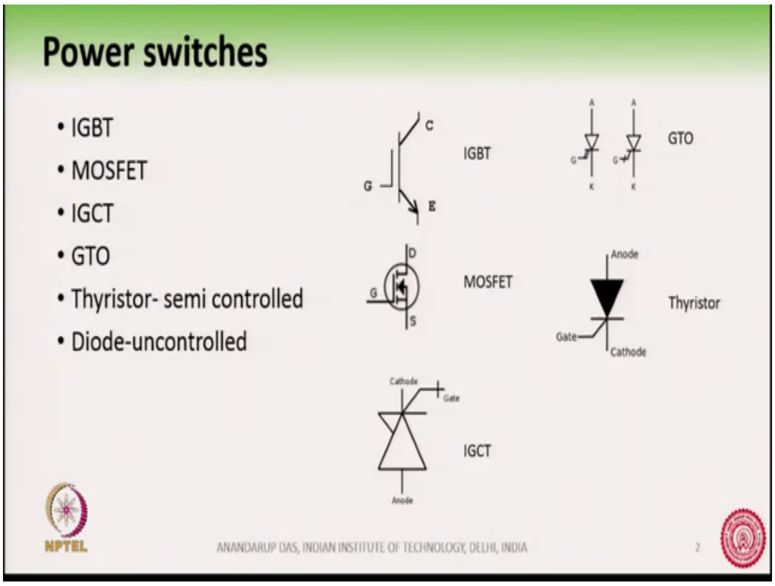
High Power Multilevel Converters - Analysis, Design and Operational Issues
Dr. Anandarup Das
Department of Electrical Engineering
Indian Institute of Technology, Delhi

Lecture – 10
Basic Introduction to Power Devices

Hello everyone. Today, we are going to talk about power switches, the switches that we use in different applications of power electronics.

(Refer Slide Time: 00:35)



So, the switches that we use in power electronics are listed as you can see here. This course is about multi level converters and the most frequently used power switch in present day multi-level converters is IGBT; Insulated Gate Bipolar Transistors. And, the symbol of IGBT is shown here, the first one the other important switch that. So, IGBT is generally used at medium voltage levels. And, so, the rating of IGBT and other devices have been detailed in the next slide, but the main switches that we use in various applications of power electronics are IGBT, MOSFET, IGCT, GTO, Thyristors and Diodes.

Now, in this course the which is based on multi level converters. The most frequently used device is the IGBT; Insulated Gate Bipolar Transistors. IGBTs come with various voltage and current ratings. MOSFETs are devices which are used slightly at a lower voltage levels and lower current levels. The symbol of MOSFET is shown MOSFETs have essentially an anti parallel body diode, which is not shown in the symbol. MOSFETs used where higher switching frequency are used compared to that of IGBT.

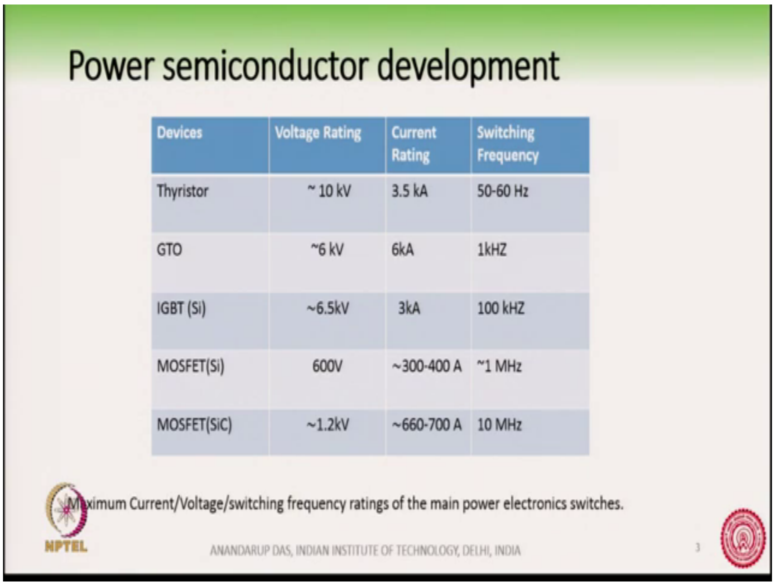
IGBT and MOSFET are the two switches that are probably now, the backbone of power electronics present at present generation. Historically thyristors were also very popular power electronic switches, but slowly we find or we are seeing in near future, that thyristors will be replaced with IGBTS and in some cases with silicon carbide MOSFETs. Variations of thyristors, thyristors are semi controlled devices, which means thyristors can be turned on, but it cannot be turned off.

