Power Electronics with Wide Bandgap Devices
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Lecture-10
GATE DRIVER PROTECTION

GATE DRIVER PROTECTION

Welcome back to the course on power electronics with wide band gap devices. Today I am going to discuss about the protection part. So how we can see the protection from the gate driver side and also from the converter side that I will be discussing today.

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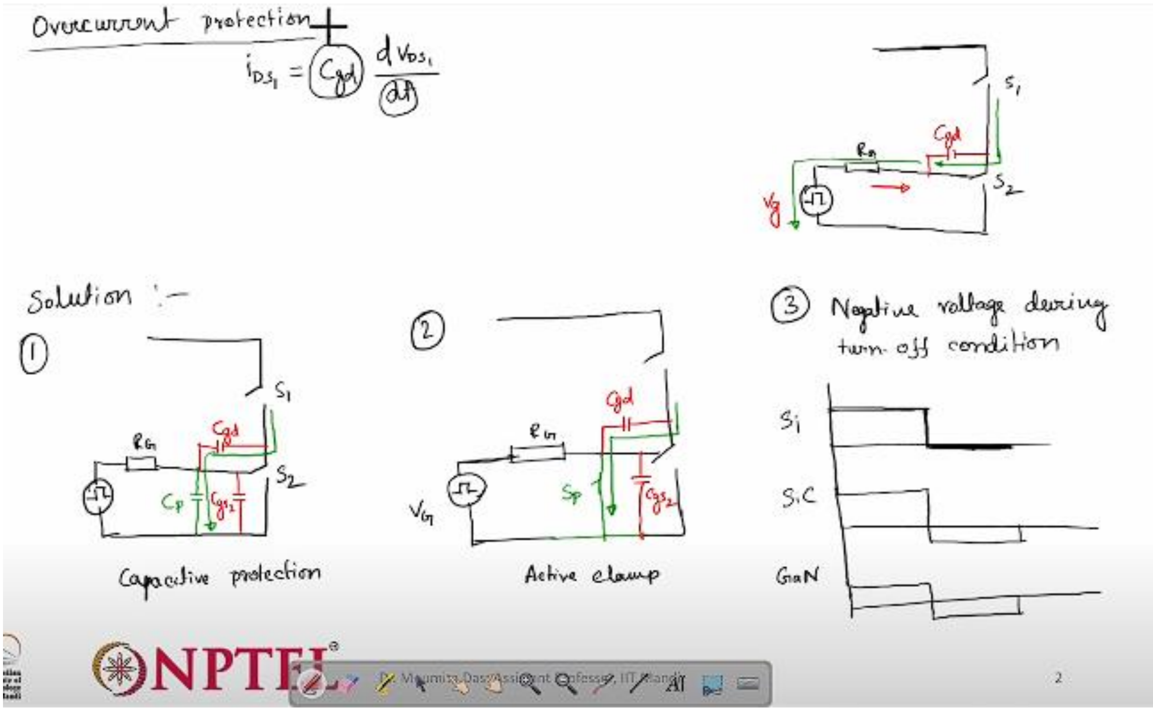

When I see the basic circuit where two switches are connected in one leg. So the circuit looks like. So let's say two switches. One upper switch and another lower switch. This is a simplified circuit which generally we use for DPT also. Okay. Switch S1 and S2. So, generally, what happens, So, in DPT We provide gate signal to one of the switches, either upper switch or the lower switch. Similar case will happen if we use this leg for any converter. So, let's say single phase inverter, three phase inverter. So, where two switches are connected, so complementary kind of pulses will be given. So, at one time only one switch will be providing gate signal. So, then what happens? So, if we are providing gate signal to the lower switch, so then this gate signal will provide gate current through the gate resistance. So, you already know about the gate resistance and what are the values we need to be connected with respect to the gate resistance. Whenever there is current flow through the gate resistance to S2, so then what happens, Current path will be like this. This S1 switch is having different capacitances.

Similarly, S2 is also having different parasitic capacitances. So one of the capacitance, generally, parasitic capacitance that is inherent to the switch, it is connected between drain and gate. So, that is known as CGD. You know about this particular capacitance and how to measure this capacitance. Now, whenever any switch is turning off, let us say switch S1 is turning off. So, then what will happen? there will be a current path through this capacitance to the gate resistance and then it will go to the gate and then whatever component will associated with the gate driver. So this particular gate driver signal, I am assuming, this will be after all the components of the gate driver, means isolator, then the driver, then if there is decoupling capacitor, after that, we are getting this signal. Now if there is a current component which will go to this gate driver, so then it will flow through all the associated component. If there is isolation, then there will be some protection, but otherwise it may destroy the device. So the current flow path in this particular case, it will be from S1, so S1 is switching off so in that case S through S1 then CGD then it will flow through RG And then it will go to the gate drive components. So you can see the green color component. So the red one is associated with the switching signal with respect to S2. And S1 is turning off. And the current associated with green. We can represent this in terms of So, we can represent this, Let's say this is IDS1. It will be equal to Cgd and depending upon the turn of voltage, so whatever will be the voltage that will be coming across S1, so then we can represent this as dV/ dS1 divided by dt, right.

$$i_{DS_1} = C_{gd} \frac{d V_{DS_1}}{dt}$$

Now this wide band gap devices it is having this dt very small. So because it will be operating at high frequency, then if this component, so it is expected that dt and Cgd both will be small in case of high frequency wide band gap devices. If dt is small if we try to go for very high frequency then this current component will be very high. So, then what will happen if this current component is very high then there will be a huge current which will be flowing through the parasitic capacitance to the gate resistance and the driver component and it will destroy the driver. So that is why it is important to provide protection with respect to this kind of fault. This kind of fault we can protect in different ways, so what are the different ways we can provide, so this is the problem with respect to the over current due to the turning off of the complementary switch. It can happen whenever there is a turn off of the upper switch if there is a turn off in the lower switch this kind of problem will not come mostly it will come with respect to the upper switch turning off so then we can provide solution in different ways. So this is due to the overcurrent. So the solution we can provide in different ways. So one of the solutions is by providing a capacitive path in parallel with the gate to source resistance of the switch S2. Means the switching diagram it will look like, so, we have two different switches and each switch will have their parasitic capacitances S1, S2 and we have this gate driver of S2. Only S2 component gate driver I am showing because S1 will be in turning off condition. So, that gate driver I am assuming it is not providing any signal. So, that is why I am not showing it at this moment. So, now you know that there is a capacitive component here, so which is causing problem, this is known as Miller capacitance Cgd. Then there is also a capacitive component between gate to source of S2. So, this capacitance I can represent as

