High Power Multilevel Converters – Analysis, Design and Operational Issues
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Lecture – 38
Basics of Gate Driver Circuits

Hello, everyone today we will study Gate Driver Circuits for IGBTs or for power devices. So, this whole gate drive circuits actually is a very big subject because there are many types of power devices like Thyristors, IGBTs, MOSFETs all of them will require gate drivers. However, in line with this course I will keep this discussion within IGBTs and MOSFETs only, I mean the gate driver circuits for IGBTs and MOSFETs only.

Another reason why we have done like this is like we also see that in near future IGBT and MOSFET is going to play the most dominant role as the preferred power electronic device. So, it is; so that is why we are putting our focus on the gate drive circuit designing for this devices IGBTs and MOSFETs.

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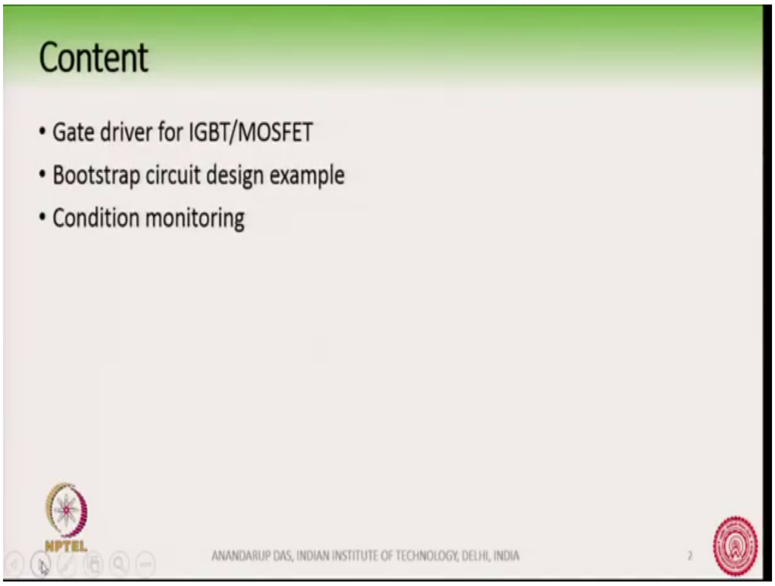

Now, so, the gate driver for IGBT and MOSFET we will this we will cover. And then we will also see a little bit of bootstrap mechanism and although not exactly part of it, but we would also kind of like cover a little bit of condition monitoring because they are somehow related with each other this gate drive circuits and condition monitoring of power devices. And we will also take a small example of an IPM along with this ok. So, the first question that comes up is why do we need a gate driver circuit?

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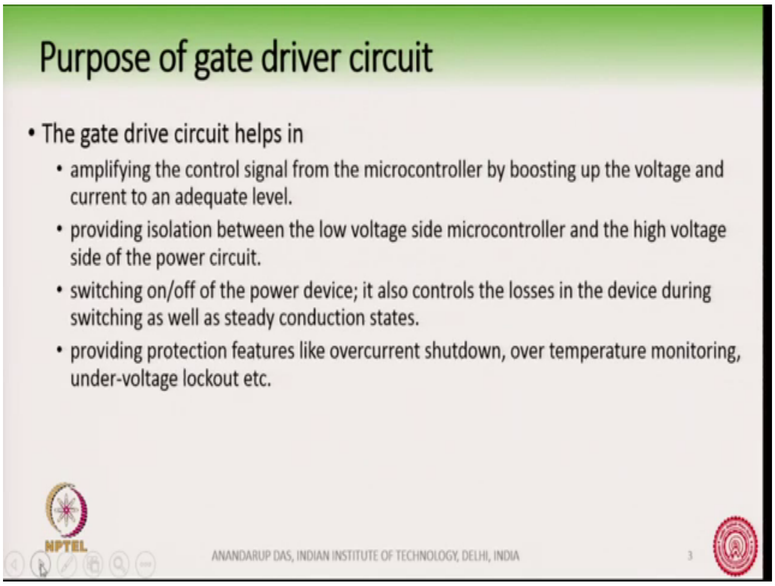

Now, many power devices they are like this IGBT or MOSFET they are high they are handling high power at a very high voltage ok. And often the gate current or the gate charge required by these devices they are quite substantial. Many times we see for example, that the gate current required by an IGBT or sometimes a silicon carbide MOSFET also can be several amperes 2, 3 amperes the peak gate current can be such high values.