And, variations of thyristors include GTO; Gate Turn of Thyristor where the thyristor the GTO can be turned on as well as it can be turned off. So, GTO is a fully controlled device. IGCT has also been introduced, but it has not been very popular and has not been able to replace IGBTs. IGCTs also a fully controlled device, there is of course, the diodes are used frequently in power electronics and diodes are an uncontrolled switch.

So, diode is basically a valve it allows the current to flow in one direction only. So, these switches are basically, what we use in all of in all of power electronics. Now, in multi-level converters on which this course is focused we will mostly use IGBTs. Now, we can also use MOSFETs as building blocks in multi level converters and we see that in near future in particular silicon carbide MOSFETs are going to play a very important role in multi level converters.

As of now IGBTs are used extensively in multi level converters, but silicon carbide MOSFETs or gallium nitrate or wide bandgap devices, these are slowly going to replace the silicon based devices in perhaps 1 or 2 decades of time.

(Refer Slide Time: 05:21)



So, what are the typical power ratings that we see? For example, if you see thyristors, thyristors have the highest voltage ratings like about close to 10 kilo volt and it can carry a lot of current 3500 ampere or something close similar to that, but you can see the switching frequency is very less 50 to 60 Hertz and thyristors are semi controlled device. So, which means it can be turned on, but it cannot be turned off at our wish.

GTOs, GTOs are the next version of thyristors. So, it can be turned off and it has a higher switching frequency and that it can operate about 1 kilo Hertz, but GTOs again have like in order to turn off the current, huge amount of current needs to be taken away or extracted from the device. And, that is why the gate driver board of GTOs are substantially big in size.

Silicon based IGBTs in particular for medium voltage applications, which where the ratings are shown around 6.5 kilo volt and 3 kilo ampere as the maximum rating of IGBT silicon based IGBTs. This silicon based IGBTs are very popular and the different ratings of IGBTs are available. For example, 600 volt, 1200 volt, 1700 volt, 2300 volt 3500 volt 4500 volt and 6500 volt.

So, different voltage ratings and for each voltage rating we have a large number of current ratings available for these IGBTs. And, they can switch substantially higher than thyristor or GTOs and going up to like 100 Kilo Hertz. Although, for high power application we never switch at 100 Kilo Hertz, we switch very less maybe around 5 to 10 Kilo Hertz of switching frequency. Even with for multi level converters the switching frequency of IGBT can be very very small, it can be close to the order of say 100 to 200 Hertz only, because of the large amount of power that has to be handled by the IGBTs.

When we will later in the course, when we will talk about multi-level converters, we will see that how this 6.5 kilo volt or like low voltage IGBTs how they can be arranged in a clever fashion so, that we can reach very high voltage levels. So, one of the application of multi-level converters is say HVDC; High Voltage DC transmission, where earlier days historically, thyristors were used. And, nowadays in particular with the advent of module at multi-level converters MMCs, we see that IGBTs are now used.

Now, for this HVDC application the voltage can be several hundreds of kilo volts. For example, we can easily have a HVDC transmission at plus minus 200 kilo volt or plus minus 400 kilo volt, and probably carrying a power of in the range of some giga Watt of power or several 100s of mega Watt power. Now, for that 100 or plus minus 200 kilo volt of HVDC transmission, we can use a series connection of IGBTs, we will see this later, but these IGBTs are individually rated for a much less voltage.