Cgs2, right. what we can do we can provide another capacitance path here. This let's say the capacitance we are providing as c protection capacitance cp. Now why how this will help so whenever i am providing this capacitor in parallel with another capacitor. So, then what will happen? Whenever there will be a current component which will be flowing from S1 to CGD, then it will pass through the CP to the ground. So, this CP will provide path for this current. Now based on the current level, we can actually provide this value of Cp and it is coming in parallel with Cgs2 but there is a problem. Because, we are providing this CP in parallel with CGS2. And CGS2 or the gate to source capacitance, it is one of the main components to turn on and turn off the device. If we try to increase the capacitance, since we are adding it in parallel to gate to source capacitance. So, it is coming as kind of higher capacitance value as compared to the capacitance, which is present in the switch S2. So, then what will happen? So, these capacitance will increase turn on and turn off time because we have to charge these two capacitances now in place of one capacitance. So, then there will be a restriction of switching frequency or there will be increase of switching on and switching off time. Again, like we have to see what kind of value of gate resistance we can connect. So, that may increase the complexity or that may provide restriction in the operation of wide band gap devices. So, then we should not always use this kind of connection in order to protect the device from overcurrent. Now, there is another kind of solution, which we can use, so that is kind of active solution. This is known as active clamp. So how this active clamp is functioning? So two switches similarly, I can just show the connection. So gate is connected here and this gate resistance, obviously it will be connected like this and then this is how the gate is connected. Now, we have similar kind of capacitance path which is causing the problem. We have our gate capacitance Cgs2 as I have seen in the previous diagram. Now, instead of connecting capacitance here, we can connect another MOSFET or switch. So, this we can connect as another switch. Let's say this switch as protection kind of switch or active clamp switch. Now whenever there will be high current, so this switch control will be checking the current level or the voltage drop across this Cgd. beyond or the voltage drop it is showing it is not within the limit then it will sense that and it will activate this switch since it will activate the switch during this fault condition this switch act as short circuit. Now it will provide path for the overcurrent. So then in that time the overcurrent or the current which is coming from switch S1 so that will flow through switch SP to the ground. That way we can protect the gate. So this is known as active clamp. And this is capacitive protection. So, one of the problems is that it will increase the current in this path, it will be very high, it will destroy the circuit. Another problem is that the current which is flowing through RG to VG, it will increase voltage drop across the gate. So, if there is a condition switch S2 is also off, we are not providing any gate signal. So, then what will happen? This voltage drop can cause the threshold voltage of the gate voltage to go beyond the minimum value means if threshold voltage is provided 3 volts and in case of this high current if the voltage drop across Rg that increases or the voltage drop across gate to source, it increases beyond the threshold voltage, let's say it is 4 volts, then what will happen? It will turn on the device, turn on the lower device. So, that is known as false triggering. So, in that case, so this will happen if we are providing gate voltage 0 to some positive value. So, there is a chance that it may go beyond the threshold voltage during this kind of fault condition.

So, in order to protect the device from that kind of condition, so during the turn of time we can provide negative voltage. So, this you already know for silicon generally we provide gate voltage from 0 to let's say 15 volts or in that level right and during the turn off condition voltage will remain 0 during sorry turn off condition voltage remains 0 turn on condition it is some negative for silicon. Now in case of silicon carbide and GAN it is advisable to provide some negative voltage. Now this is for like safe operation of device. Now the disadvantage of this kind of gate supply is that we need two different polarity for gate voltage. In case of silicon only we need one polarity voltage. So, that is the main problem, but if we can provide this positive and negative voltage during turn on and turn off condition then this kind of fault if it happens then device will be protected by using this kind of voltages. So, this is with respect to protection from over current during switching condition, switching turning off condition. so you can actually note down this is over current protection.

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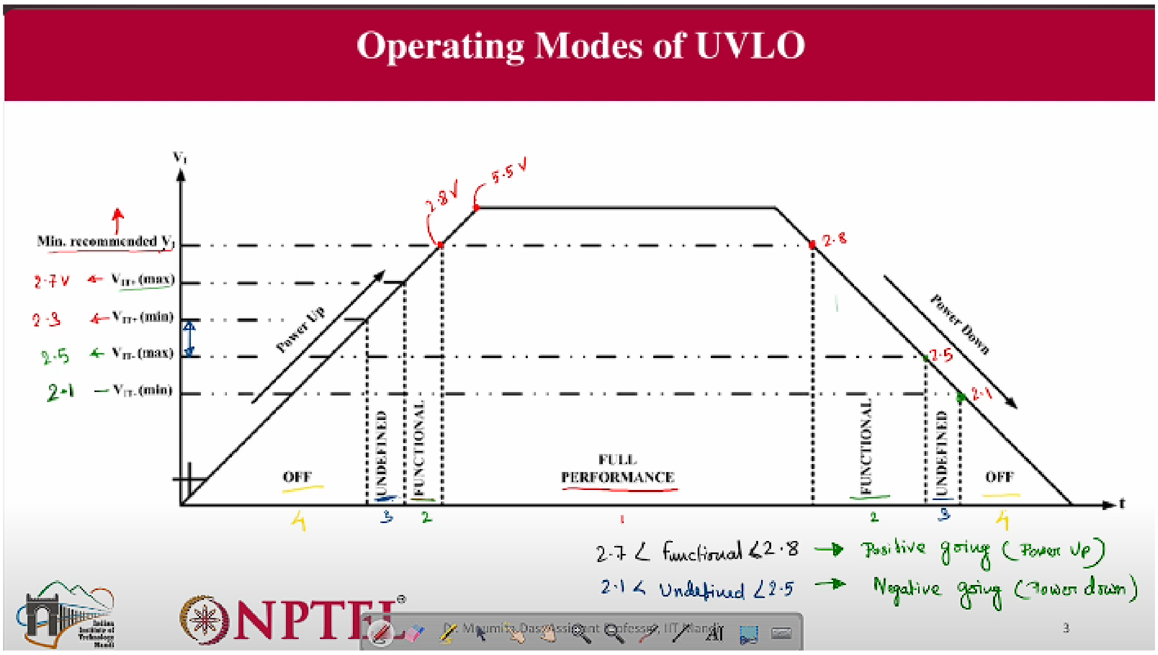