Now, this high current cannot be always supplied by microcontrollers. Microcontrollers generally they operate at a low voltage and the IO pins or input at output pins they are often unable to provide large like this several amperes of current ok. Also often these IO pins are probably say around 3.3 or 5 volt output and the gate driver requirement for the power devices will often ask for like a 15 volt supply.

So, there should be an I there should be an intermediate stage kind of like a buffer which will amplify the control signal from the microcontroller to an appropriate level suitable for the power device and the gate drive circuit does this job.

So, it is kind of like an intermediate buffer which amplifies the voltage and current level. So, this is the first functionality of a gate drive circuit. The second important functionality is isolation, the control side is often at a low voltage and users may be accessing parts of the control system which is connected to the microcontroller. Whereas, the power side may be several 100 of volts or maybe kilo volts or we have seen that in our course.

So, from the safety point of view from the operator an isolation is often required, the isolation is provided by gate driver circuit may be through a transformer isolation or may be through an optocoupler isolation like that. So, gate drivers are often essential from the safety point of view.

Thirdly the gate drivers have actually can control the switching on and off of the power device, how fast the power device can turn on or turn off, the gate drivers have control over that. And that will again determine what is the switching loss in the device and hence the efficiency of the converter. Not only the switching transitions gate drive can also control what is the say steady state for example, what is the collector emitter voltage across the IGBT at steady state or what is the eventual RDS on of the MOSFET which has been turned on.

So, these values are controlled or can be manipulated using the gate drive components ok. And so, this is also one more important function and modern days gate drive are circuits along they come with a gate driver IC. And they can provide you a lot of additional features and more in most importantly they can provide you many protection features like over current shutdown over temperature under voltage lockout etcetera.

These protective features as provided by these gate driver ICs are often very useful while running the converter. And as a result the gate driver circuit is one of the most integral, one of the most important and integral part of any power circuit design.

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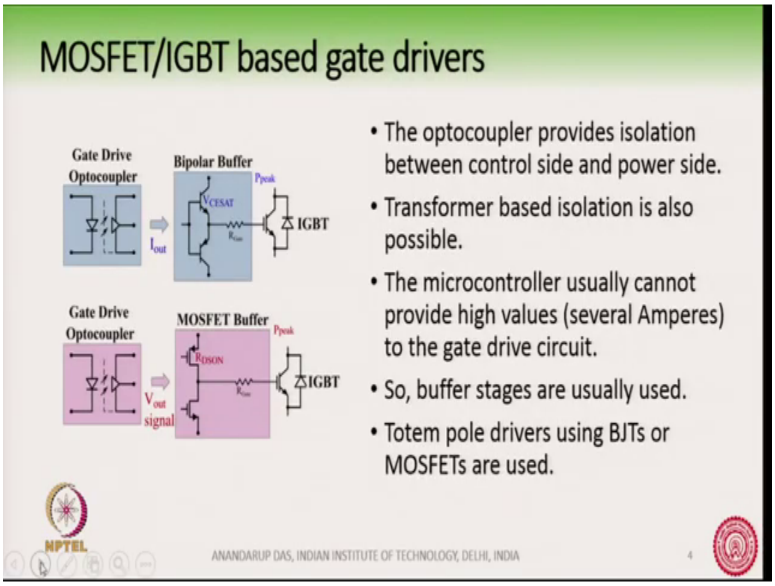

So, what are the possible gate drive circuits? Generally these gate drivers can be classified into like a bipolar or BJT based or a MOSFET based as you can see in the diagram here. You can see here that there is an isolation stage and then there is a buffer or driving stage and here is our power switch, we have taken an IGBT here. The IGBT and the MOSFET they are driving part or the gate side is very similar ok.

So, we will see that most of the things that we discuss is equally applicable for both IGBT and MOSFET. Now, here on this diagram you can see that there is an optocoupler here which is providing the isolation and here there is a BJT in a totem pole configuration and driving the IGBT ok. So, this totem pole configuration can be also made with a MOSFET it can be made with a BJT. And this is the stage which amplifies the voltage and the current ok. So, this is the buffer stage.

Now, both BJTs or MOSFETs can be used, BJTs are cheaper whereas, MOSFETs are faster. And modern day like people are slowly adopting the MOSFET based buffer in particular for silicon carbide MOSFETs people are shifting towards the MOSFET based buffer.