So, like we can typically use 3.3 kilo volt IGBTs or sometimes 4.5 kilo volt IGBTs, but several of them are cascaded in a clever fashion with capacitors. So, that we can reach a very high voltage of plus minus 200 kilo volt, 100s of IGBTs can be connected in that way. So, and this is the trend, which is which is kind of like very popular. Nowadays is that when you want to go for a high voltage application, then instead of using high voltage switch go with go for many number of low voltage devices and connect them in cascade.

The reason for this is primarily, because the with the low voltage devices the expertise, which we have is much more than with that of with the high voltage devices. For example, the gate driver boards and the amount of knowledge that the company or the manufacturer have with say 1200 volt IGBTs is much more, the amount of knowledge and expertise that is much more with 1200 volt IGBTs rather than with a 6.5 kilo volt IGBTs.

So, many manufacturers tend to go with this 1200 volt IGBTs, but connecting them a lot of them in cascade or series connection. We will see this later in somewhat more details, when we how do we cascade them and how do we connect the topologies like that. The other device that we have here is the silicon based MOSFETs. Silicon based MOSFETs are used extensively at low voltage applications. For example, automotive power electronics, that is like everywhere or predominantly silicon MOSFETs are used.

So, they are like maximum voltage rating is 600 volts, but 100 volt MOSFETs for example for various 48 volt applications are very popular, then you have 600 volt is the maximum rating and around 300 to 400 ampere, but you can see the switching frequency of MOSFETs can go very high ok, much higher than IGBTs ok. And, then we have something which we have written at the end is silicon carbide based MOSFETs or rather I should modify this and say that wide bandgap based devices made up of better material ok.

Silicon carbide or gallium nitride these devices, based on these material are much having it can tolerate a higher temperature and it the voltage blocking capacity is also substantially high. As of now the silicon carbide MOSFETs are coming around 1200 volts and 600 to 700 amperes the maximum rating, but the switching frequency can go very high, like 10s of mega Hertz.

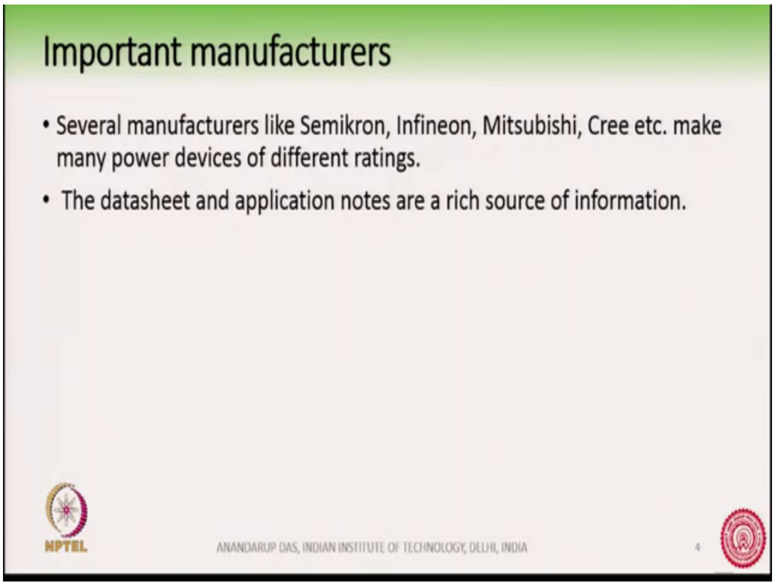
Now, although the silicon carbide MOSFETs are now coming into the market, we will see that silicon based IGBTs will continue to dominate at least for the next decade.

And, slowly thyristor based devices it is expected, that thyristor based devices or thyristor based converters will get slowly replaced by all these silicon based IGBTs. And, silicon carbide based devices will slowly replace or will be the most dominant power devices in near future.

