoupling capacitor it is present in order to provide any noises or transient if it is required so then that can go from the decoupling capacitor Now this protection board is provided in case if there is any short circuit condition so that we can actually provide protection to the network so that we can limit the current flowing into the circuit by the protection board so that is why it is provided The bleeding resistance or the bleeder resistance, why it is provided? You know like when we are testing the circuit, you have seen in the previous slide.

So the inductor current, what is happening? It is having some significant value. So you can see here after the double pulse test, the inductor current will have significant value. Now, if inductor current is having significant value, we cannot leave the circuit in that condition. So, let's say if we have to test the circuit for another voltage and current level, then we have to assume that inductor current will be starting from zero. So, that is why after every test, this inductor and capacitor has to provide path so that it will discharge. So, then that is why this capacitor, inductor will provide this charge to the capacitor and capacitor will discharge through this bleeding resistance So, that is why this bleeder resistor is provided in the DPT circuit So, this is all about introduction of DPT circuit In the next class, I will be discussing about the design procedure of this DPT so what are the different components whatever the different components you get to see here in this network how to design it and how to select the pulse width so those i will be discussing in the next class thank you so this is the reference book which you can refer thank you