Design of Power Electronic Converters
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Lecture 9
Different types of power diode

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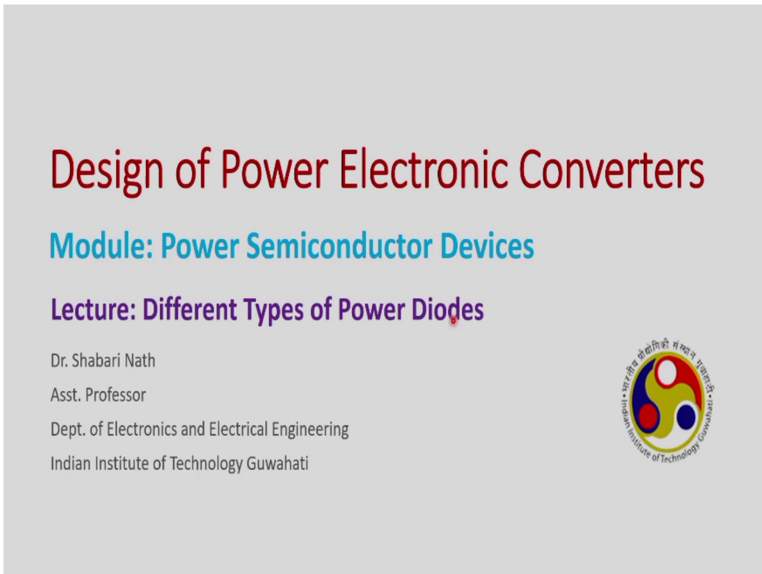

Welcome to the course on Design of Power Electronic Converters. Today, we will begin with the module Power Semiconductor Devices. In this module, we will be discussing the three important power electronic devices, diodes, MOSFETS and IGBTs. There are many other power electronic devices, but we will be focusing only on these three, because presently these are the three devices, which are used mostly. And so today let us begin with diodes. So, first let us see, what are the different types of diodes which are used in power electronic converters.

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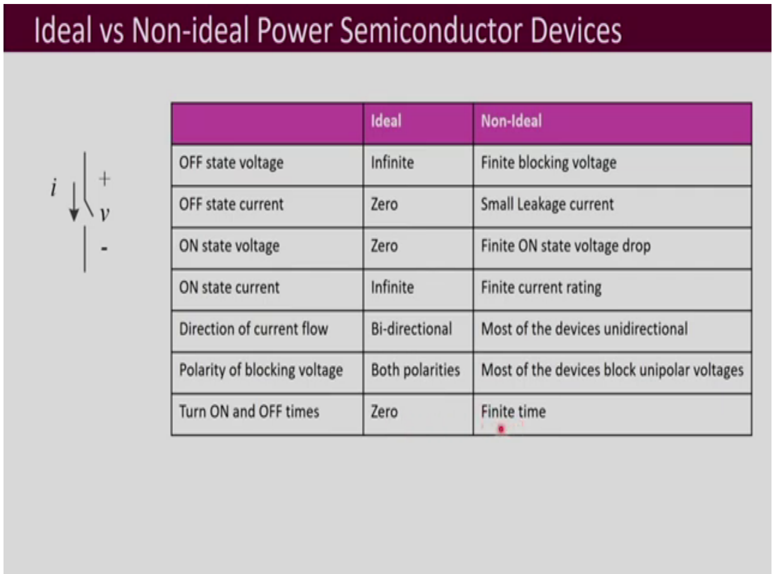

	Ideal	Non-Ideal
OFF state voltage	Infinite	Finite blocking voltage
OFF state current	Zero	Small Leakage current
ON state voltage	Zero	Finite ON state voltage drop
ON state current	Infinite	Finite current rating
Direction of current flow	Bi-directional	Most of the devices unidirectional
Polarity of blocking voltage	Both polarities	Most of the devices block unipolar voltages
Turn ON and OFF times	Zero	Finite time

Before going into the devices, let us also look into the differences between ideal versus non-ideal power semiconductor devices. So, this is a table, which actually is noting down the differences between ideal devices and non-ideal devices. Previously when we did the analysis of power electronic converters, then we assumed all devices to be ideal. But we know that practically they are not ideal.