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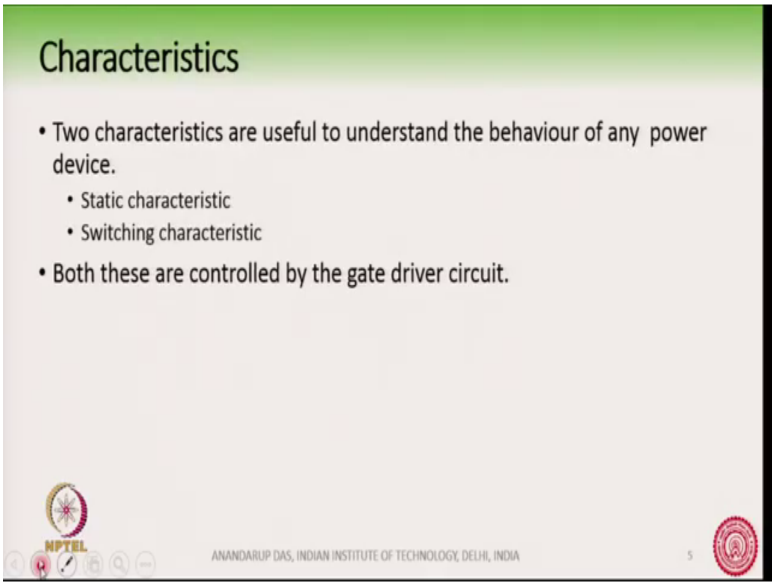

Now, there are two important characteristics that we must remember when we understand the behavior of any power device; one is the static characteristic and one is the switching characteristics.

And both of them can be controlled by the gate driver circuit what is the static characteristic. Static characteristic means what is the steady state condition in the power device; that means, when the device has fully turned on or when the device has fully turned off what is the behavior of the device? Of course, when it is fully turned off except for a very small leakage current, we can assume that the device is almost like an ideal switch; that means, it is fully cut off.

Whereas when it is fully turned on the device is not an ideal switch in remember in power electronics at least in modern times we treat or we try to emulate the power devices to behave like a switch, that is on or off switch nothing intermediate because at the intermediate level the power device will have a lot of loss. So, we would like to either put it fully on or fully off.

So, that the loss is minimum across the power device. Now, when does device or the power device is fully turned on there are non idealities and the main non ideality is the voltage drop across the device or in in case of an IGBT or the RDS on which also translates to a voltage that is the drain to source resistance of the MOSFET.

So, these non idealities will cause conduction losses during normal operation when the device is fully turned on and what is the switching characteristics? Switching characteristics is the transition from on to the static characteristics and from the static characteristic to the off.

So; that means, switching characteristics happens when the device is turning on and when the device is turning off. So, we will first see the static characteristic. How do I know what will be the behavior of the device when it is fully turned on?

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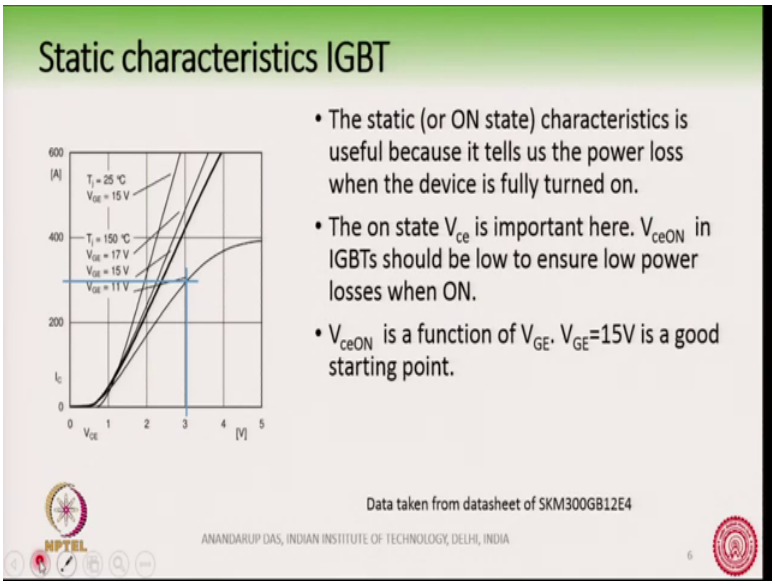

So, in order to understand suppose we take an example of an IGBT first, here we see a curve of the collector current IC versus V CE that is the collector emitter voltage. Now, initially the device is turned off, so there is no current flowing and V CE is 0 when the device has been fully turned on and it is conducting current. Then you can see that across the collector emitter junction or across the collector emitter terminals of the IGBT there is a voltage drop and this voltage drop is a function of IC; that means, when IC is changing V CE is also changing.