So, many silicon carbide based devices like, silicon carbide based MOSFETs have already come into the market like, many PV converters. Are nowadays coming in the market with silicon carbide based MOSFETs and because they can switch very fast. So, the size of the passive components inductors capacitors, these will these are going or the size of them or going down.

In case of multi-level converters, silicon based IGBTs are going to dominate, but in near future probably silicon carbide based devices are going to replace. These silicon based devices simply, because of the reason that silicon carbide is a better material electrically.

(Refer Slide Time: 14:38)

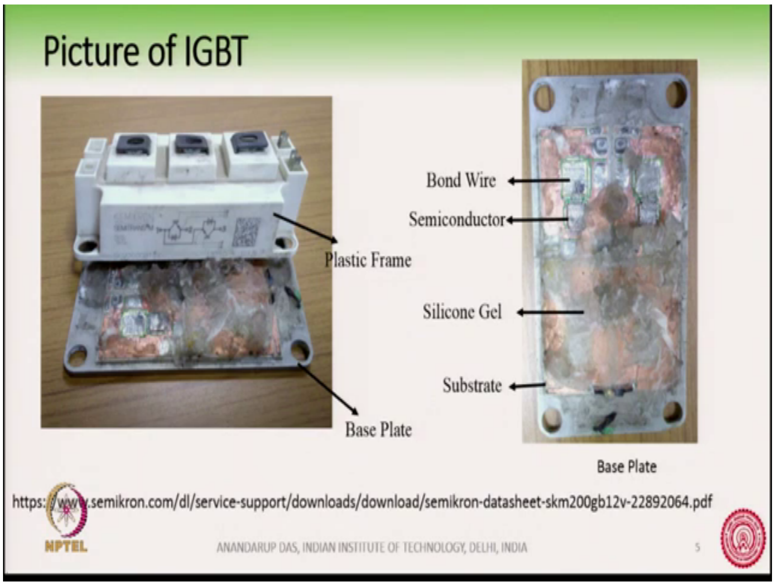


So, this is kind of like a rough status or state of the art of how the devices stand against each other as of now. There are several manufacturers who make power devices and like, Semikron, Infineon, Mitsubishi, Cree, they make power devices of a large number of different voltage rating and current ratings. If you go to their websites these manufacturers, if you go to their websites you get a lot of information.

And, these information are very very useful and for any design engineer or for anyone who is studying power electronics, it is a must that you visit these the websites not only to know about what are the types of devices available, but also to know that there is a something called as application notes for these devices, where the typical applications and what are the challenges in those applications, how to overcome those challenges? For example, how to design a gate drive board for these devices many useful information are available in the websites of these manufacturers.

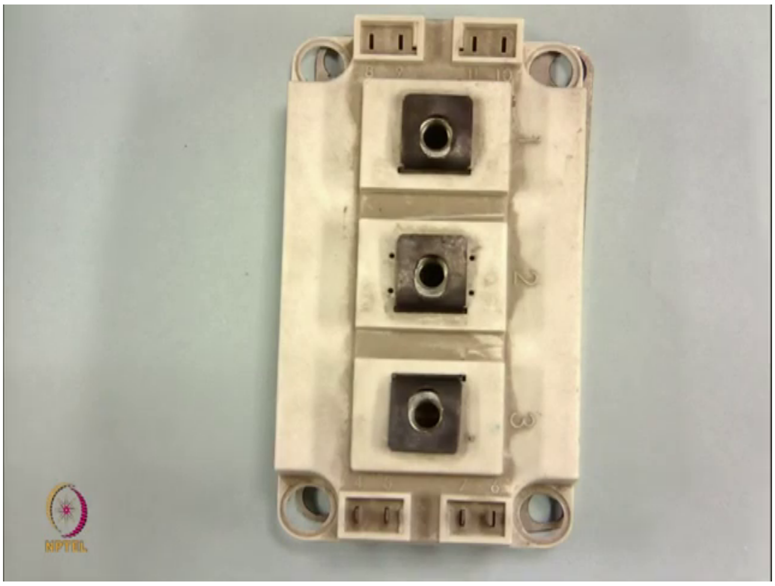
So, the application notes are must be studied along with the devices. So, that the person can learn what are the real life challenges, how to implement many things, how to design heat sinks, how to get the heat dissipated and many other things from the application notes?

