Design of Power Electronic Converters
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Lecture:20
IGBT Datasheets - II

Welcome to the course on design of power electronic converters. So, we were in the module of power semiconductor devices and we had started discussing IGBTs. So, in last lecture, I had started discussing some of the datasheet notations and some of the performance curves which are given in the datasheet of IGBTs. Now, let us continue discussing further the datasheet of IGBTs.

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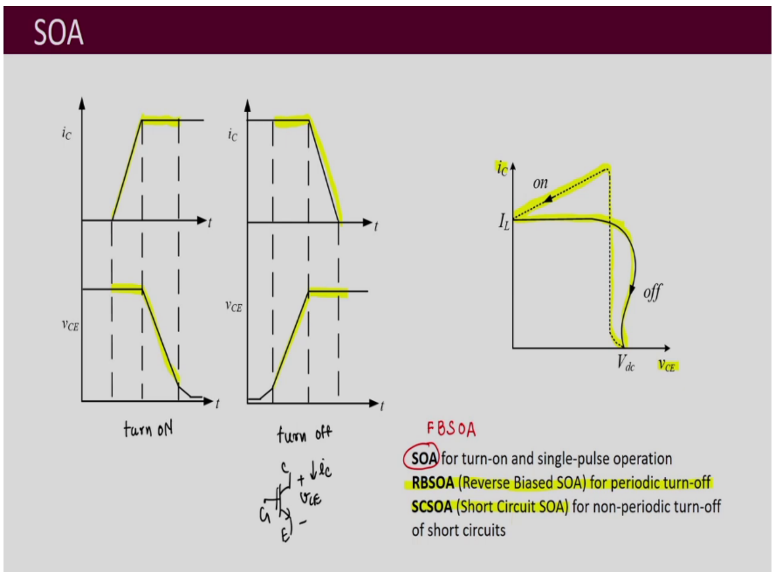

So, one important term that is given in datasheet is SOA or safe operating area. While discussing MOSFET also I had taken it up now, it is also applicable for IGBTs. So, let us look into it, what is the origin of it. So, this shows turn on process and during turn on what happens is that first there is a delay and then after that the current increases and at the time the collector to emitter voltage is not changing much.

So, if we plot a graph between this collector to emitter voltage and collector current then what will happen is that this voltage remaining same this current is going to increase and then after that what happens is that this collector to emitter voltage decreases and the collector current is still high.

So, that is what we see here the collector current remaining high, this collector to emitter voltage decreases. Similarly, during turn off, what is going to happen is that first the current does not change, but it is the voltage which builds up. So, current is not changing it is the voltage which is first building up and then the current decreases and the voltage remains close to the blocking voltage and that is what we observe that the current is decreasing here. So, what we see here is that, this trajectory has to be inside a particular area for a safe operation.

So, that is safe operating area otherwise the device may get damaged. So, then for MOSFET what we had seen was that we saw only one SOA diagram, but for IGBTs there are different SOA diagrams which are provided. So, first one is simple one, SOA for turn on and single pulse operation that means while the IGBT is conducting, what is the area inside which device should operate the voltage and current limits what it should be a within which the IGBT should operate while it is conducting. That means turn on or during the pulse you have applied. So that is the simple SOA operation.

And then there is another one which is called as your RBSOA, reversed biased SOA for periodic turn off. Now, reverse biased SOA, it is basically associated with the turn off process of the IGBT. So, while the IGBT is turning off, the time duration is very small, because the turn off time is usually small as compared to while it is conducting and the device is operating. So, there are certain different limits that are there during that so it is called as reverse biased SOA. And to distinguish this SOA which is for normal operation this is also sometimes called as the forward biased SOA, FBSOA.

Then there is another one in IGBTs which is called as the short circuit SOA, SCSOA. Let us say the IGBT has to withstand a short circuit, there is some short circuit and that may be for a very small-time duration and the device might have to carry huge amounts of current during that time and that means, the devices conducting and the voltage across it also might be very small and this is something that is going to happen once in a while, its' not going to happen periodically.

