Power Electronics with Wide Bandgap Devices
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Lecture-8
GATE DRIVE FOR DYNAMIC CHARACTERIZATION - Continue

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Hello welcome back to the course of power electronics with wide band gap devices. Today, I am going to continue the discussion of gate drives and going to discuss details of the gate drives parameters.

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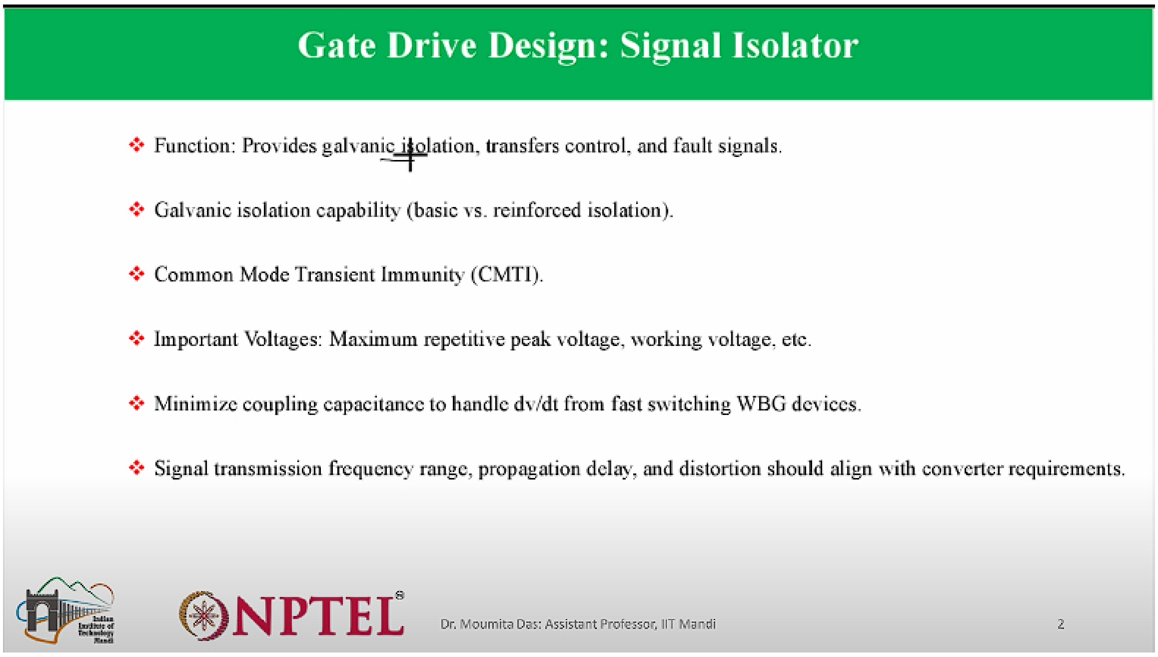

So as you know the first component which I have shown in the previous lecture that is signal isolator. So, in gate drive design that is the first component which comes just after the microcontroller. So, what is the function of this signal isolator? Why we need to provide the isolation? So, the main thing is that we it provides galvanic isolation. So, galvanic isolation it provides some potential difference between the input and the output. So, this is very important so that it can actually transfer the signal which will be getting from the microcontroller to the power circuit. So, that transfers the control signal and then it actually separates the fault signal. So, that fault signal will be separated through this isolation process. So, if there is a fault in the microcontroller side, then that will not be transferred to the power converter and again same way, if there is any fault in the power converter side. So then it will restrict the transfer of that particular fault to the microcontroller side. So that is why we need this isolator. Now this galvanic isolation capability, so basic versus reinforcement isolation is that, so basically it can provide basic potential difference which will be like maximum potential difference can come in the device, so that can be selected based on the rating of the device and additionally we have to consider the transient parameters. So basically if there is any ringing or any oscillation, so that this should be able to handle that. So the isolation potential should be more than the device voltage rating and it should also have common mode transient immunity. So now if I consider a wide band gap devices it is supposed to operate at high frequency. High frequency means there will be a problem of dv/dt, di/dt. So this transient immunity capability should also be included in this signal isolator. So, the important voltages are the maximum peak repetitive voltage, working voltage, etc. Minimizing the coupling capacitance to handle the divinity from fast switching wideband gap devices. So, this property should be included in this signal isolator. so signal transmission frequency range propagation delay distortion should align with the converter requirements. So these are the parameters of signal isolator. So when we are going to consider it for wide band gap devices all these parameters should be taken care of or it should be provided in the data sheet of the signal isolator, that it should be it should have sufficient this parameter so that we can use it for wide band gap devices Now, how the signal isolator looks like?