ok. now the device if this kind of condition happens device will be protected. Now there is also condition when, the device, there is no fault is happening but still there can be mal-operation. So, how that can happen? So, generally what happens? The voltage what we provide to any circuit, it may happen that there will be some fluctuation. So, now this fluctuation can cause voltage level to change. So, let's like take an example of battery supplied power converter. So, battery voltage generally varies some minimum to maximum voltage. So, if it is varying, so then what will happen? The voltage whatever is going to the circuit that will also vary. Then there can be a condition when the device whatever voltage it is getting it may not be sufficient for full performance as you can see from this particular diagram. So, this here you can see different sections are given for the device operation. So, the device you can see here in the middle portion the full performance it is shown. So, full performance it is shown. In the condition, when there is a voltage level, so there is like minimum recommended voltage is given. If the voltage level is above that voltage, then only the device will be able to operate in full performance condition. And if it is not above that minimum voltage level, so then what will happen? There are different condition. So, you can see like just adjacent to full performance condition, there are two conditions in both sides basically same condition that is functional. You can see here the functional condition. So, the second condition is the functional condition. So, you can see this is second condition, the functional condition. So functional condition where you can see the voltage rating of the device it is less than minimum recommended voltage but above certain threshold voltage, VIT plus maximum. So, this threshold voltage if it is, so that is also generally given in the data sheet. In silicon data sheet, this ratings are already given. But for silicon carbide, you may get or may not get. For GaN, you will not be able to get this kind of voltage level. So, now if it is above this maximum voltage level, so then what will happen? The device will be in functional condition. Functional but not in full performance condition means device will be operating but it will not be giving the full performance right. Now there is a condition adjacent to functional so that is written as undefined condition. So undefined condition where this device voltage you can see is between VIT plus minimum and VIT minus maximum in this particular range. So basically in this particular range this device is written as undefined. Undefined means what? The device whether it is on or off that is not known. It may be on, may be off. That depends on like many conditions so that will be difficult to predict and also say that within this voltage range what will happen. If we expect that device will be off, then it may not also happen. It may happen the device is on. So, that is why this voltage level is known as undefined. And adjacent to it, the device voltage when it is like below this IT minus minimum, so that is in off condition. So, you can see this is in off condition. So, there are basically 4 different operating region in any device if the device voltage level changes. If the device voltage level is above the minimum recommended voltage level, so then what will happen? Device will be operating properly in full performance range. You don't have to worry in that condition. But considering different situation in the converter it may happen that the device condition is changing so that then this kind of condition will happen, right?,

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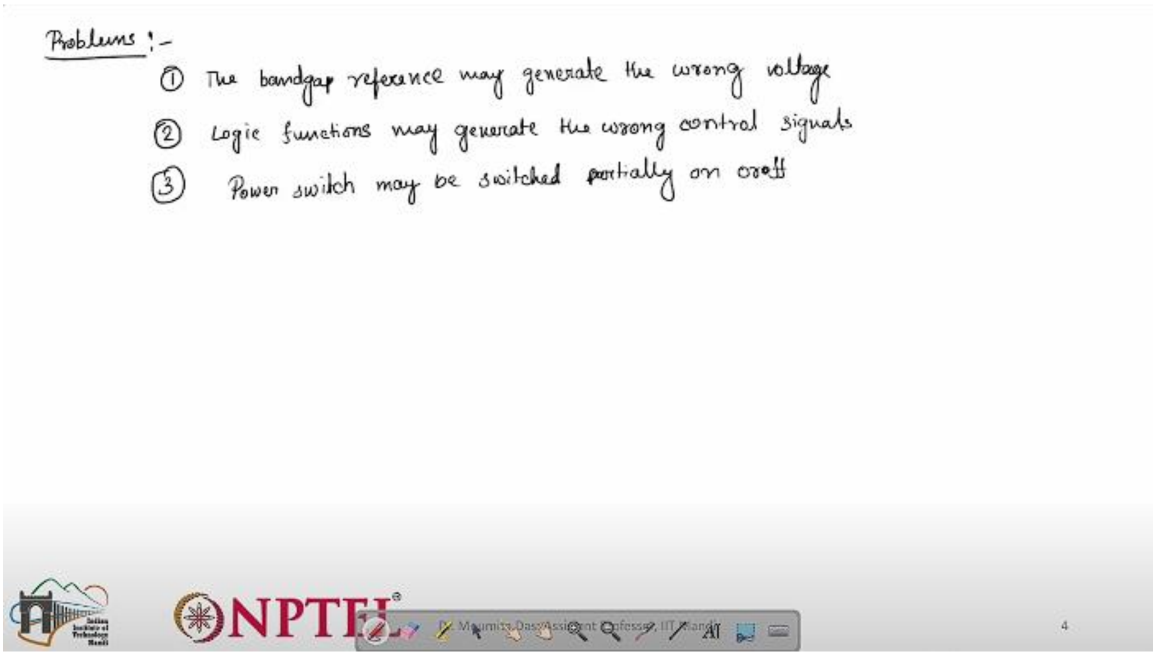