(Refer Slide Time: 16:29)



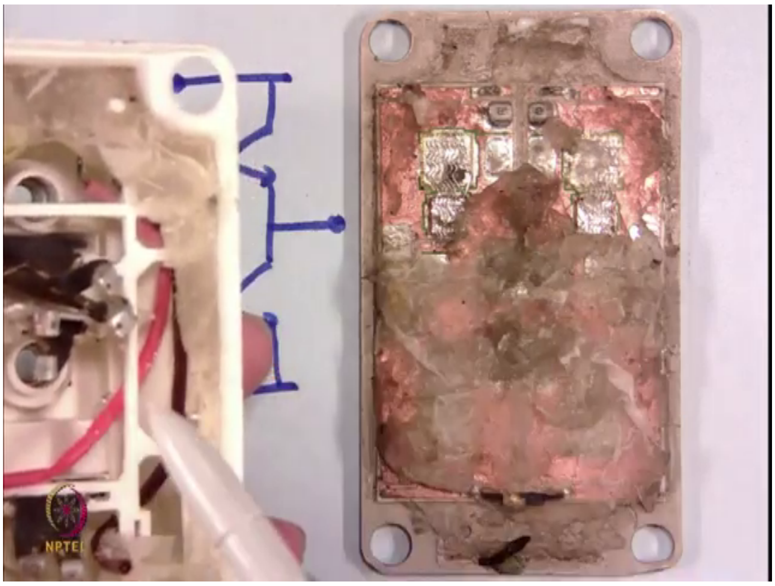
So, here I am showing basically a picture of the IGBT and let me also show you the real picture the real device here yes.

(Refer Slide Time: 16:48)



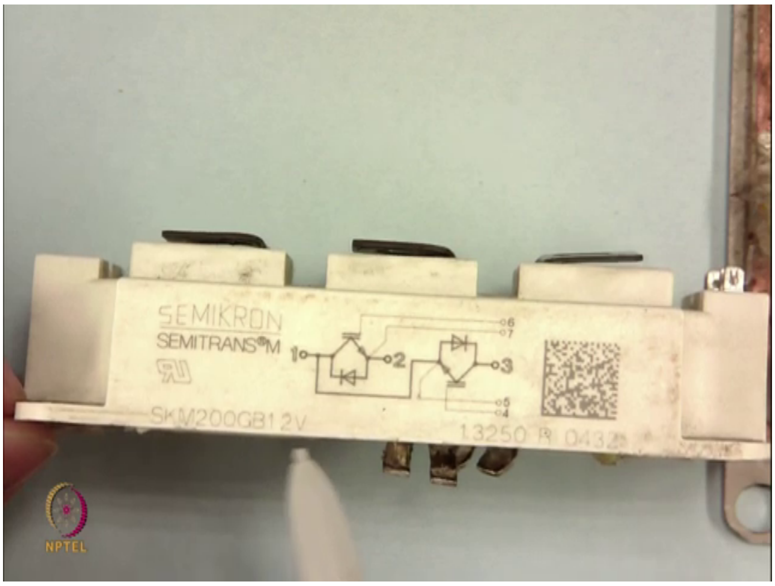
So, this is the IGBT that this is 1 IGBT, which we have taken. So, if you see the size of this is a pen here, or maybe I will put my hands here, and you can see what is the size of this device? And, this is an IGBT which we have actually while we were doing experiments in the lab, we had destroyed the IGBT and so, I thought of like opening up the device and see what is inside? So, if you so, this is like this is the case, if you open it; if you open it comes something like this.

