Design of Power Electronic Converters
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Lecture 10
Diode Characteristics

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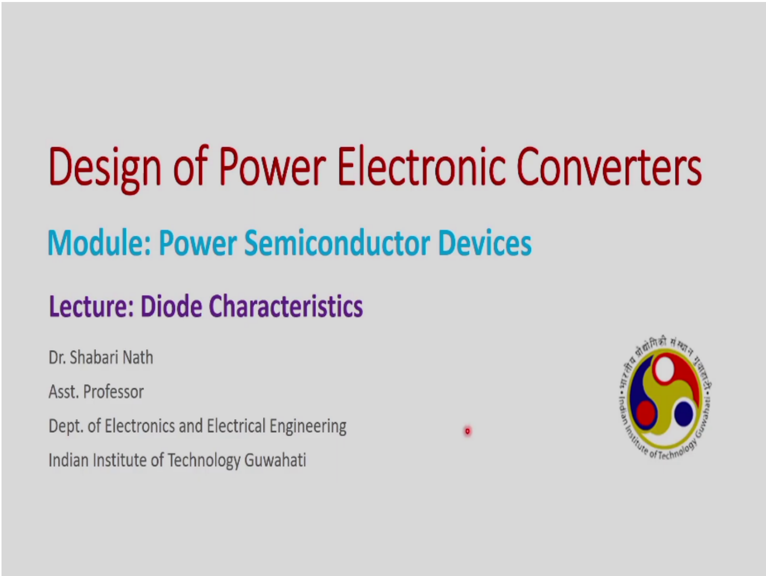

Welcome back to the course on Design of Power Electronic Converter. So, we were on the module of Power Semiconductor Devices and today's lecture, we will be discussing diode characteristics. So, let us first discuss the VI characteristics of the diode.

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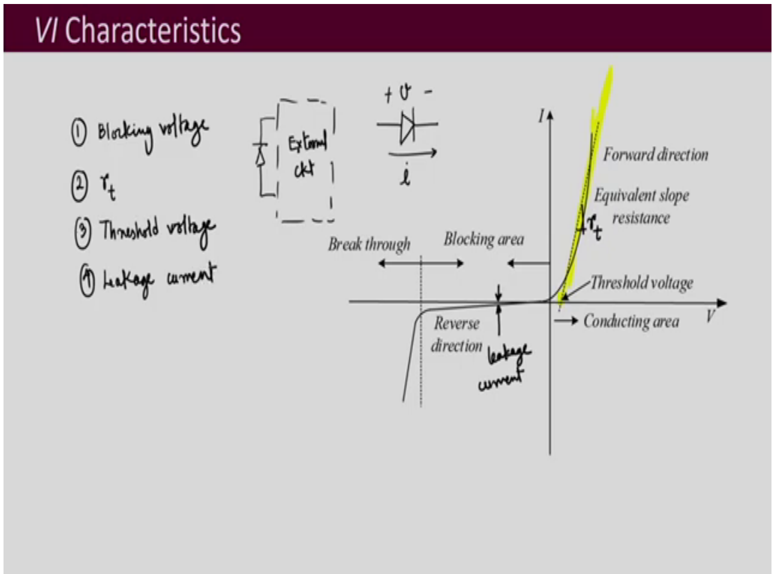

So, in a diode what you have is, when it is going to be on at that time there is a small threshold voltage, which it has to exceed and then after that the current in the diode starts to increase. So, if this is diode, then the current through it is i and the voltage across it is v. So, while it is forward biased, that means it is on. So, at that time, it has to exceed this threshold voltage for it to conduct and then this current just simply can increase and it is actually limited by the external circuit.

So, when I say external circuit what I mean is that, the diode is connected to whatever power electronic circuit it may be connected to so that is the external circuit, that limits the current while the diode is forward biased. And if you see the nature of this rise it can be approximated to a straight line, a sloppy line. So accordingly, if this line will have a slope and that slope we can represent as r_t, the forward slope resistance. So, this part is conducting region that means it is basically forward biased and the diode is going to conduct.

And then while it is reverse bias the diode blocks the voltages, so there is a small current, that flows through this diode and that is leakage current. And as this reverse voltage continues to increase, then what happens is that, beyond a certain voltage the diode cannot block that voltage and basically you can say the breakdown happens, this is also sometimes called as the avalanche breakdown. So, this is the limiting voltage or you can say the blocking voltage of the diode, which you will be seeing in the data sheet.