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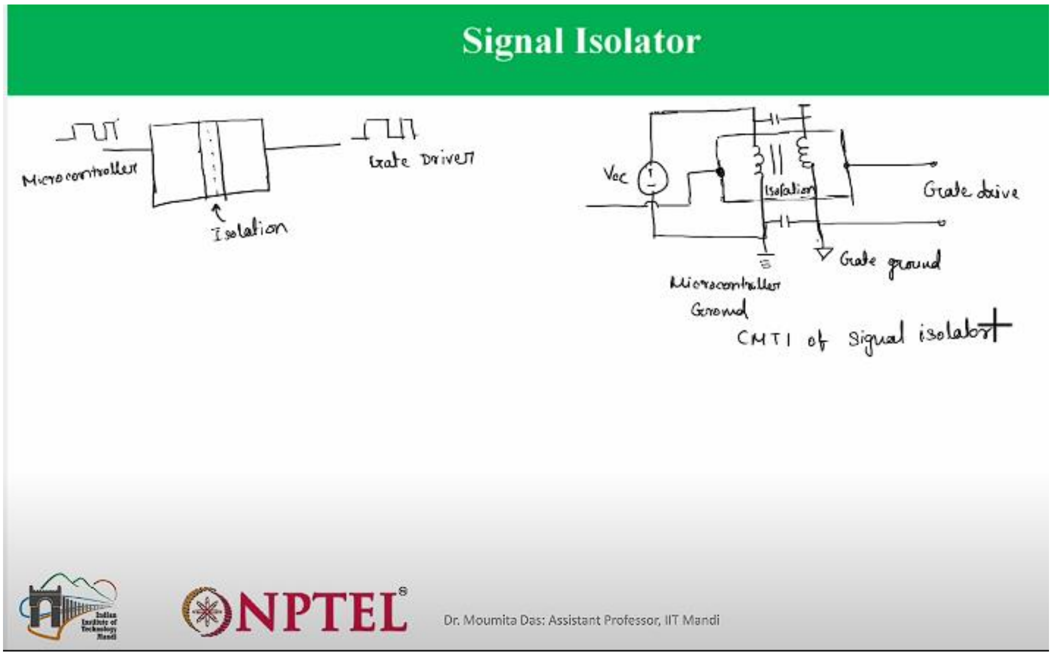

So, basically whenever we get any signal from microcontroller, so the microcontroller signal it will be in the lower voltage level as I have discussed in the previous lecture. So, it should be either let us say 3.3 volts, 1.8 volts or 5 volts. So, now this voltage we provide through to the signal isolator. Now signal isolator it will have isolation and output we will be getting similar voltage. So this will be from microcontroller or intelligent controller or FPGA anywhere like, which will have this signal generation capability. So we can get it from the function generator also. And it can then pass it through the signal isolator. Then it goes to the power converter side or the gate driver. So this will go to the gate driver. And this is the isolation. So now one property is that, it should have isolation another property is that it should have common mode trans it should have basically you can see here sorry you can see here common mode transient immunity. So these two factors should be there, first is isolation this galvanic isolation and common mode transient immunity. So these two properties are the basic property along with it additional things are required for wide band gap devices, those are important but those are not essential but these two properties are essential in signal isolator. So then if we if i consider this common mode transient immunity, so then how this circuit should look like so basically if we have any circuit which is having isolation. So, this is the isolator what we are talking about. So, it is, so if we have any transformer kind of structure, so then it will just provide isolation. Now, what we have to do for this common mode transient immunity? For that, basically this kind of capacitors are connected and this will have so this this will be connected to a power supply, it's a positive voltage VCC is connected here and then microcontroller output, it will be actually connected in this midpoint then which will be giving output this midpoint to this ground. So, this will go to the gate drive. So, this is actually serve as input of gate drive. Ok? So, this is the ground of gate and this is the ground of microcontroller. Gate ground and microcontroller ground. So these two ground should be different. So there should be isolation between these two ground. So that there should not be connection between the input and the output. So these are the two requirement for signal isolator. So this is the circuit for common mode transient immunity of signal isolator. So, this is generally provided within the signal isolator chip. So, we just need to look for the properties which we will be needing for any particular device.

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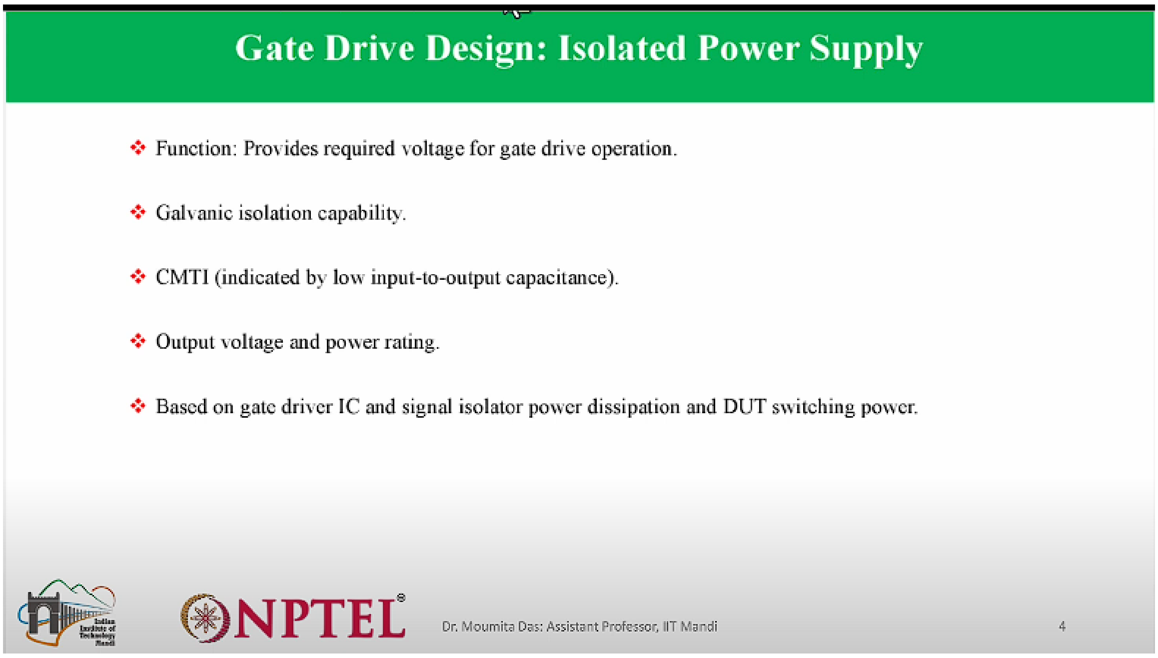