So now if this is happening, then what is the problem? Like why we have to bother about this kind of different conditions? Okay, fine, device may be functional, may not be functional in undefined condition or full performance condition. So, what should we do or what are the problems may happen? So, the problems associated with this kind of conditions are, problems will be first problem is that the band gap, this band gap reference may generate the wrong voltage. So then whatever voltage you are expecting you may not be able to get that so like say some converter is connected to some DC load so you are expecting that DC load will be having 24 volts where probably you are charging battery or something But due to this you may not get 24 volts. It may happen that you are getting 18 volts or let's say 15 volts. So then the voltage will not be desirable. So whatever you are like using it for. So that is one of the problems. Second thing is that logic functions may generate the wrong control signals. Now generally what happens whenever we are generating any control signal that takes some feedback, now feedback if it is taking so then what will happen so feedback we consider that output voltage will have some value now if it is not within the range then what will happen the control signal which will be generated that will not be appropriate so then in appropriate kind of control signal will be generated and then get turn on and turn off will also be kind of not desirable, so then again it will not give the desired output. Okay, and the third point is that power switch may be partially on or off. So, the device may be partially on or partially off. So, that is why we need to consider or some devices driver will have this feature included in it which is known as UVLO feature. So, under voltage lockout. So, this is the full form of UVLO. So, then what will happen? It will consider condition so where the device is operating properly means if there is any condition is happening in the converter due to which the device voltage is not within the suitable range. Let's say minimum recommended range is V1 so then what will happen it will consider that cycle to not operate that particular device. So, then what will happen? In the next cycle, it will provide the required voltage to the device, so that device will operate properly again. So that is known as power sighting. So basically if there is any fault or anything that causes this kind of problem so the UVLO feature will get activated and it will ensure in the next power cycle device will operate properly so that the system can be protected from the mal-operation or undesirable kind of operation which may happen due to any condition.

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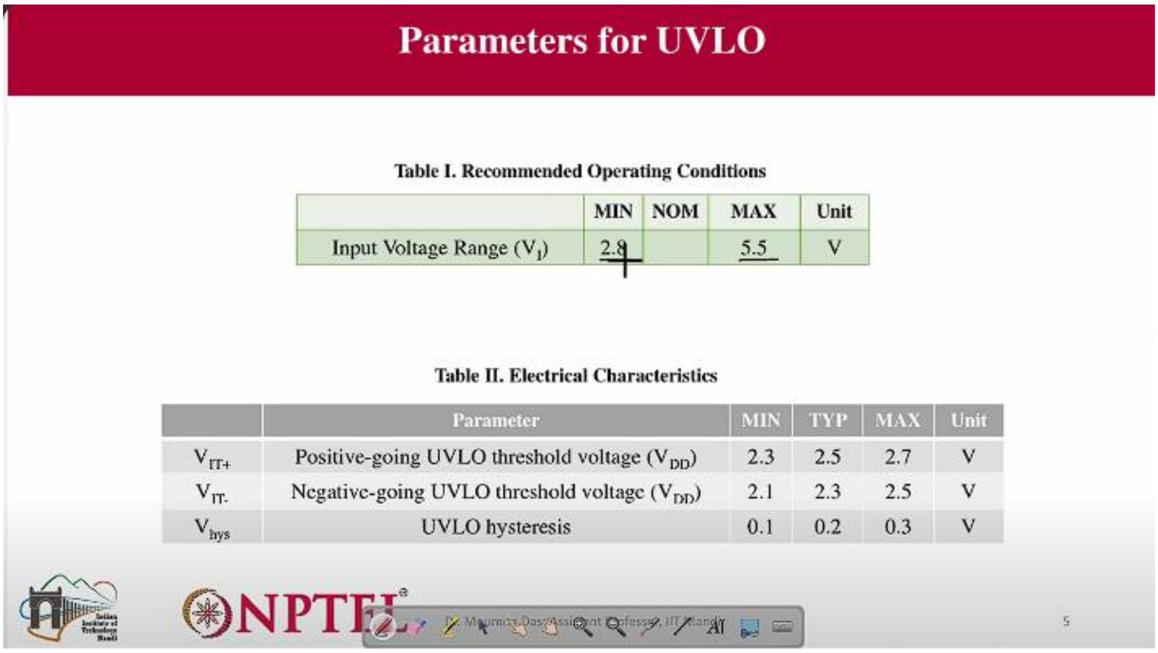

Parameters for UVLO

Table I. Recommended Operating Conditions

	MIN	NOM	MAX	Unit
Input Voltage Range (V_I)	2.8		5.5	V

Table II. Electrical Characteristics

	Parameter	MIN	TYP	MAX	Unit
V_{IT+}	Positive-going UVLO threshold voltage (V_{DD})	2.3	2.5	2.7	V
V_{IT-}	Negative-going UVLO threshold voltage (V_{DD})	2.1	2.3	2.5	V
V_{hys}	UVLO hysteresis	0.1	0.2	0.3	V