As compared to turn off process which is going to happen periodically. So, this short circuit is something a non-periodic phenomenon. So, during that also, since IGBTs have some short circuit withstanding ability, there can be some limits defined which is short circuit SOA, which is also sometimes provided in some of the data sheets for some IGBTs.

So, that is short circuit SOA. So, three of them FBSOA forward biased SOA, then reverse biased SOA and short circuit SOA. These are different types of SOA's for IGBTs.

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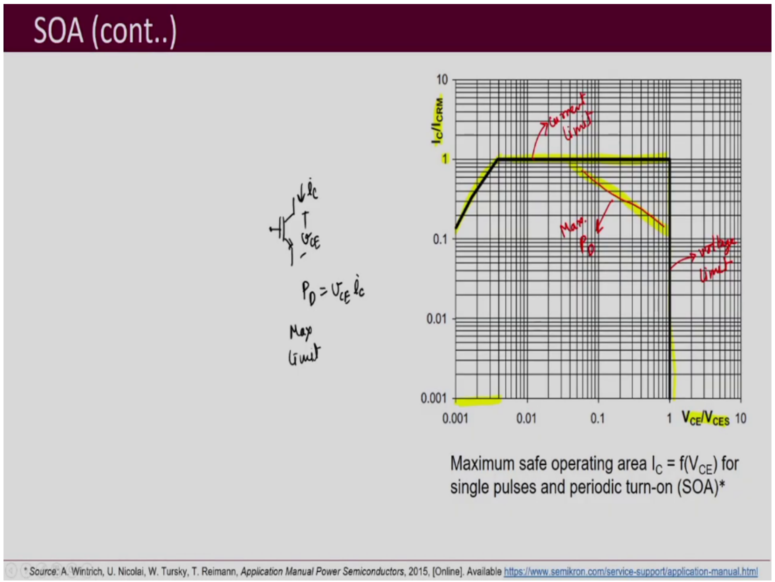

So, now, let us look into this normal SOA or the FBSOA. So, what you see here there is first one limit, this is like a line with a slope and at this point of time the collector emitter voltage is small. So, this is basically the limits defined by the saturation region. Now, do not think that 1 A of current is going to flow, this is given as a ratio with respect to maximum pulse current that can flow and this also here is given as a ratio with blocking voltage.

So, then after that what happens is that, so, this is given by the on-state operation or saturation operation of the IGBT then there is this one which is basically current limit. So, this is current limit and then there is this one which is voltage limit and in some of the datasheet you will also see this kind of a sloppy line which is not given here because this is taken from Semicron and they are not giving the linear operation limit because power dissipation limit is basically when it goes into the active region or it is operating in the linear mode.

So, power dissipation is basically,

$$P_D = V_{CE} i_D$$

So, how much this maximum can be there is a limit on it. So, depending on that you can get this line. So, that is contributed by maximum P_D and further in some of the data sheets people also give secondary breakdown. There is a phenomenon called a secondary breakdown that happens in IGBT.

So, those limits also may be there in SOA diagram. So, in SOA curve, all these limits are there the current limit, voltage limit, power dissipation limits, and the first limit because of during saturation what are the currents and voltage limits when the voltage is very small at that time and secondary breakdown limit. So, these are usually the limits in FBSOA or the simple SOA diagram.