Now, next is the isolated power supply. So, we have seen signal isolator so that provide isolation to the signal. Now, we have another component which is isolated power supply. So, why this isolated power supply is important? So, this provides required voltage to gate drive. So, basically both signal isolator, gate drive and if we have decoupling capacitor, if that need power supply so that will come from this isolated power supply. So it provides required voltage to each component and also it should have galvanic isolation capability. Along with providing required voltage, as you know microcontroller voltage is around 3. 3, 5 or 1.8 volts, so that will not be suitable to drive the switch or the device. So that device, if it is silicon then it should have rating let's say 0 to 15 volts is for silicon carbide minus 2 to 15 volts and for GaN minus 4 to 6 volts. So, anyway it is not equal to any of the voltage level. So that is why we need to amplify the voltage as I have discussed earlier. So that voltage supply will come from this isolated power supply. Along with providing this required voltages, it provide galvanic isolation and additionally it also should have this same common mode transient immunity. So that there should not be any ringing or anything will be transferred through this isolated power supply and previously through this signal isolator and it should match with the output voltage and power rating based on the gate driver IC signal isolator power dissipation and DUT switching power. So what should be the rating of this isolated power supply? So that rating depends on different factors. So, this output power rating, so basically this isolated power supply provides power to all the component of gate drive. So, all the component means first is the signal isolator. So, then it should have power rating which is greater than signal isolator plus, gate drive power. So, whatever power will be dissipated in the gate drive plus the power loss in the switches during the turn on and turn off. So, this is true, this comes from the switch part. So, this switch power it will actually loss in the switches. switch during the turn on and turn off.

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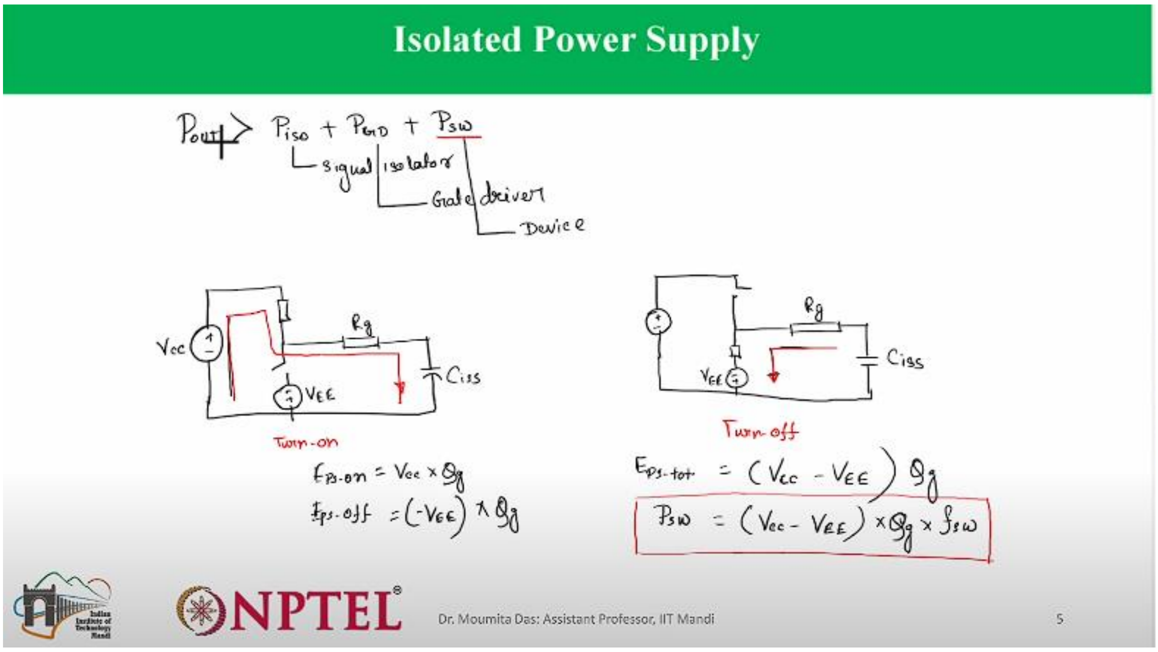

So how this looks like? So as you can see, so this you can understand it comes from signal isolator, this from gate driver and this comes from the device. So, gate driver and signal isolator probably you understand. So, it is like to function these components, these power supplies, power losses will be there. Now, with respect to the switch, how it looks like? So, whenever any switch turn on or turn off, so if I consider two different supplies, so let's say Vcc is the positive voltage. Generally, for silicon carbide and GaN, we need two different power supplies.