(Refer Slide Time: 17:36)



So, this this was the case and this is how it looks like here, there is a IGBT here.

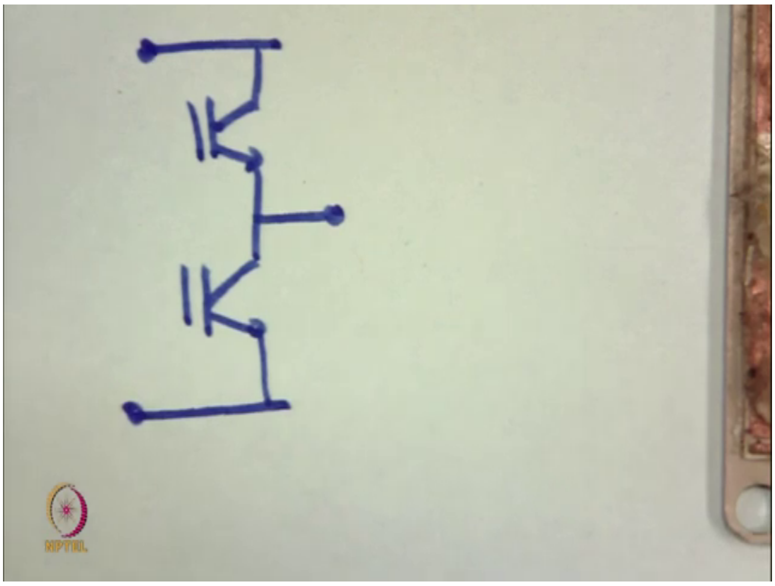
(Refer Slide Time: 17:57)



Now, if you look into this case properly you can see what is there this IGBT is made from semikron. And, it is a half bridge ok; that means, there are 2 IGBTs and anti-parallel diodes. So, there are altogether 4 devices here. And, there is something written here, which denotes the rating it is written here SKM200GB12V.

So, this basically if you go to the datasheet or if you search in the internet, you will find that this SKM200GB12V this is corresponding to a 1200 volt 200 ampere IGBT. How is the connection you can see the connection is kind of like this way the connection is?

(Refer Slide Time: 18:56)

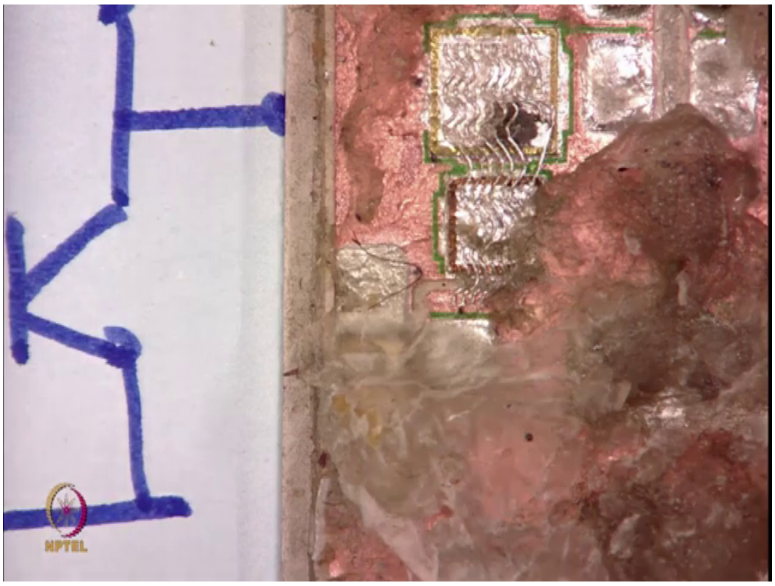


So, it is like this these are the 3 terminals ok, these are the 3 terminals of the half bridge and these 3 terminals are, this 3 terminals here these 3. These are the power terminals, because as it is written here 200 amperes can flow ok. Since, there are 2 devices as we can see here. So, this is the gate emitter terminal for device 1 and device 2 here the gate emitter terminals.