So, if this is the device, let us say it is any kind of a switch, it may be a diode or a MOFSET or IGBT, or THYRISTOR, or GTO or some other device, it is just a general representation of a power electronic switch, let us say. And then the current that is flowing through it is denoted by i and the Voltage across it is denoted by v. So, now when the device is off, so when it is off state Voltage, ideally, we assume that this Voltage can be infinity, but we know that practically all practical devices will have a finite blocking Voltage, it would not be infinite.

Then the off state current when the device is off, we assume ideally that the current is zero through it, but practically there will be some small leakage current, which may be flowing through it, even when the device is off. Then you have this on state Voltage that means when you turn on the device, there will be a small Voltage drop across the device, although it is a practical device. So, finite on state Voltage drop, but ideally, we had assumed, that it is zero.

And what could be the current that can flow through it while the device is on? So, on state current practically, there will be a finite current rating, so you cannot make infinite current pass through it, but ideally infinite amount of current can flow through it and assuming this we analyze the ideal power electronic devices.

Then direction of flow of current, current flow, now if it is an ideal device current can flow in either direction, so it can flow in this direction downwards or it can flow upwards also. So, we assume it to be bi-directional ideally, but most of the devices carry current in one direction, when we consider the practical devices, most of them are unidirectional, that means they allow the flow of current only in one direction. I am not saying all of them are unidirectional, there are devices which can allow current in both directions as well, but many of them are unidirectional.

Then polarity of the blocking Voltage, that means, when you apply a Voltage over here and the device is off at that time the Voltage, that it can block its polarity can be of either polarity, when we assume it to be ideal. But for a practical device, most of them block unipolar Voltages. Now, there are devices like THYRISTOR, which can block Voltages of both polarities as well, that is why most of the devices I have written not all of them block unipolar Voltages, there are also devices which can block bipolar Voltages.

And then turn on and turn off times. So, when we analyze the ideal converter, we said that it turns on instantaneously, it turns off instantaneously. So, the turn on and turn off times were zero, but in a practical device you will have some finite turn on and turn off times. So, these are the major differences between ideal and non-ideal power semiconductor devices.

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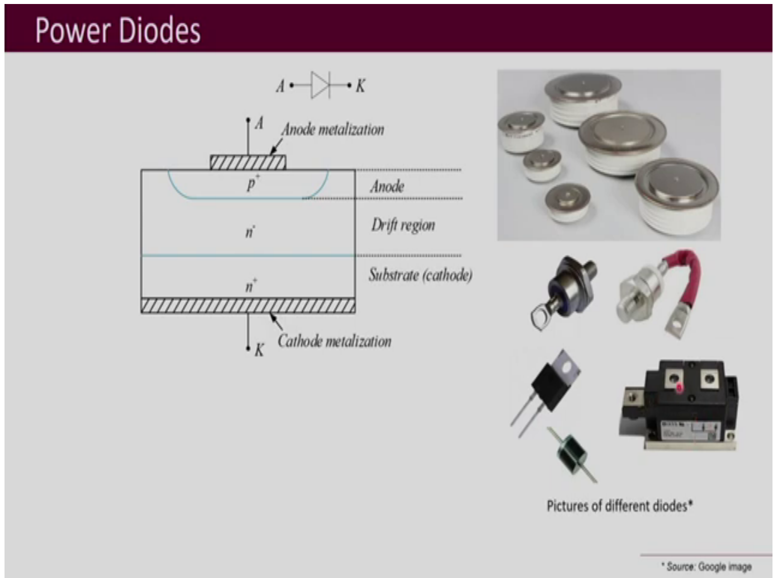

Now, let us begin with power diodes. So, this is the physical structure of the power diode, where you have a p+ region and then you will have n- and n+ region and then you have the anode and the cathode and this is the symbol of the diode, which you must be familiar with.

Now, in this course, we will not be discussing the physics of the device, you might have studied the physics of most of these power semiconductor devices before, even if you have not studied or you are not good at it, you do not have to worry in this course, you will be able to follow the contents of this course without having much knowledge of the physics of the semiconductor devices.

Now, these are some of the pictures of different diodes. So, this is a small diode of lesser ratings, then this is a power diode which you can see that it is bigger, it is a discrete diode. Then when you go for higher Voltages in current ratings, you will be seeing power diodes like this. So, one of these terminals is anode, another terminal is cathode. And you can see here, how thick is the wire, so from this you can imagine that what could be the current rating of this diode.