So, this part is basically the blocking region beyond that it cannot block and this is forward bias region the conducting region, where once the voltage exceeds the threshold voltage the current starts to increase very rapidly, the current can be very high and basically limited by the external circuit. This you may be familiar with and might have studied before.

So, the important things that you know from the vi characteristics is first is the blocking voltage, then you get to know this forward the slope resistance r_t and then you also get to know the threshold voltage, and one more you get to know is the leakage current. So, these are the things, that you get to know from the vi characteristics of the diode.

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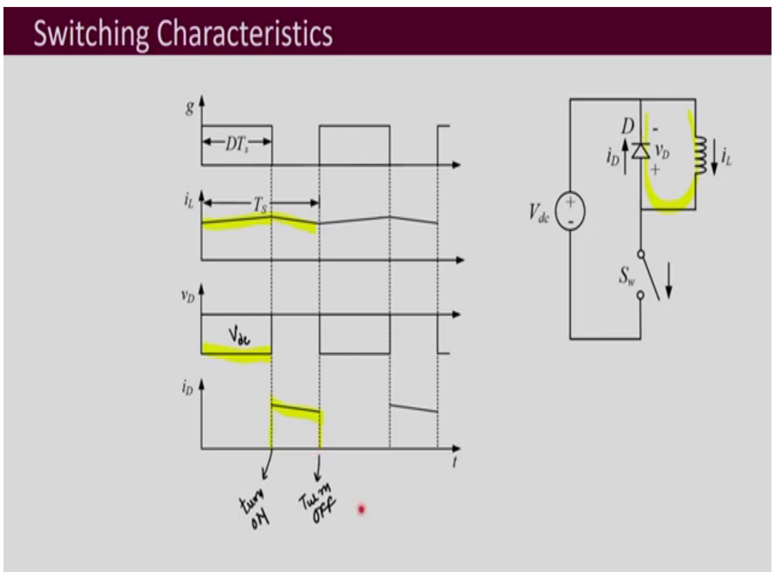

Now, let us look into the switching characteristics of the diode. So, to explain the switching characteristics, I have used this circuit and this is the circuit, which is mostly used for studying the diode characteristics, switching characteristics practically also. So, what you have is the diode, which you are going to test and then you will be having another switch and then inductive load, you may use very highly inductive load and a dc supply.

So, we can give this kind of gate pulses to this switch. So, when this gate pulse is provided the switch turns on and at that time this inductor current flows through the switch. And so, the diode is off during that time. And this diode is at that time blocking this voltage, so this voltage will be V_{dc} voltage, which the diode has to block. And the current is going to slightly increase, because we are assuming a big inductor and the voltage applied over here is positive. After that what happens is that, that you turn off this switch.

So, when we turn off this switch the current then flows through this diode, it has to freewheel through this diode. So, the diode is supposed to carry the inductor current, so this is the point at which the diode turns on. So, here this diode is going to turn on. And then after that when the device is turned on again i.e. the switch is turned on again the diode turns off. So, this is the point at which the diode turns off. So, if we observe these two areas, then we will be able to study the switching characteristics of the diode.

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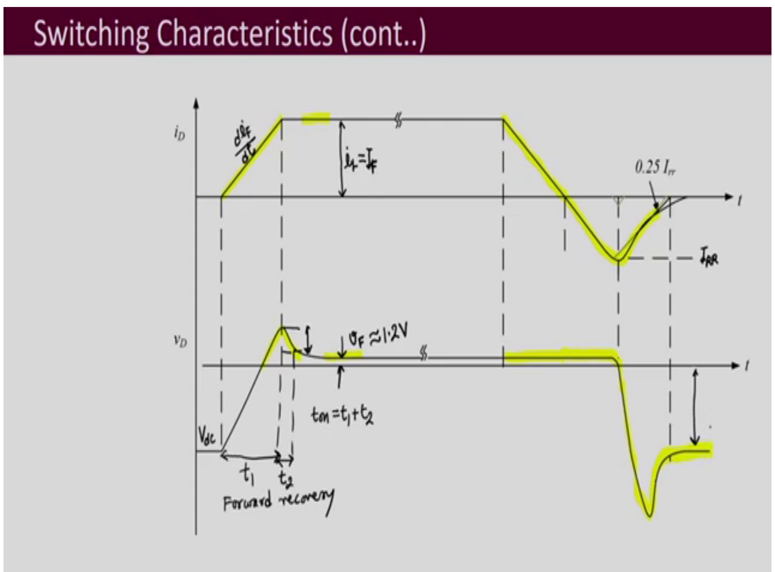

So, let us look into the switching characteristics of the diode now, this is the i_D waveform and this is the v_D waveform of the diode. So, now when this diode starts to turn on, prior to that the voltage over here, the diode was blocking is equal to V_{dc}.