So, the gate signals will come to these terminals here. This is a plastic case and this plastic case is electrically it isolates the electrical part from the rest of the environment. If you see here then you see that the whole of the semiconductors the IGBT and diode the semiconductor is sitting on a substrate. The substrate is the copper colored layer, which you can see here. The semiconductors actually are sitting here and here.

Over which there is a sticky substance here, this sticky substance is made up of silicon gel the it. So, when you open the casing you will see that the whole device is filled up with the silicon gel. The purpose of the gel is to prevent the semiconductors from coming in contact with moisture ok. Now, if you clean up this gel like, I have done here, then you see that you basically reach to the semiconductor.

(Refer Slide Time: 21:31)



Here you can see the bond wires. This is the IGBT the chip IGBT here and the semiconductor IGBT. And, here is the diode chip there. And, they are connected via this bond wires, you can see the bond wires. Some of these bond wires have been lifted. As you can see here some of the bond wires have been lifted there is a black spot probably this black spot is one of the reasons, that this device had failed there was a local, thermal, hotspot most likely.

And, also you can see that they are the IGBT and diodes are interconnected via this bond wires. There are actually 4 such IGBT diode pairs in this half bridge. So, there is 1 2 3 4 4 such pairs. So, if you look also the heat sink or if you see the base plate of this device you will find that, it is made of a highly thermally conductive material. Now, remember that temperature control or keeping the temperature inside power devices is very important requirement. The main reason of failure of power semiconductors, the primary reason is height or prolonged temperature exposure.

So, all power devices are rated for a certain temperature limits. For example, junction temperatures in many power devices is recommended to be like, 100 and 50 degrees ok. So, junction temperature will be the temperature inside here whereas, case temperature. In many cases is recommended or should be close to like between 60 to 70 degrees maximum, it should be less than that if possible. Now, temperature plays a very vital role in the lifetime or in the longevity of devices.

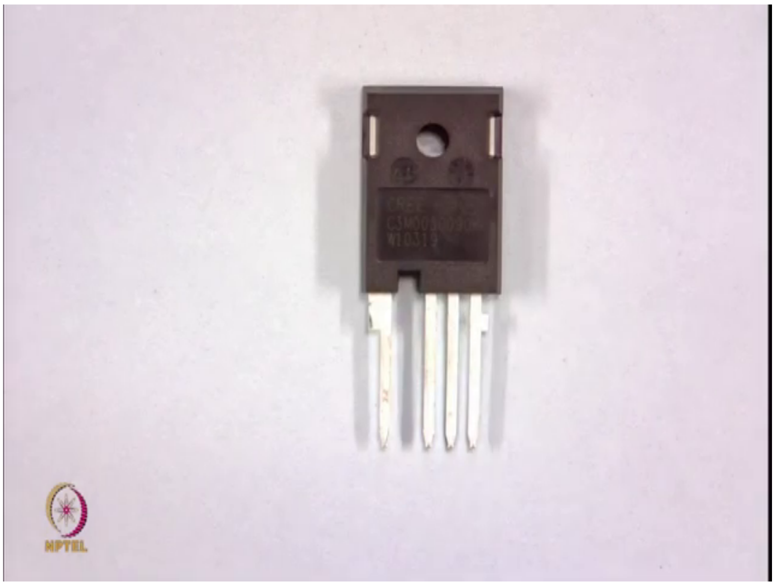
So, there is something called as an Arrhenius principle; the Arrhenius principle is used in the industry quite frequently. And, it says that for every 10 degree centigrade rise in temperature, the lifetime of the device goes down by half. So, every 10 degree centigrade you increase the temperature the lifetime will go down by half this is just a very thumb rule, but it is practiced in the industry.

And, this principle is very important while you design the heat sink or while you design how much should be the losses in the device. So, on one hand you would also you would like to increase the switching frequency, because then your inductor capacitor sizes will go down, but increasing the switching frequency will lead to increased losses switching losses. And, losses means more temperature rise, because losses will appear as heat and it will increase the temperature.