So, then this will look like, so basically when the switch is on the current will flow through the gate resistance Rg and then this will go to the capacitance of the switch, input capacitance of the switch Ciss. So, the and this particular, so if there is any negative supply which we need for this wide band gap devices, so then this negative supply will not be in working condition, this particular loop will not be in working condition during the turn on condition. So, the current will flow from the positive supply through the gate resistance to the input capacitor. So, this is during the turn on time. Now, during turn off time this positive supply will not supply power to the input capacitor. So, basically in this time what we will see? We will see input capacitance should discharge and until and unless this Ciss is discharging the device will not turn off. So, then this discharge should happen through the gate resistance, Ciss and this will flow through the negative supply. If it is connected to ground then it will flow through the ground. Okay. So this is the current flow direction during the turn off time. This is during turn OFF. So, you can understand now how the currents are flowing in both the situation due to this current flow. So, this VCC and VEE, this comes under isolated power supply. If we need only one supply then probably VCC will be sufficient for silicon only one supply is required positive supply. So, then VCC is sufficient for GaN and silicon carbide, it is preferred to have negative supply also so that is why this VEE is also shown here. So now during this charging and discharging process there will be power loss and that power loss will happen through this gate resistance and the resistance which will be coming in the path as I have shown in the blocks. So, this through these resistances their power losses should happen. So, this power loss is considered as the switching loss. So, how we can quantify this loss? So, during the turn on time, so during turn on time the energy which will be required, so that we can actually denote as positive supply voltage multiplied by charge required to charge this input capacitance

$$E_{PS\text{-}on} = V_{CC} \times Q_g$$

and during the turn off time, so this will be negative supply since it is negative so this minus sign is coming multiplied by same charge need to be dissipated.

$$E_{PS\text{-}off} = (-V_{EE}) \times Q_g$$

So now this charge is dissipating so the total energy which will be required in this particular process so turning ON and OFF the gate so that we can represent as multiplied QG.

$$E_{PS\text{-}tot} = (V_{CC} - V_{EE})\, Q_g$$

Now, if we have to get the power loss which will be equal to PSW which I have shown here this PSW. So, this PSW equal to this VCC minus VEE multiplied by QG gate charge and switching frequency.

$$P_{SW} = (V_{CC} - V_{EE}) \times Q_g \times f_{SW}$$

So, as you can see from this expression, so this expression shows, this loss, switching loss depends on the frequency of operation, supply voltages isolated from the power supplies and the gate charge required. So, these are the components are related to the switching loss and this output power rating of this isolated power supply should be not only more than the switching power loss, but also in addition to that gate drive power loss plus isolated, signal isolated power loss. So, this all these factors will come. So, this should be the rating of the isolated power supply, ok.

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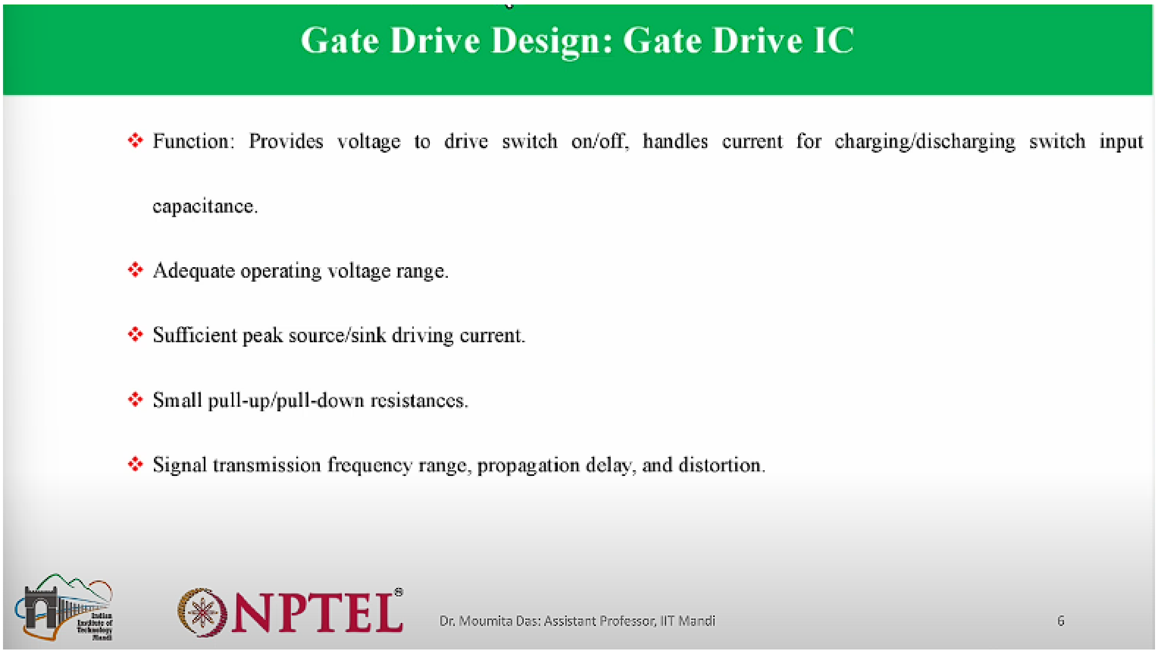

Now, this isolated power supply will be supplying power to both signal isolator and gate drive. So, now what is gate drive? So, gate drive, so if we consider any car, so it is basically working as a main engine. So, signal isolator, it is basically working as steering wheel and then isolated power supply, it is like petrol or gas tank and then gate drive is the main engine. So, this is actually main component which is providing voltage to the gate. Before it there will be definitely other components will be required, but ultimately this will be directly connected to gate. So, it provides voltage, so, it provides voltage to drive switch ON or OFF. So, this is the main component which is coming before the switch or the gate which we know. So there it will be connected. So it handles the current for charging or discharging. So because it provides voltage to switch ON and OFF, so then what should be the rating of this gate drive? So then, this voltage rating of this gate drive should be more than the supply voltages. So, that should be more than. So, if we have two supplies. So, then VCC minus VEE. So, this gate drive voltage should be this. Now, it is since it is providing current for both charging and discharging. VGD is greater than Vcc minus VEE.