After that when the diode starts to turn on at this point, then what you can see is, this current increase and at that time the diode voltage also starts to reduce, and it becomes 0, before the current has reached to its final on state current value over here. And what it does is that it increases further and it does not settle to its on-state voltage drop, forward voltage drop, but it shoots through. So, there is an overshoot here and then it finally comes down and settles to the on-state voltage drop.

So, what we see here is that, there are two intervals over here, so this interval we can name it as t_1 and this one we can name it as t_2. So, this effect of the voltage increasing and having an overshoot, this is called as the forward recovery. So, this is called as the forward recovery and this time is called as the forward recovery time.

Now, this much that overshoot, that you see over here this overshoot may be of the order of 30 to 40 V in some cases, and this may become a problem sometime in some of the circuits. And this is also associated with the rate of change of the diode current, that means, the rate of rise over here, while it is going into the forward biased mode. So, this slope we can name it as $\frac{di_F}{dt}$. If you see the data sheets many times these forward recovery related parameters, they are specified with respect to a mentioned rate of change of current by the manufacturers.

Then what happens is that, after this turn on process is over, turn on time

$$t_{on} = t_1 + t_2$$

This is mostly the turn on time of the diode. Then the diode is on and then it has this on state voltage drop or the forward voltage drop, which we can write it as v_F and it is typically about 1.2 V for many of the power diodes. Not necessarily all of them will have 1.2 V some of them may not have I mean it may change, but many of them have this 1.2 V. And if you see this current will be equal to i_L the inductor current, for the circuit that we have chosen and this is also many times written as equal to i_F, the forward current.

Now, let us look into the turn off process. So, when the diode starts to turn off over here, then what happens is that the current first decreases. So, while the current is decreasing at that time there is no change in the diode voltage. So, the diode voltage still is small at that time, then current further becomes 0, and increases in the negative direction and it keeps on increasing. And till also that time what you can see is that, this diode voltage is still small and this current reaches to a point, which is called as the reverse recovery current I_{RR}, it reaches over there after that it starts to decrease.

So, at that time what happens is that, this diode voltage that builds up very quickly in the opposite direction and there is also a shoot through over here and then it comes back to its blocking voltage, which is equal to V_{dc}. So, this is equal to blocking voltage V_{dc}.

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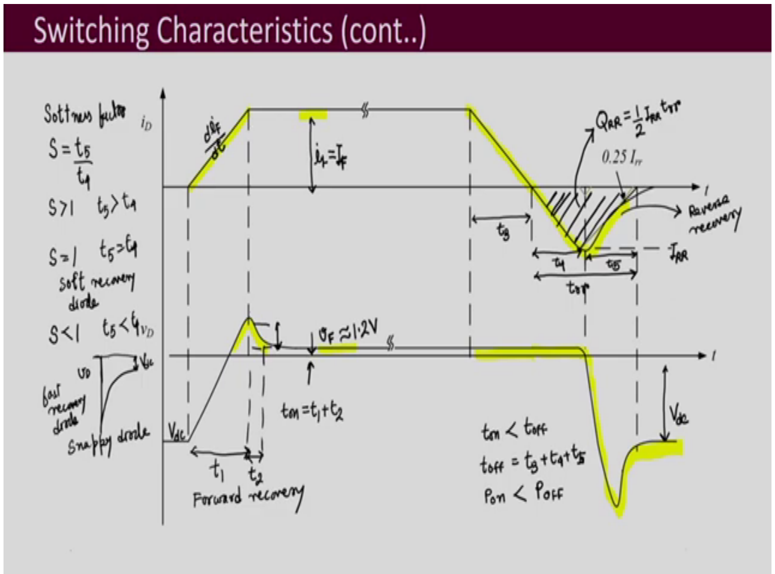

Now, here during this part, there is a charge that is associated with this area, area under this current curve has got a charge associated with it and that is called as Q_{RR}, the reverse recovery charge and this is like a triangular area. So, we can write it as

$$Q_{RR} = \frac{1}{2} I_{RR} t_{rr}$$

where t_{rr} is the reverse recovery time. And what is the reverse recovery time? The reverse recovery time is equal to this time t_{rr}, where this current is becoming negative and this can be divided actually in two parts, when reverse recovery current is increasing and when reverse recovery current is decreasing.