So, now these are the different parameters of ULO just to give you the example like practical kind of idea how it is. So, the input voltage range it is given minimum 2. 8 maximum 5.5. So, then you can see here. So, the input voltage minimum here it is recommended minimum voltage V1. So, it is given there minimum voltage is 2. 8. 2.8 volts so if it is above 2.8 volts so you can see the characteristics if even if it is 2.8 volts so the point will be here right so here although it is in these points but still the device will be in full performance condition so if it is like 5.5 volts then the points will be here so this is 5.5 volts and this is 2.8 volts so in both the conditions so the device will be operating properly in full performance condition. So now this is the characteristics with respect to under voltage lockout. The positive going UVLO threshold voltage which is known as VIT plus. That is given minimum is 2.3 and maximum is 2.7 volts. So you can see here, so this threshold voltage 2 point this is given minimum is 2.3 and maximum it is given 2.7 volts. So if it is between 2.7 and 2.8, so then it will be in the section 2. So between 2.7 section 2, 2.8. So, this is one condition. So, if it is within this range then it will lie in the section 2 in functional condition. Means if it is above the positive threshold voltage and below the minimum required or recommended voltage then it will be in section 2 which is known as functional state. You can see here negative going UVLO threshold voltage that is minimum is 2.1, maximum is 2.5. Then this you can see this minimum is 2.1, this I can show you in different color. This is 2.1 and maximum you can see here, this is 2.1 and this is 2.5. So, then you can see here so this is 2.5. So, this is during the negative out, so you can see here it is also written here negative going UVLO threshold voltage. So, negative going means this is positive going when the voltage is increasing, negative going means when the voltage is basically decreasing. So, you can see here, so in this particular state it is shown the voltage is basically decreasing in this particular points. Okay, then this is known as undefined kind of state. So, this section 3 you can see here. So, when it is between two, so you have to remember this particular state when the voltage is increasing, the positive going voltage, so positive going. positive going or you can see from here power up. Now if it is within 2.1 to 2.5, 2.1 to 2.5 2.1 to 2.5. Then you can see here section 3 are undefined. I can just write down here undefined. Similarly, I can write this part here as, this will be easier to understand, functional. So, this is during power down condition or negative going condition. This is during the negative going power down. Now this you can understand now. So this undefined and functional state for positive going and negative going it is for different voltage. You can see this functional state during the negative going it is basically in between the voltage level 2.5 to 2.8. Okay. So this functional state for negative going and the positive going it is different you can see from this dotted line so with respect to this you can actually point write down different voltages so here you can see this is actually it is given 2.8 and this is 2.5. and this one undefined here it is 2.1 so you can see the functional state for power down condition between 2.5 to 2.8 and functional state during the positive going condition or the power up condition it is between 2.7 and 2.8. so it is different so if you are turning off the switch then the functional state will be different and if you are turning off the switch then it will be different similarly undefined state for the power down condition it is 2 point between 2.1 and 2.5 and undefined state during the power up condition that is between 2.3 and 2.7. It is again different so and the off state will happen when it is below 2.1 volts. So here in this case, during the turning on condition off state will happen means the device will remain in off state till it reaches to 2.3 volts and device will turn off till whenever it will reach to 2.1 volts, so you can see the difference in the voltages so these two that is why this power up slope and power down slope it is you have to pay attention so uvlo where you are actually applying so when it will be applied so it should not happen that it is taking different voltages during turn on and turn off condition then there will be again mal-operation. So now another condition is given here which is known as UVLO hysteresis. So you can see here here the minimum voltage is given 0.1 volts and maximum is given 0.3 so in between it is having 0.2 volts different. So what is this hysteresis so hysteresis is something So, if there is a condition when there is a change in the input voltages then it will not immediately affect the device. So, it will wait for some time to see whether that is sustaining or not. So, this hysteresis band within this voltage level what will happen the device will not get affected. So, if it is like beyond this then the device voltage will get affected. So that is why this band is very important so that just to see just to provide protection, so if there is any change so that should not immediately affect the device. Just to protect the device from that kind of condition. Okay. So this is known as UVLO.

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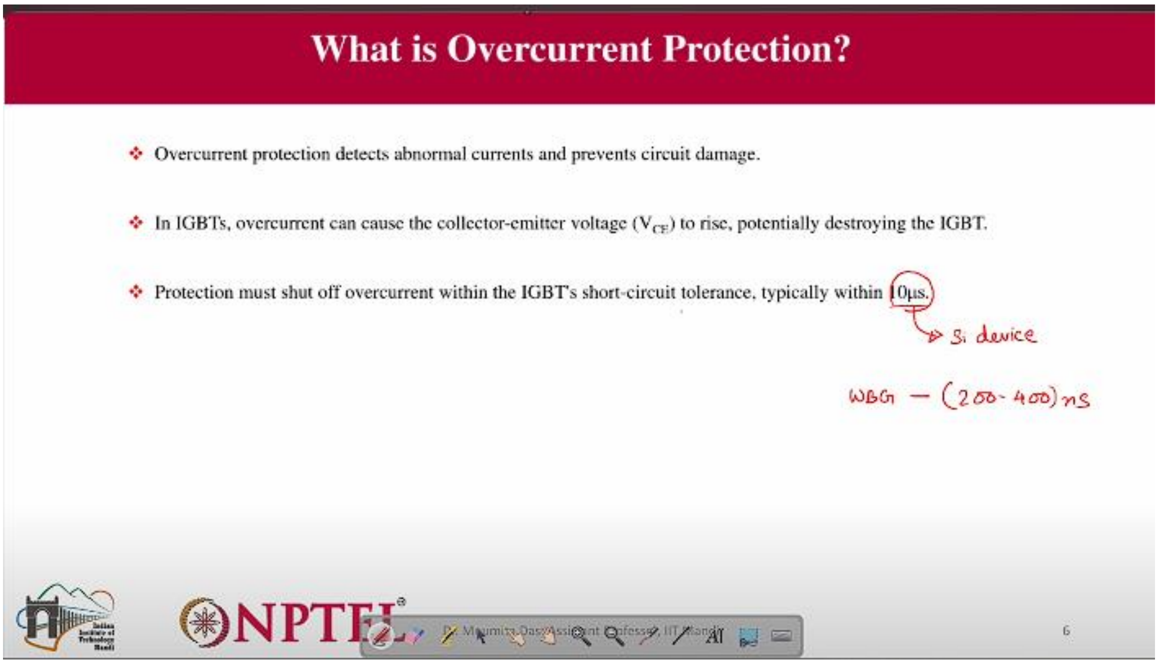