$$V_{GD} > (V_{CC} - V_{EE})$$

So, then current rating also matters here. So, then what should be the current rating? So, the peak current the source or sink, the peak current of gate gate peak current should be less than Isource or sink.

$$I_{G(peak)} < I_{source}/I_{sink}$$

So Isource and sink should be able to provide the required gate current. So this required gate current will be equal to this VCC minus VEE and whatever resistance, gate resistance either it will be external resistance or the internal resistance or the resistance of that particular supply path.

$$I_{G(peak)} = \frac{V_{CC} - V_{EE}}{R_g}$$

So all will come here as the gate resistance. So this peak value depends on the resistance and the supply voltage supplies and this peak voltage sorry, so I will just make it capital otherwise it look like, it's different component, so this gate current should come from the power supply. So the power supply should have the current rating more than the gate current. So that it should be able to provide that much current. And obviously also the voltage rating should be more. So, these are the different components of the gate drive. So now it should provide the adequate operating voltage range. It should provide sufficient peak source and sink driving current. And in addition to that this gate drive IC it is desired to have small pull up or pull down resistances. So this resistance plays very important role in the turn on and turn off process. And this signal transmission, frequency range propagation delay, and distortion this also need to be considered in this particular IC.

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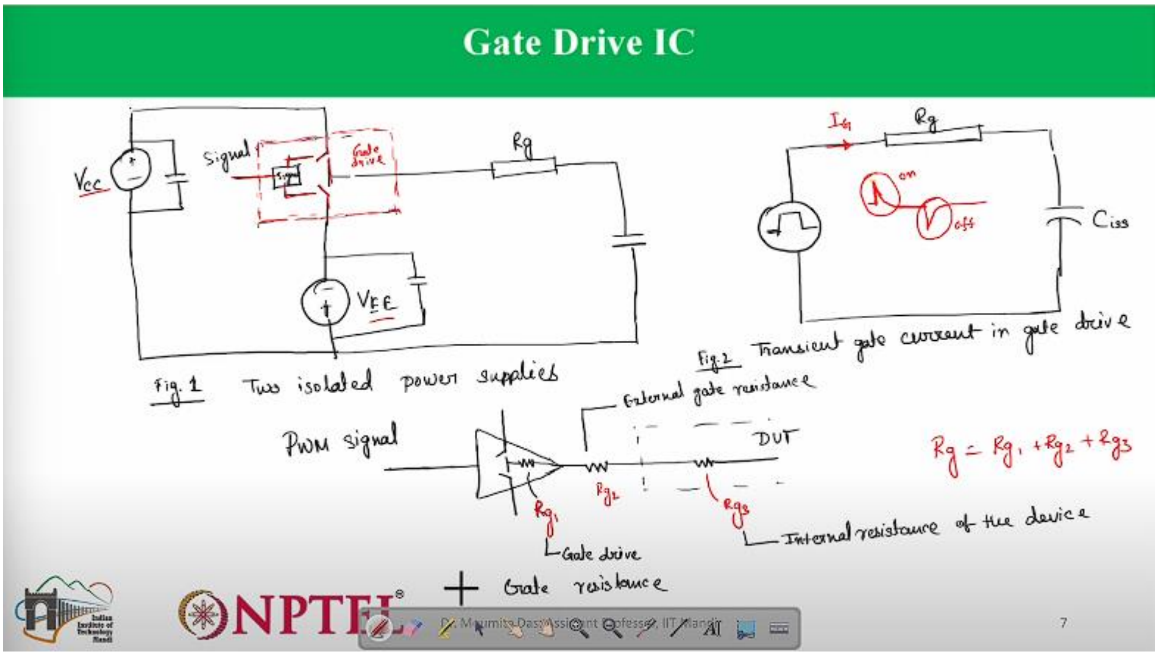