So, let us give some name to each of these times, let us call it as t_3 and this is equal to t_4 and this is equal to t_5. So, this process is reverse recovery and this plays a very important role in selection of diodes.

Now, what happens is that, t_{on} time is usually smaller than off time for a diode and when you select a diode, it is the off time which plays more important role than the on time, because off time is then the deciding factor for switching frequency. And this off time you can see that it is sum of these three t_3, t_4 and t_5 and in that the one which is dominating is going to be t_{rr}, the reverse recovery time.

And also, the diode switching losses during turn on is lesser than the loss that happens in turn off. So, when you calculate the switching losses also at that time it is the diode turn off loss, which contribute more in the total switching loss of the diode and that is why that is given more importance.

Now, one more thing that you can observe here is that there is this shoot through, that is happening in the voltage. So, this shoot through in the voltage, if it is too high, then that may damage the diode and that is also decided by the interval of these t_4 and t_5 and also the stray inductances that may be there.

So, now there is a term linked with this reverse recovery of diodes, which is called as softness factor and it is represented by S and that is given by $S = \frac{t_5}{t_4}$. Now, if S is greater than 1, that means t_5 interval is greater than t_4. So, what it means is that, that this process over here, this is going to take longer for the voltage to come down over here it is going to take more time. And some oscillations also may be there, may be the reason why it may take more time for the voltage to come down.

And then, suppose S is equal to 1, that means t_5 is equal to t_4, in that case the diode is called as soft recovery diode. And there may be situation, where S may be less than 1, that means t_5 is less than t_4, what it means is that, that this diode voltage it just is able to snap off here, so this increase. So, this is v_D, while you are turning off, it just quickly settles down to this voltage of V_{dc}. In that case you have a high overshoot transient, that will be there and this is usually faster recovery diode.

And in that case, you can also say that if this also can be called as a snappy diode. So, this is also sometimes specified in the data sheet and you should be looking for that what is the nature of the transient in the voltage during turn off, whether you are getting some kind of oscillation that means it takes more time for the voltage to go to the blocking voltage or I mean it is snappy diode, then in that case there may be a greater overshoot that may be happening.

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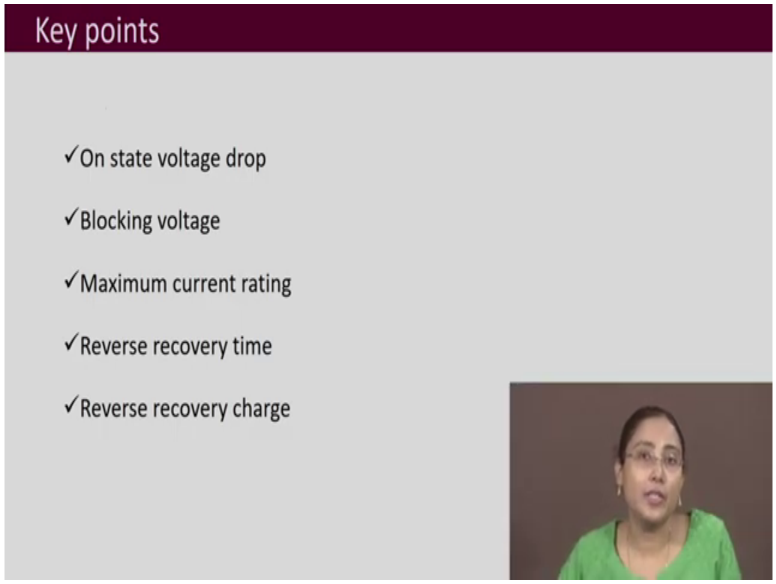

So, what are the key points of this lecture? So, first is on state voltage drop, the forward voltage drop, that plays an important role in selection of diodes. Then the blocking voltage or the breakdown voltage, that is that what is the maximum blocking voltage, the diode can withstand. Then the maximum current rating of the diode and the turn off process of the diode is more important than the turn on process. So, reverse recovery time, reverse recovery current and the charge associated with it, that you should be paying attention to. These are some of the key specifications of the diodes, that you should first look for while choosing it for particular design. Thank you.