Then diodes of even higher rating, they are also available in this disk form. So, there are disks you can see over here how big these disks are and from there again you can imagine how high these current ratings of these diodes may be. So, high blocking Voltages and current ratings may be there, then these types of diodes can be used. And then when the ratings relatively reduce, then we use these types of diodes and further you can see smaller diodes.

And then sometimes there may be integrated modules, this is an integrated module which contains two diodes inside it. So, that is why, since two diodes are connected inside you can see three terminals coming out here.

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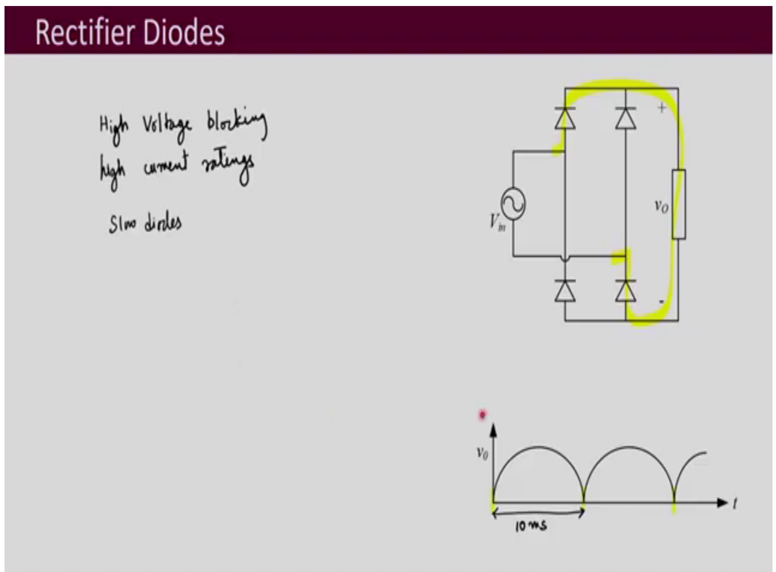

Now, let us see what are the different types of diodes that are required for different, different applications of power electronic circuits. So, this over here I have drawn a rectifier and usually over here the supply Voltage will be known 50 Hz supply Voltage and the current ratings of these diodes may be very high. The rectification may be happening so, the Voltage this may have to block and the current that this has to carry may be of very high. So, when we have a rectification application in that case, we will require high Voltage blocking capability and high current ratings.

Now, if we see the output Voltage over here, let us say this is a nature of the load is such that you get these kinds of fully rectified Voltages. So, then if let us say this is 50 Hz, this frequency of this supply is 50 Hz, in that case this will be 10 milliseconds. So, one diode over here when it conducts, it conducts for half the cycle and another diode conducts for another half the cycle. So, in that case in 10 milliseconds time, somewhere here you will have the turn on and turn offs of these diodes taking place, that means the turn on and turn off requirements of this kind of a rectification example is not very demanding.

So, therefore we can use slow diodes for rectifier applications. So, these are the three main requirements that we see for rectification application, high Voltage blocking capability, high current ratings and the turn on and turn off times are not so much of a requirement there. So, this kind of diodes, which have these types of characteristics, which are designed to satisfy these requirements, they are called as this rectifier diodes. These are basically slow diodes with high Voltage and current ratings.

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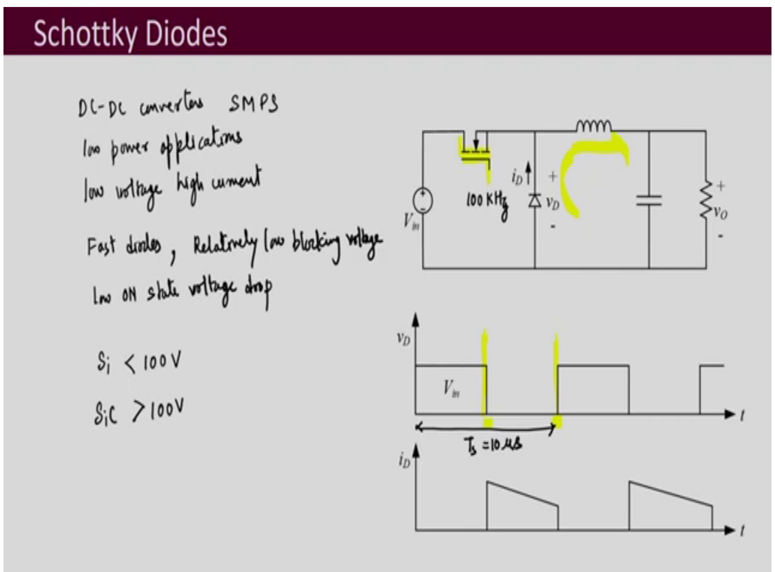

Now, next let us look into the application of DC to DC converters. So, DC to DC converters, let us say we are using it for SMPS applications. So, those are mostly low power applications and the power requirements, the power levels are usually up to few hundred watts and there they are many times called as low Voltage high current applications.