Now, this gate drive how it looks like. So, basically when we are talking about any gate drive, so, inside the gate drive there are basically switches. So, if I consider the positive supply voltage here. So, generally what happens across each supply there will be decoupling capacitor. So, that it can restrict any noise from the supply to go into the particular component. Now this will be connected to the gate drive IC. So now this gate drive IC will have two different switches. Okay. So now these two switches will be connected to signal isolator, signal or signal generator. So basically signal will be going into these two switches. Okay. Now this is your signal. I hope you can see this. So this entire thing, so let me draw the block in different color so that it will be visible to you clearly. So the entire thing comes under this gate drive. So this output of this gate drive will be connected to gate resistance and then, here if we have any like negative supply, this will be connected here, as I have shown in the previous slide VEE. so we can represent the same terminology here and again there will be one capacitor, decoupling capacitor will be connected across it, and this will be connected to input capacitors similar diagram as I have drawn in the previous slide. Only thing is that gate drive part is shown here. So gate drive part what are the things there, so two switches you can see are connected back to back okay and one signal is basically from signal isolator signal is going to this different switches. So, based on the signal type whether it is like high or low, so this gate drive accordingly will provide the output and the voltage level will based on the voltages which are connected here. So, if it is high the voltage level will be with respect to VCC, if it is low voltage level will be with respect to VEE. So, this switches of this gate drive component, it just provide this ON and OFF signal. And it amplifies based on the power supplies. Okay. So this is basically two isolated power supplies are provided here. Power supplies based gate drive. So now we can have like one isolated power supply. We can also, if it is like only one switch then we can think of like non-isolated voltage regulator. So different things can be connected. So now when we are providing gate drive so then what is happening, so output so we will have this kind of signal going from gate drive to the switch. So then there will be resistance Rg. Now this gate it is going to the capacitor. So this since it is providing the gate current, so the gate current here it is IG. Now, IG peak I told you. So, this should be like VCC minus VEE divided by RG. So, this gate current how it should look like? So, it is initially assuming this capacitor will be in uncharged condition. So, then high gate current will be there. So, then this will be picky in nature. So, it will look like so initially there will be high gate current and then eventually it will go to 0 and then what will happen when the capacitor will turn off. So, that time the current will again be high in the opposite direction. So basically just let me draw it without the scale. So it should look like, so the capacitor initially when it is charging high current is there when it is discharging there will be high current so this is during let's say ON and this is during the OFF condition, so these two currents will be there and that is why it is important to see what are the peak rating. So basically this peak point you can see here this peak point what is the value of that our power supply should be able to provide that much peak current okay. so, Now, you know about this gate drive circuit and the current rating, the voltage how much it should be, current how much it should be. Now, you can see here the gate resistance it is shown as Rg. Now, Rg is not that simplified kind of resistance. So, it comes from different parts from the gate drive. So, how it will be like we can divide. So, let me just write down this as Rg. Okay, so how this resistance is coming? So, there are actually three parts in this particular resistance. So, when we provide this PWM signal, PWM signal we are providing from signal generator or microcontroller or FPGA anything. So, then it goes to the gate drive. So, gate driver will have obviously, this is having, sorry, two different obviously switches inside it as you have seen in the diagram, so it is having like two different supplies. So, you can see here three resistances are coming. So one resistance Rg which we can actually, so there is another resistance let me draw it. So this will be part of the device, the third resistance. So let me write these three resistances as Rg1, Rg2 and this is Rg3. So now these three resistances are coming from three different parts. So first is this, this particular Rg1, it is coming from gate drive. So this is from the layout inside like how this gate drive layout is inside any particular chip. So from there one resistor resistance is coming so that can be also considered within this Rg. Now RG2 is external gate resistance, that we are connecting external gate resistance. that from the data sheet we can see that how much it can be connected. So based on that and based on our frequency of operation, we can connect this resistance. Now Rg3 is something which will be there inside the device. So this is part of the device. I can also write down as device under test. So you know this already DUT. So this Rg3 is internal resistance of the device. So you can see here so Rg is basically equal to Rg1, Rg2 plus Rg3 and which is known as gate resistance. So when we connect any resistance externally then we say that is external gate resistance but it comes under gate resistance and this is something we are representing in all the diagram as Rg. So you can see here, so I can write down this is the resistance, gate resistance. So this is figure 1, this is figure 2, this is figure 3. So these are the different component of the gate drive.

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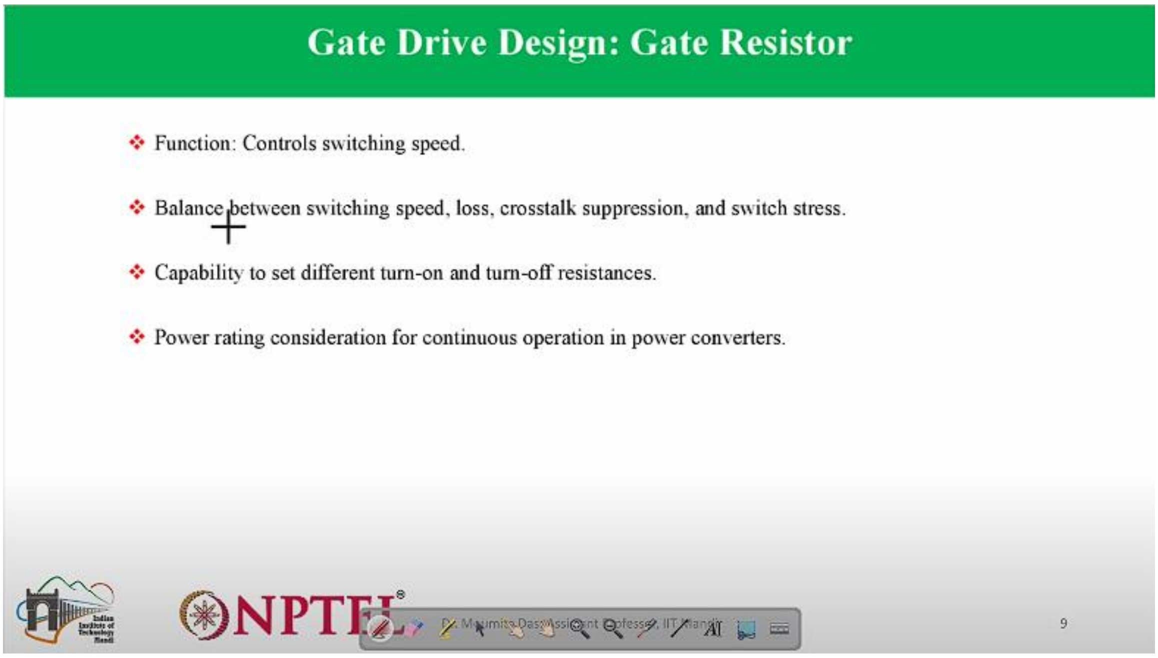

So gate drive once you have gate drive then what comes next? So that already you know that is the gate resistor. So gate resistor it main function is to control the switching speed. So, if it is fast, if the like frequency of operation is very high, then the gate resistance will be very small. So, again like there will be some optimum value required for the operation, otherwise there will be problem of ringing and oscillation if the resistance is very small. So, that is why we have to balance between switching speed, loss, crosstalk separation and switch stress. So, these are the parameters decides what should be the optimum value of the gate resistance. Okay. This capability to set different turn ON and turn OFF resistances. So when I say get resistor, so till now you have seen only one resistor which is connected right? So the same resistor, so if I go to the previous slide so then you can see here the same resistor is basically using for turn ON and turn OFF time, so the capacitor input capacitor the charging of the capacitor is through the resistor charges. Similarly when it is discharging it is also discharging through the same resistance, right then if we have the same resistance then what will happen? then the optimum point will not be able to achieve. So if it is possible to set different turn on and turn off resistances then probably we can achieve the optimum value optimum value, operation point so the power rating consideration for continuous operation in power converters is required. So basically power rating depends from the obviously the power converter rating.