Ideally in an ideal device this V CE should have been 0, but being this being a non ideal device there is a finite value of V CE and this V CE times IC is the power loss in the device when it is fully turned on that is the conduction loss. Now, as you can see this data is taken from one of the manufacturers datasheet a SKM300GB12E4 this is a 300 ampere 1200 volt

IGBT. So, this is a data this data has been taken from the datasheet of this we have taken the curve from there.

Now, one thing you observe here is that V ceON is a function of V GE, you can see here several curves and these curves change according to the gate emitter voltage. So, the gate emitter voltage is what is controlling the collector emitter voltage ok. So, more is the V GE or higher is the value of V GE you can see that for a specific value of IC higher values of V GE will cause a lower value of V CE ok.

And so this gives us a clue that V CE, V GE should be sufficiently high. So, that the V CE on should be low when the device is fully turned on because we want to reduce the losses. So, here you can see two examples I have taken say IC equal to for IC equal to 300 ampere if the V GE is 11 volt then we are operating somewhere here whereas, if V GE, so somewhere here which means the V CE is about 3 volt here. On the other hand if for the same current IC about 300 ampere if the V GE that is the gate emitter voltage is 15 volt, then I am somewhere here and this point which is about maybe 2.2 volt, the V CE.

So, therefore, this tells us that V GE should be sufficiently high usually 15 volt V GE is a good starting point for these devices that is also recommended in many of the application notes and data sheets. At this point I would like to mention that for understanding this lecture or to supplement this lecture you should see many datasheet and application notes that this is a very big source of information and you should go through them very carefully. There are lot of datasheet and application notes available in the web and you should go through them.

So, this is what we said that V GE is. So, if the gate emitter voltage is 15 volt, then we can it is a good starting point, so it is like somewhere here. Too much of high value of V GE even if you go V GE more than fifteen volt it is possible definitely and V CE will go smaller and smaller. But then you will see that very high value of V GE will during the short circuit condition of the IGBT the current through the collector emitter will be very high ok, I the V GE is very high. So, there is therefore, a compromise here.

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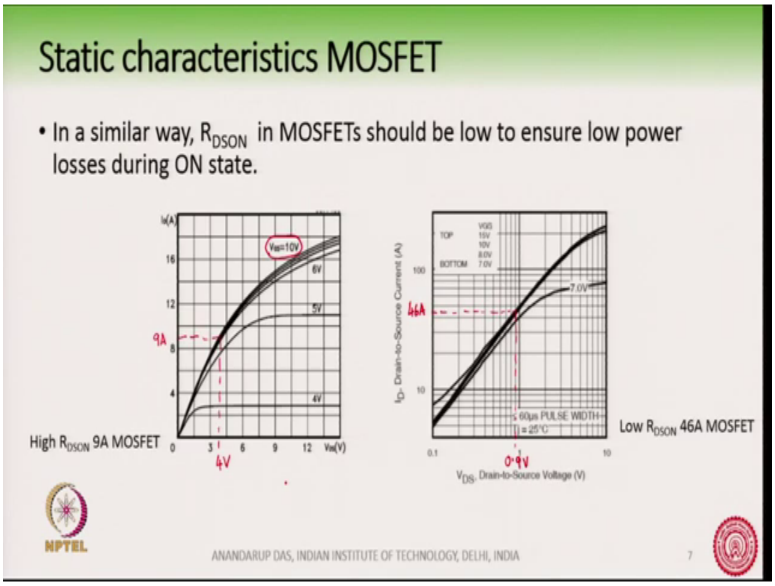

In a similar way for a MOSFET also the same phenomena happens. Here we have shown two curves from the datasheet of two MOSFET; one is a 9 ampere MOSFET and the other one is a 46 ampere MOSFET. And again we are trying to plot I D versus V DS, here also I D versus V DS. Here you see for example, suppose for this MOSFET 9 ampere we are saying, so we are somewhere like here 9 ampere and you can see here the V DS may be roughly around 4 volt; 4 volt here and 9 ampere here ok. For a V GS value maybe we can take a V GS value of 10 volt ok.

Now, for this 46 ampere MOSFET you can see here that suppose again I take a V GS of 10 volt, so it will be on this curve here. You can see that for the rated current of say 46 ampere, so 20, 30, 40. So, we are maybe somewhere here we are somewhere here. So, this is where the VDS is which is about 0.9 volt ok.