So, elaborate arrangements must be made to take this heat out. In many cases we find that in a power converter the material that has the largest volume is the heat sink. So, the temperature rise is something which must be controlled and elaborate arrangements are made. For example, in power converters sometimes we find, that the size of the heat sink is or the heat sink has the largest volume of among all the components in a power electronic converter. It is because we would like to dissipate the heat as effectively as possible and we would like to keep the temperature down.

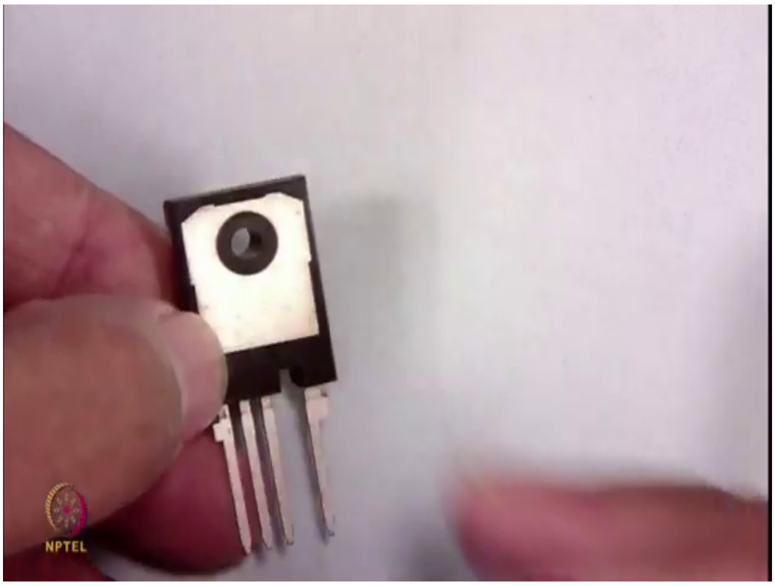
Not only for the steady state operation of the device, but also in terms of the longevity of the device. So, you will find that like this here in this device you will find that the base plate the size of the base plate you can see is substantially big so, as to dissipate the heat effectively.

(Refer Slide Time: 27:33)



So, apart from this we also have I have brought another device, this device this is the this is a power silicon carbide power MOSFET. We know that power MOSFETs has 3 terminals drain gate and source. However, this particular device has 4 terminals, we will see this this is basically a silicon carbide MOSFET 900 volt and 63 amperes and it is made up it is made by a manufacturer called cree silicon carbide MOSFET. So, these are the terminals of the device.

(Refer Slide Time: 28:17)



But, also you see that the base plate is present here. This device this package is called to 247 packaged with 4 terminals ok. Now, why 4 terminals they basically this device since silicon carbide can switch at a much higher rate. So, the loop inductance in the gate drive path has to be minimized, because otherwise the l D I D T due to this loop inductance can be very high.

So, to minimize the loop inductance the source the source is the there are two terminals available from the source. One is the source terminal, which is carrying the current main power circuit current, which is flowing from the drain and going through the source. And, there is a second source terminal sometimes called the Kelvin source terminal. And, this terminal is connected to the gate driver board, in order to minimize the loop inductance seen by the gate driver board.

So, you can see that so, this is a single silicon carbide MOSFET and you can understand the size of this of device, it is compact. Many such silicon carbide devices are now coming to the market. And, we expect that in near future at least at the low voltage level silicon carbide will become the most popular device. The cost is at present quite high, but the cost will substantially go down, once more and more adoption of silicon carbide takes place.

So, with this we conclude the basic introduction to the power devices, where we see that the silicon based IGBTs are going to dominate, the market, at least at the medium voltage medium power rating in multi-level converters also IGBT silicon based IGBTs are going to play the most important role, but slowly within a couple of decades many of these applications will see more and more use of silicon carbide or other wide bandgap devices.