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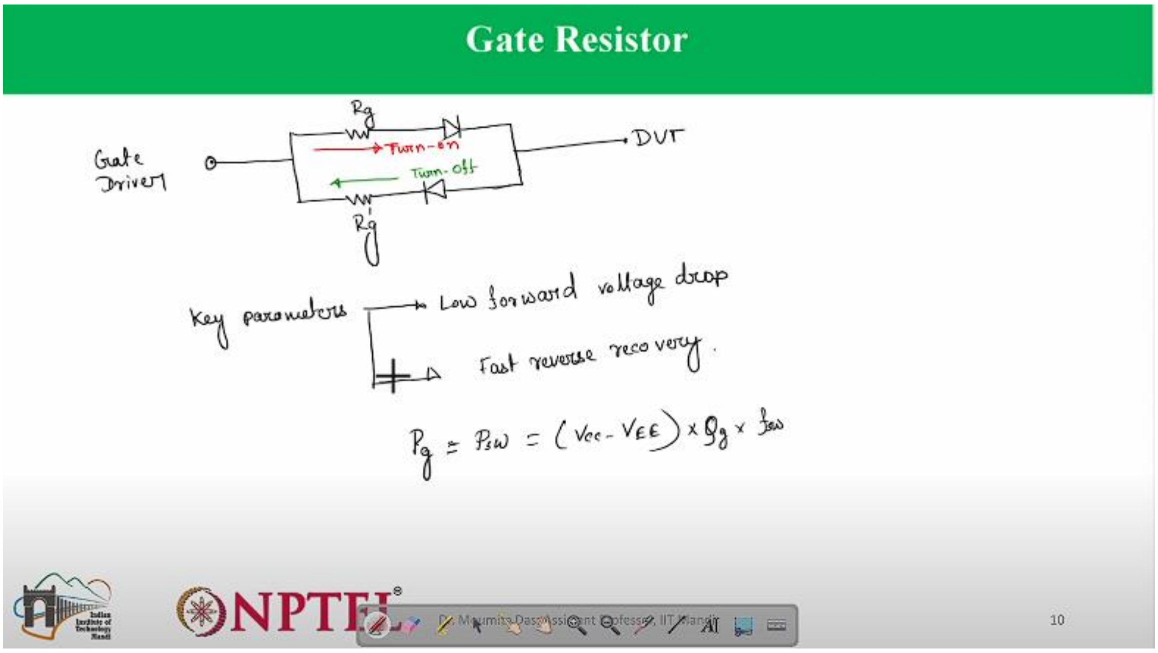

So now if we have different gate resistance. So basically during the turn ON, we can have like resistance let's say Rg which you have already seen. So this will be connected in series with a diode so that it will provide path only for the turn ON time. Now similarly, we can have another resistance which we can actually denote as Rg'. So this can provide path for the discharge of the capacitor. So basically the path for turn ON it will come from here. Similarly path for turn off it will come from here. So these are the two different resistances we can consider and it will provide the optimal value. So this is input will be connected to basically the output of the gate driver. and this output will be going to this device under test. Okay, so we can have two different resistances the main thing is that the key parameter which we need to consider in this gate resistance is so basically, we have to see that forward voltage drop is low and fast reverse recovery. So, based on this, we can actually select two different value of the resistance. So, fast reverse recovery obviously then like we have to provide the resistance which probably will not be equal to the forward conduction. So, the power rating of this resistance, power rating should be depending upon the converter. So, it should be equal to which we have discussed earlier switch power loss. So, that you have already seen. So, it is equal to VCC minus VEE. So, these are the supplies of the gate driver IC multiplied by the charge required for the input capacitance multiplied by the switching frequency.

$$P_g \approx P_{sw} = (V_{cc} - V_{EE}) \times Q_g \times f_{sw}$$

So, this should be the power rating of the gate resistance that we need to consider. Now, you know what are the parameter we need to consider for the gate resistance. Now, another thing is the decoupling capacitor. So, this is not mandatory, but it is always good to have decoupling capacitor in any circuit. Why? Because it provides an energy for gate current pulses during switching transient. So, switching transient means like during the turn ON and turn OFF time. So, there will be transient oscillation, ringing, high like high current, high voltage. So, that can come from this decoupling capacitor. Generally, what happens? This power supply is isolated power supply is or actual power supply that will be placed far away from this like gate driver or any particular IC. So, if we have decoupling capacitor it will not only decouple the ringing which will generate from the supplies or anything at the input also it can provide the switching transient. So, basically it should have sufficient voltage rating and adequate capacitance to maintain the stable gate voltage. So, we have to provide the stable gate voltage even during the switching transient. So minimized ESL is preferably using surface mounts ceramic capacitors and parallel configurations. So now how these capacitances are looking like.