So, clearly you can see that the right hand side characteristics the MOSFET having this right hand side characteristics is having a 0.9 volt only as compared to about 4 volt for the left hand side MOSFET characteristic. So, therefore, the right hand side one the MOSFET the 46 ampere MOSFET has will have much less conduction loss when the device is conducting as compared to the left hand one and this is something which must be kept in mind.

So, this is the steady state characteristics where you should be always seeing that where is your device operating. Again it will depend on the load line where is the load line and where you are exactly operating on the load line. So, you will have to see that where is the device operating ok.

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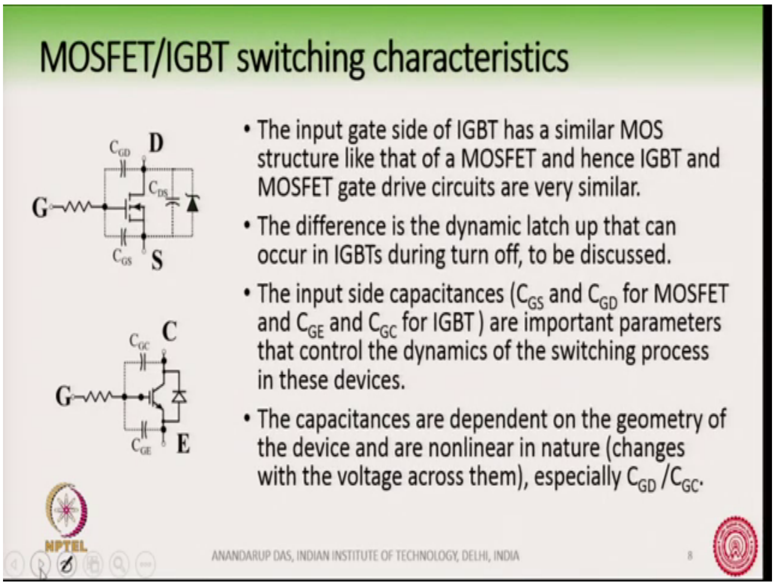

Now, next comes the switching characteristics ok. So, we have covered the static characteristics and we are now looking into the switching characteristics. Now, as you can see we have shown a MOSFET here drain, gate, source and collector, gate, emitter here for the IGBT.

Now, the input side of IGBT has a very similar MOS structure like that of a MOSFET and so IGBT and MOSFETs have gate circuits which are very very similar. The gate drive circuits or the analysis for the gate drive circuits are more or less same for both IGBT and MOSFET. There are some differences of course, like there is a dynamic latch up that that can occur in IGBTS during turn off, but relatively speaking they are very similar, the gate drive circuits for IGBTs and MOSFETs are very similar and they can be often interchanged.

Now, the input side capacitances. So, here you can see that there are capacitances C GD, C GS, C GC, C GE ok. So, they originate from the structure at the or the geometry of the device ok. And the basic idea of the switching characteristic is that we have to charge or discharge these capacitors. So, from the circuit point of view without going into the physics of operation of these devices, if we look from the circuit point of view we can say that these capacitors are the most important components and these capacitors the way we charge them or the way we discharge them how fast we charge them how fast we discharge them, the whole switching characteristics of the device is dependent on that ok.

So, these are the important parameters to keep note of and we will come repeatedly to this. Now, unfortunately these capacitances are not fixed values and they are non-linear in nature because as the voltage is getting applied the capacitors are changing their values ok. How it happens? If you go into the physics of the device you will be able to understand I would I would not like to go into that, I would like to restrict myself to the fact that the capacitance values is changing with the application of the voltage across them.

So, this capacitor for example, this GD, C GD or C GC they are highly non-linear in nature ok. So, this is the challenge how do you charge or discharge the capacitors in a fast time where the capacitances are non-linear in nature.