Now you have the protection in the driver's circuit. So you have given protection from the turn on on or off condition of the device from the over current part so that is different kind of over current that is due to the miller capacitance. Now that you have given the protection with respect to change in the voltage so that device operates in full performance condition always Now this kind of protection is given in the gate driver. Now if there is a condition which is happening in the converter side not in the device side exactly but eventually it will affect the device. So if there is a condition of over current, so what is this over current? So over current it can it will be generally abnormal kind of condition and it will, if there is a such kind of situation then there will be obviously circuit damage. So this IGBT over current can cause collector emitter voltage or you know in MOSFET drain to source voltage to rise and then eventually it will destroy IGBT or the MOSFET. and that is why we have to provide protection. Protection can be provided in different ways through gate driver from the converter side different ways. So we have to provide protection from this kind of conditions, so that, we can shut down the device eventually it will shut down the operation of the converter. So that over current within IGBT short circuit tolerance it is generally within 10 microsecond and this is for silicon device means if there is a condition some fault is happening due to that there is a cause of over current, so then that over current can flow through the device until this protection gets activated that can silicon device can take 10 microsecond. So within this time if protection gets activated the device will be safe. But this wide band gap devices, they are actually very delicate kind of devices. Because you know it is having intrinsic kind of characteristics and its high switching frequency operation due to that the parasitic components associated with it is very small. That is why the tolerance level of these devices is also for very small time. Means these devices can tolerate this kind of over current for 200 to 400 nanosecond around that range. So it may be slightly higher or lower but it will be within this range. So you can see here this tolerance capability of this wide bandgap devices is much much lower than that of the silicon device. So that is why we have to, like see how we can protect these devices. These devices are having different types of advantages, but this comes along with these disadvantages. So we have to, so not exactly disadvantages, the properties. So we have to look for the solution which can meet this requirement of the wideband gap devices. So, till now whatever protection is available for silicon based converter that either it is like included in the gate driver or the converter, so that takes into account this time that is 10 microsecond. But if we have to consider this wide band gap devices time, then we have to look for different other solutions. So that is why this is very important for designing of any converter.

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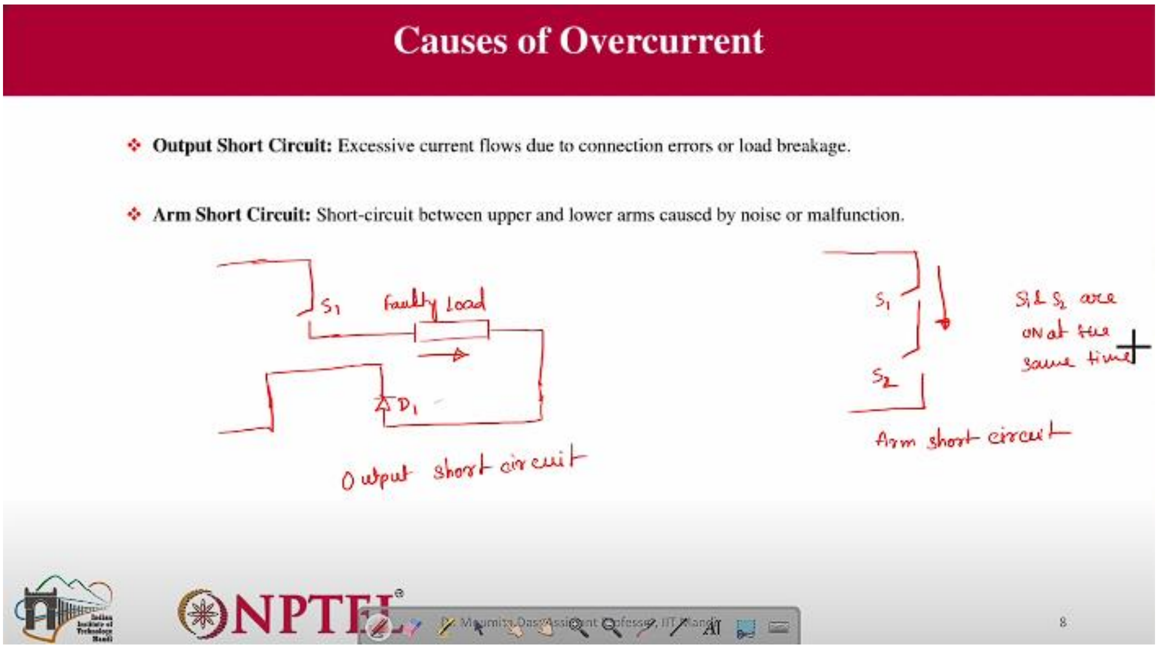

Okay. Now these causes of overcurrent. What are these causes? So these causes generally can be anything. So there is like output short circuit or arm short circuit. Means like output if there is a load connected. So somehow the load there is some fault due to that this short circuit is happening. So then there can be overcurrent. So, then another is the arm short circuit. Arm short circuit means if any leg two different switches are connected. So, let's say two different switches are connected in any leg. So, due to some reason, these two switches are on at the same time. So, then this will cause this arm short circuit. So, this is arm short circuit. Now output short circuit, if let's say this device is connected to the output some load is connected, some load, and this load is connected. So let's say and the return path of the load will be through some other device, let's say diode or switch something will be there. So then what will happen this device if there is a short circuit in the load, the device and diode, here the short circuit is between S1 and S2. Here S1 and D1 are operating fine, but the load, there is a problem in this load. So, then again it is causing short circuit. So, this is known as the output short circuit. faulty load S1 and S2 are ON at the same time.