Now, let us look into this buck converter circuit. So, let us say this MOSFET, this is switched at a frequency of 100 kHz. Now, SMPS application mostly the switching frequencies are above 100 kHz, most of the times. So, in that case this switching time period T_s, this is going to be equal to 10 ms, if we assume the switching frequency to be 100 kHz.

So, this is the Voltage waveform across this diode, so when the switch is on this is blocking, this input Voltage and the diode starts to conduct, when the switch is off. And this is the current the diode is carrying when the switch is off, that means this diode has to carry inductor current when the diode turns on. So, now what we see is that, this diode turns on over here and turns off over here. So, this period is very short, that means for this kind of an application, what we need is very fast diodes, where turn on and turn off times are very small.

But if we see this low Voltage and high current, that means the blocking Voltage need not be very high. So, relatively low blocking Voltages and current rating are reasonable. So, that is the requirement of the diodes, which will be used for these kinds of DC to DC applications. And one more thing is that, when the diode is on there is a small Voltage drop across it, while it is conducting. Over here this ideal waveform that we have shown, we have shown here it to be 0, but practically it will not be 0, there will be a small forward Voltage drop across the diode.

Now, if this is there that means what every time the device is conducting, that multiplied by the current, there will be a power loss conduction loss, that is going to happen across it. And of course, whatever is this diode drop that is occurring that drop is going to be subtracted from whatever output Voltage you are going to get here. We had seen this effect in the simulation also, the LT spice simulation that I had shown you before.

So, we would like this Voltage drop on state Voltage drop to be ideally 0, and if it cannot be 0, practically, then as small as possible, which is I mean low on state Voltage drop is good to have in any converter. So, let us say that is also a requirement to reduce conduction loss, so low on state Voltage drop. So, these are satisfied by the diodes, which are called as Schottky diodes. These have very low on state Voltage drop, they turn on turn off very quickly, they are very fast diodes, but the problem with these Schottky diodes is that, it is very difficult to make them above 100 V.

So, sometimes up till 200 V also you may be able to find out a Schottky diode with silicon as the material. With silicon, Schottky diodes are mostly available till 100 V. Now, there are devices made with silicon carbide, where you can make Schottky devices greater than 100 V also, but those are relatively little bit more expensive than silicon diode. Most of the converters presently are using silicon devices and there these Schottky ratings that you can get blocking voltage capability is usually below 100 V.

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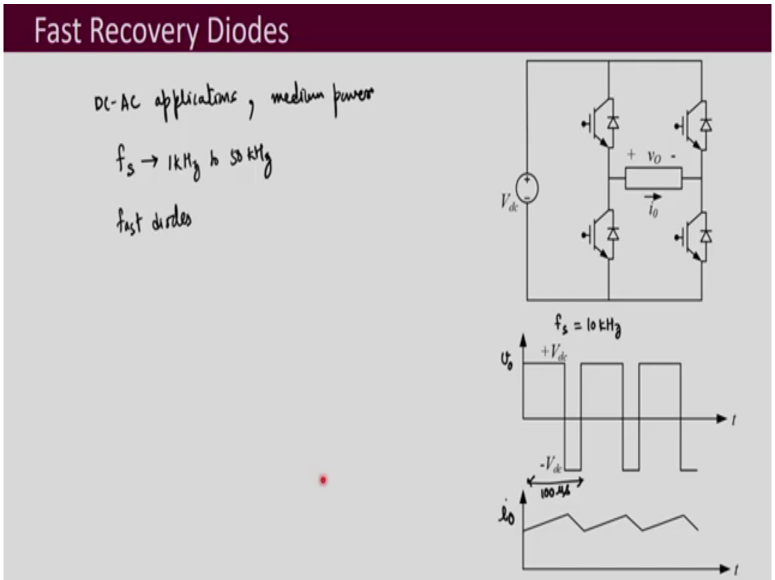

Now, let us look into DC to AC application. So, DC to AC application, if we see, so most of the time these are medium power applications and the Voltage and current both are reasonably high means the Voltage requirements are also high like, maybe it may range from 200-500 V or even more than that up till 700, 800 Vs also requirements may be there. And the current requirements are also quite high in the range of kW, these are going to be these DC to AC applications.