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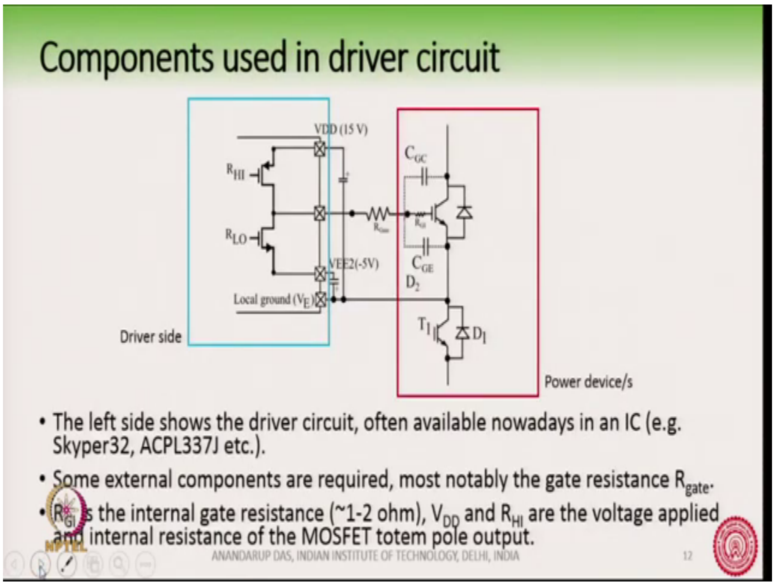

Now, before we go into the turn on and turn off phenomena, I would like to say that nowadays these gate drivers come in some form of a circuit or which is again controlled by a gate driver IC ok.

For example, Skyper32 is a gate driver board or something like that, ACPL337J is a gate driver IC ok. So, what is there inside this IC? Basically these IC have this totem pole MOSFET or BJTs along with several protection features, we will talk about those protection features.

So, you can see here I have tried to show the 2 sides; this is the driver side and this is the power side. So, this is the half bridge IGBT here this is the power device with two transistor two IGBTs. And you can also see here there is a gate collector capacitance and gate emitter capacitance here and this is the driver side. In this driver side we have the totem pole

MOSFETs and some additional components like these capacitors or this gate resistor which we have inserted as an external component ok.

So, this is this black this red box here this is the inside the power device. So, you will see here there is an internal gate resistance about 1 to 2 ohm and also you will see that for the driver side we have a V DD of 15 volt here there is a 15 volt VDD and also there is a minus 5 volt at the this side at the bottom ok.

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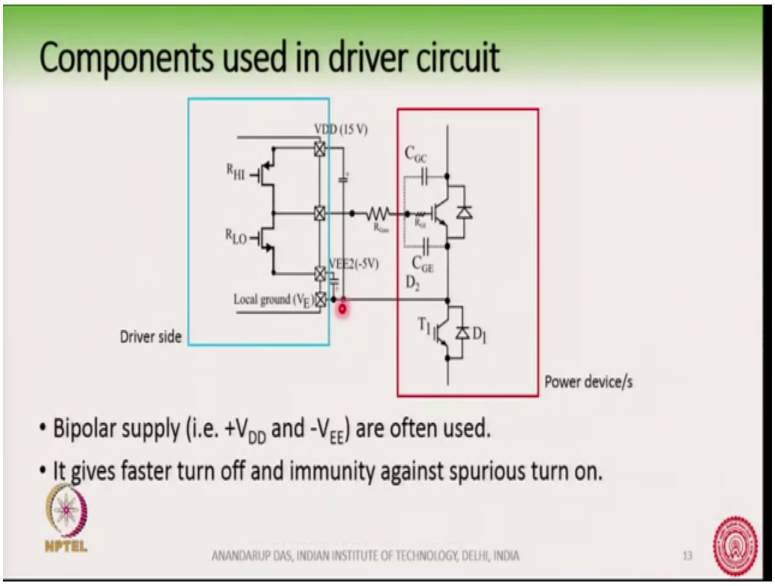

Why minus 5 volt, we will discuss in details at some point of time you will understand that the gate driver.

So, what we are trying to do here? Yeah, we are trying to charge these capacitors up. Now, we can charge this to 15 volt this is through the VDD 15 volt we will charge it through like this.

So, the charging process will basically be controlled by this R C element here. And when we want to the this will turn on the IGBT here basically we are charging this up through this R C here when we want to discharge when we want to turn off the device we will discharge the capacitor.

Now, the discharging of the capacitor will be happening like this, through this capacitor and through this resistor and like this the circuit gets completed like this. Now, when we want to discharge it we would like to discharge it at a negative voltage there are certain advantages. First is if you discharge it to a negative voltage, then it will give you faster turn off and there will be also immunity against spurious turn on we will discuss that sometime later. But you should understand that basically we are trying to charge these two capacitors up these two capacitors we are trying to charge up.

And when we are turning on the device, the V GE voltage we will go to V DD or about 15 volts right V DD is this voltage here. When we are turning off the power device then we will discharge this capacitor, but we will discharge it to minus 5 volt that is this minus V EE or minus 5 volt here and there are advantages related to it.