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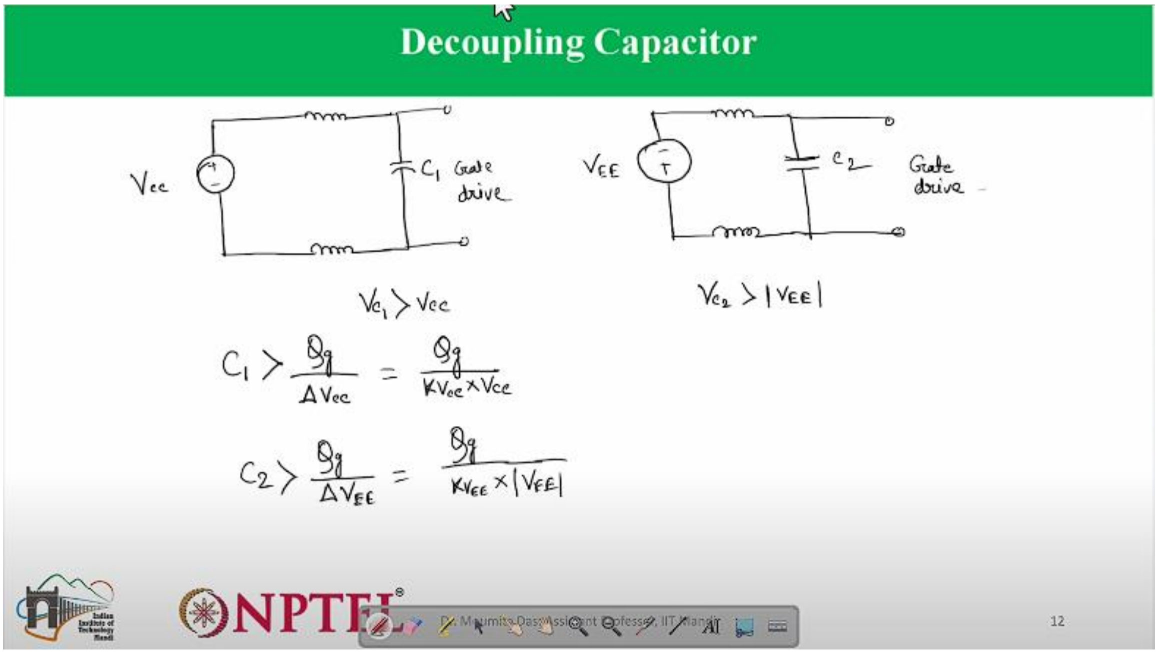

So you have seen two different voltage supplies for the gate drive, so if we have two different voltage supplies, so how it is like looking like, so basically we have VCC, so whenever we are connecting VCC to any driver or the signal isolator or anything So, then what happened? Due to the connection layout there will be parasitic inductance will be coming in that particular path. Inductance, resistance everything will come like maybe the values will be very low. Due to this inductance, due to the resistance what will happen? The losses will be there. But due to the inductance there will be parasitic ringing. So, then that ringing can be suppressed by using this decoupling capacitor. So this is the decoupling capacitor which is connected across VCC. Let's represent it as C1. Now similarly, we can have similar type of decoupling capacitor also connected across the negative supplies If at all we are having negative supplies, so then that anyway I have represented V in terms of VEE for wide band gap devices. So, that we can connect to another decoupling capacitor. So, this should be negative. So, then this will be and then this output will be going to the gate drive. Similarly, here also it will be going to the gate drive. So, initially how was the situation? So, there so in the previous also in the previous diagram I have shown this decoupling capacitor. So, either you can connect decoupling capacitor then the like ringing and all this thing you can minimized or you like remove you can remove this also, but it is always advisable to connect decoupling capacitor for high frequency operation. Okay. Now what should be the value of this capacitor. So the value of this capacitor obviously as you can understand from here VC1 should be greater than VCC because VCC is providing the stable voltage but if there is any transient condition, so that transient part should come from this decoupling capacitor. So that is why this voltage rating of this decoupling capacitor should be more than the positive voltage or similarly VC2 should be more than the negative voltage magnitude. Okay. So, these are the voltage rating of this decoupling capacitor. Then how to select this capacitance value? We can connect any capacitor but again like connecting big capacitor may cause different type of problem. So, what should be the optimum value of this decoupling capacitor? So, that comes from so basically charge requirement. So, C1 should be greater than or equal to, so let's say greater than, so it's always good to choose higher value, greater than equals to QG. divided by delta VCC.

$$C_1 > \frac{Q_g}{\Delta V_{cc}}$$

So, if there is any variation in the voltage in the input supply, so that we have to consider and the charge required, the QG remains same, it is the charge requirement for the input capacitance of the gate. And similarly, so we can represent this as QG. Qg divided by K multiplied by Vcc multiplied by Vcc.

$$C_1 > \frac{Q_g}{\Delta V_{cc}} = \frac{Q_g}{K_{V_{cc}} \times V_{cc}}$$

So, there will be some like factor like how much we want to keep this delta VCC. So, that we can consider 2 percent, 3 percent or 5 percent. So, based on that you can actually select this capacitance value. So, from there this capacitance C1 can be calculated. Similarly, C2 can be calculated from the same equation.

So, only thing is that in place of VCC we can use VEE. So, this equal to QG. C2 greater than Qg divided by delta VEE equal to Qg divided by K multiplied by VEE multiplied by mod of VEE.

$$C_2 > \frac{Q_g}{\Delta V_{EE}} = \frac{Q_g}{K_{V_{EE}} \times |V_{EE}|}$$

So this is how you can select the decoupling capacitor value and the rating. Okay, this is the reference for this different parameter of the gate drives. Thank you.