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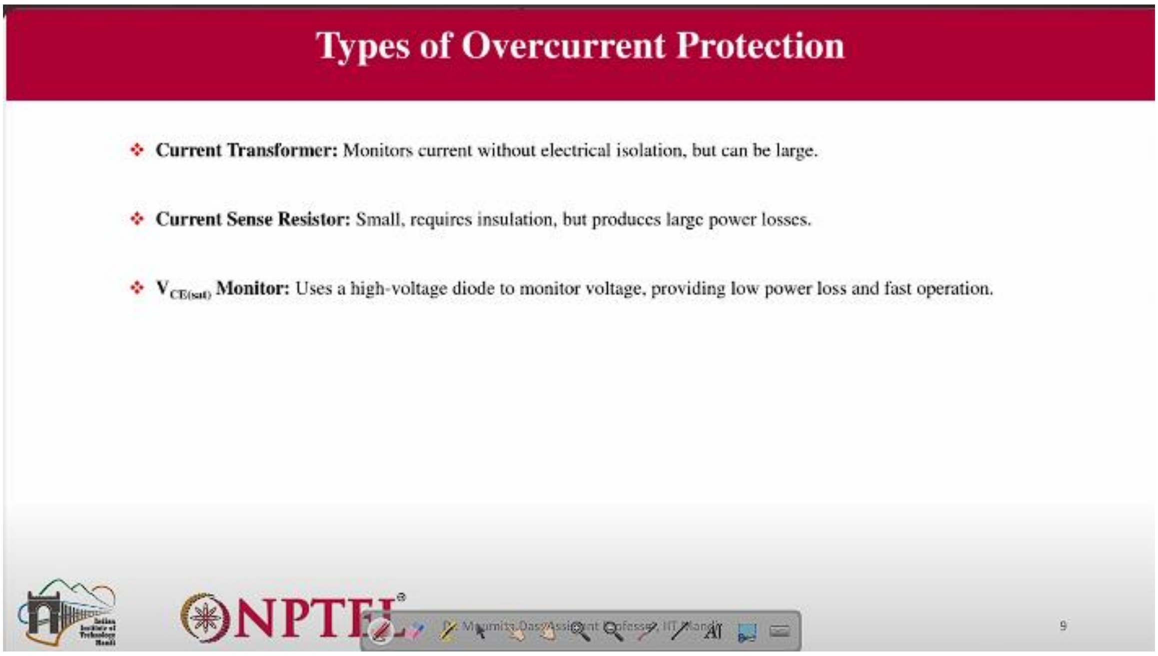

Okay, so this can cause overcurrent. Now, this overcurrent can be protect, can be actually taken care by within the circuit by using different methods like using current transformer current shunt register by monitoring VCE or VDS of the device then it can be protected.

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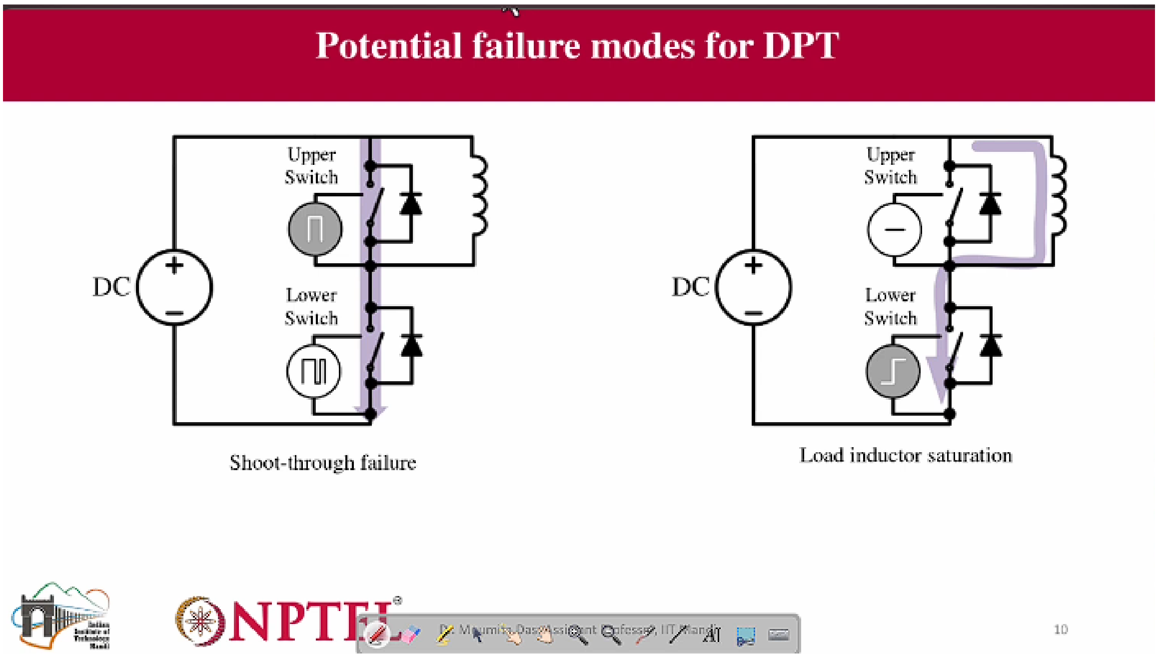

So you can see here. So, this is these are the like kind of fault, these generally happens in the DPTs. So DPT is something which we need for dynamic characterization of the device so if we consider DPT, it is like same kind of fault is happening so if two devices are ON, then shoot through fault, if there is a like condition when the there is either the load is sorted or the inductor is reaching into saturation, so then their load inductor saturation will happen so both will cause over current right. So now, this over current protection are different methods are provided using current transformer, current search register, VCE monitoring these different types of methods are provided.