And the switching frequency there, switching frequency f_s that also can be from 1 kHz to 50 kHz, this is the usual switching frequency range for these kinds of applications. So, if we see this one over here, this is the H bridge that we have discussed before. So, using IGBTs they are made and then these are antiparallel diodes, which are used with the IGBTs.

So, if we see the output Voltage waveform, so this is the output Voltage waveform Vo, that you can see here that it goes from $+V_{dc}$ to $-V_{dc}$, as these diagonal switches are turned on and off, so $+V_{dc}$ and $-V_{dc}$ is the Voltage. And if we assume that, the switching frequency is let us say equal to 10 kHz, if we assume that. So, this total period, then will be equal to 100 microseconds and this is load current i_o over here.

So, then what will happen is that, whenever these diodes have to conduct, they have to turn on and turn off. So, they will be corresponding to this switching frequency of 10 kHz and that relatively shorter time periods of 100 microseconds, that means, here also we need fast diodes. Fast diodes, but we also have to see that the Voltage and current requirements, the blocking Voltage requirement and current carrying requirements are also high together. And many times, this blocking Voltage requirement will be greater than 100 V.

So, that low on state Voltage drop, which we can get in Schottky diodes, that may not be possible to get, but we can definitely make diodes, which can recover very fast. So, fast diodes can be obtained with reasonably high blocking Voltages and reasonable current ratings. So, those kinds of diodes are fast recovery diodes. So, these are the three main types of diodes, which are used in power electronic converters, rectifier diodes, Schottky diodes, and fast recovery diodes. Now, this I am specifically telling in terms of power electronic circuits, there are many other different types of diodes, which we are not discussing here.

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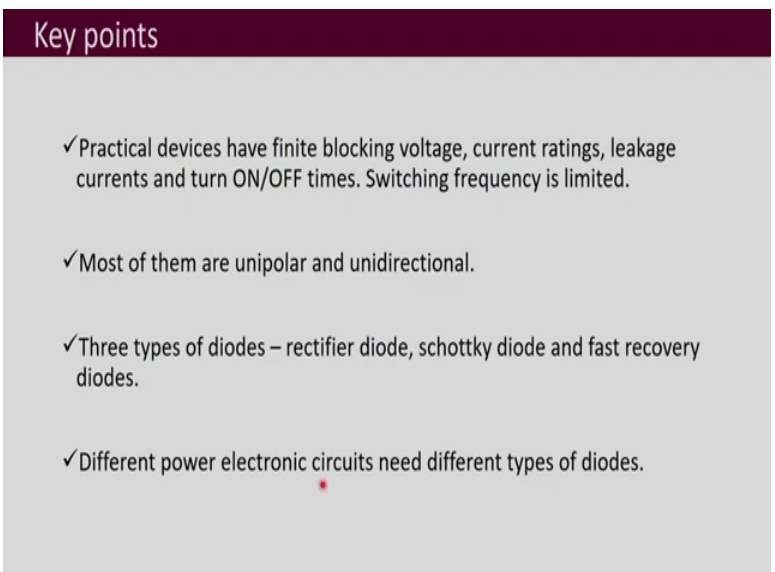

So, what are the key points of this lecture? So, practical devices have finite blocking Voltage, current ratings, leakage currents and turn on and turn off times. So, the switching frequencies are limited in case of practical devices. So, this you should have it in the mind, because when you first analyze a power electronic converter and that time you assume everything to be ideal, after that when you will be about to select devices, then you have to know that there are non-idealities. So, it is a practical device, it will have all finite ratings of everything.

And also know that most of the devices are unipolar and unidirectional, that means they block Voltage of one polarity and they carry current in one direction. So please note that, this is not true for all of the devices. So, that is why you should pay attention, which type of device you are choosing and what is its capability.

Then as I said three types of diodes are mainly used in power electronic converters, rectifier diodes, Schottky diode, and fast recovery diodes. And different power electronic circuits have different types of diodes and so as a designer you need to choose the correct type of diode for your application. Thank you.