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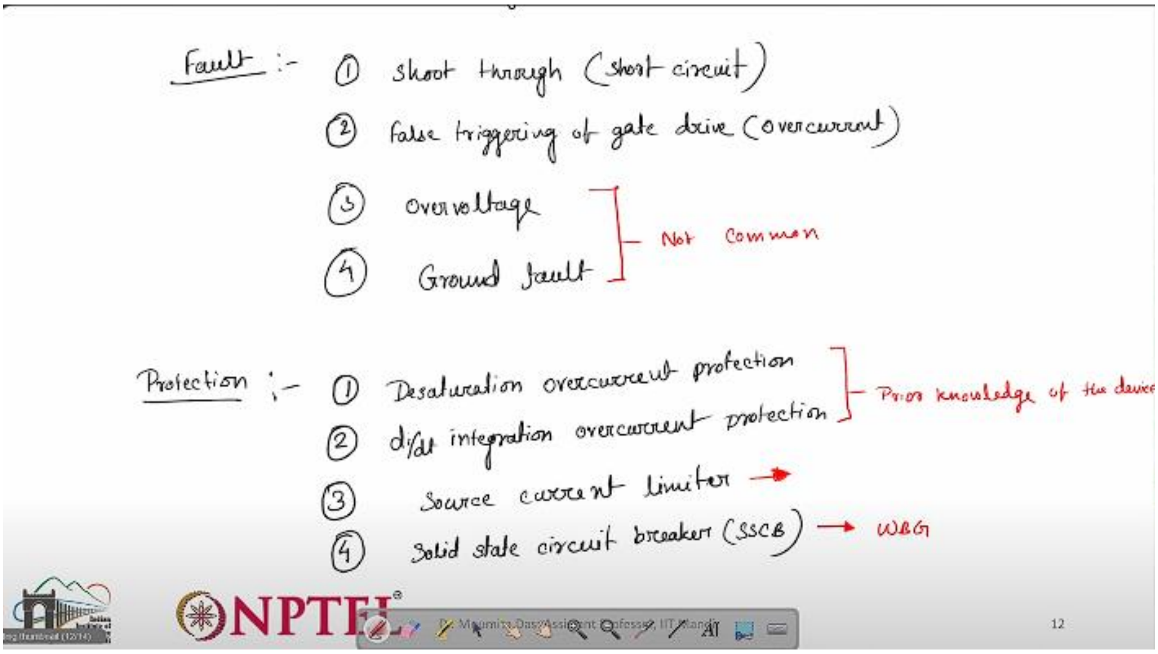

So now along with these methods, so basically the like so there can be other types of fault also so fault right now I told about only shoot through kind of fault and then false triggering of the gate drive. This is causing short circuit. So, this can be anything through like either devices or the load is faulty or inductor is reaching into saturation and this will cause over current. There are other faults which is which are over voltage. and also ground fault. Now these two faults over voltage and ground faults are not very common and doesn't create that much problem. So these two faults, I will not be discussing in details. So this is not significant. or not common. But the short circuit and the over current, these two faults are very common and this I will be discussing in details. So the method which I will be discussing for protection, they are desaturation. So in this case we have to sense either collector to emitter voltage of IGBT or drain to source voltage of the MOSFET to provide this kind of protection. Second is the DIDT integration over current protection. So, in this case we have to see the DIDT, what is the level of DIDT and that through that the over current protection will be provided. Third is the by providing current limiting in the supply voltage. Current limiting DC voltage source current limiter through the source current limiter. So if we can provide current limit in the source or from where it is like supply is provided then we can actually restrict this over current. Because it will not come from the source because current we are restricting from the source itself. So then we can protect. Now fourth is the like most common or recently used one that is solid state circuit breaker. So these the three method two methods basically the first two methods what I have shown here here we need prior knowledge of the device. We need prior knowledge and this one kind of it is like something which probably not useful for all the practical applications. So, it is not always possible to provide current limiter. So, if we are doing lab experiment then it is fine, otherwise it will be difficult to provide this kind of limiter in any practical application.

So, now the fourth one which is where we don't need prior knowledge of the device. So this will be suitable if we are actually exploring any new device or wide bandgap device. There we always don't know that what kind of condition we require because through the experimentation probably we are learning about this new device. Then by using this solid-state circuit breaker, we can provide protection for wide bandgap devices during the overcurrent condition. This overcurrent can come from shoot through or the false triggering of the gate signal. So, then this can be used. So, I will be discussing in details of this in the next lecture.

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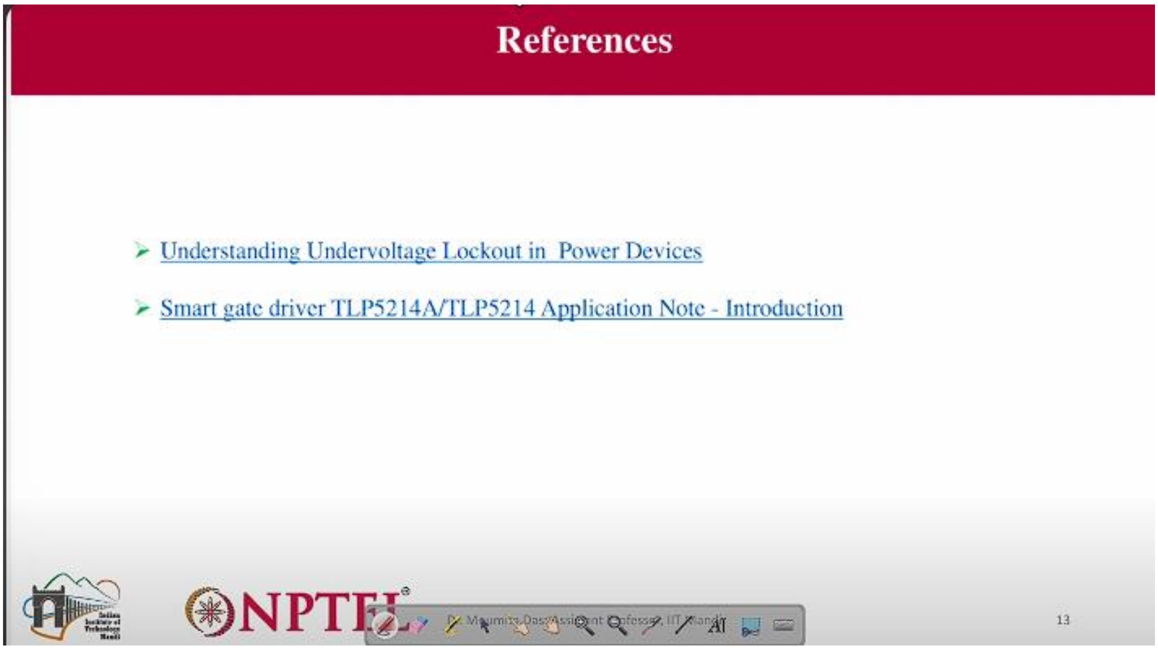

So these are the references for different this under voltage lockout protection and this drive about the driver and the book already I mentioned in the previous lecture that you can use in order to understand different types of protection of the DPT circuit. Thank you.