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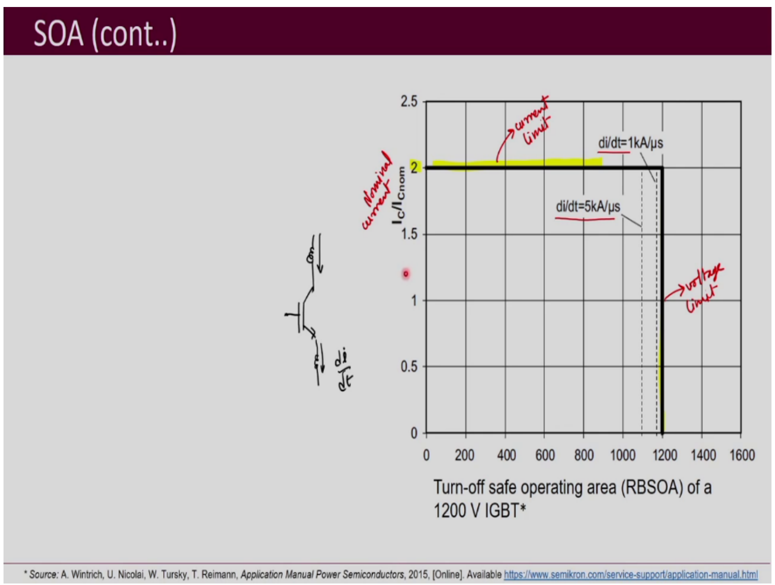

Then, let us look into turn off safe operating area, which is basically RBSOA. So, here you can see this is given twice of $I_{C(nom)}$ the nominal current. Now, usually what happens is that IGBTs or all these power semiconductor devices, there is not just one chip inside the IGBT.

It may be several of small, small chips that may be there which may be connected in parallel and that may form one device which is what you obtain from the outside as the case and the ratings are corresponding to that one device where actually you may be having several of small, small chips that may be connected in parallel. So, nominal rating is basically whatever a chip is capable of carrying current multiplied by the number of chips.

So, then usually the ratings are close to I_C the continuous DC current rating. And so, the during turn off, some of the manufacturers give the limit as twice of this $I_{C(nom)}$ i.e. twice of that current is what during turn off the device can withstand. And so, basically this one is current limit and here what you see this one is voltage limit.

Now, here what you observe is this $\frac{di}{dt}$ limits are given. Now, in an IGBT what will happen is that let us say this is IGBT. So, there may be some stray inductances also that may be associated. So, during turn off as the currents are changing through these ones, so, then there is an $\frac{di}{dt}$ associated, whatever is the rate of change that is going to affect what is the voltage that is going to appear across it and so, finally, whatever is the voltage the device might have to withstand.

So, that affects basically the turn off process and so, $\frac{di}{dt}$ limits are also there and they also reduce the SOA. You can see that this RBSOA area, you can see here that this line is corresponding to 1 kA/nS and as this $\frac{di}{dt}$ increases it increases to 5 kA/μS. You can see that this SOA is reducing.

Now, we do not see any of these sloppy lines here, which was because of the power dissipation limit, because it is only for the turn off, a very small period while the device is turning off. And so therefore, those linear region limitations are not applicable in case of RBSOA. So, they are not present in RBSOA diagrams that you see.

Similarly, you can also see short circuit SOA, the difference will be there that these voltages that you see here collector to emitter voltage, this will be much smaller because much smaller voltage should be there across the device at the time and the current that this can carry for that very short time period of short circuit that may be very high.

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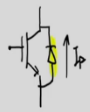
Notations related to Ant-parallel Diode



Notation	Meaning
I_F	Diode continuous forward current
I_{FM}	Diode maximum forward current
V_{FM}	Diode forward voltage
t_{rr}	Time required for reverse recovery current in the diode to decay
Q_{rr}	Reverse recovery charge

Then further there may be notations related to anti-parallel diode, this I had told you that most of the IGBTs the manufacturers make, they come with additional anti-parallel diode. So, this is that anti-parallel diode and so, the characteristics of this diode will also be provided.

So, forward current I_F is what could be the maximum rating of that. Then the pulse rating, diode maximum forward current for short duration I_{FM}, this is continuous current and forward voltage drop what could be the forward voltage drop across it, then reverse recovery time t_{rr} and reverse recovery charge Q_{rr}, these are also usually provided in the IGBTs datasheet.

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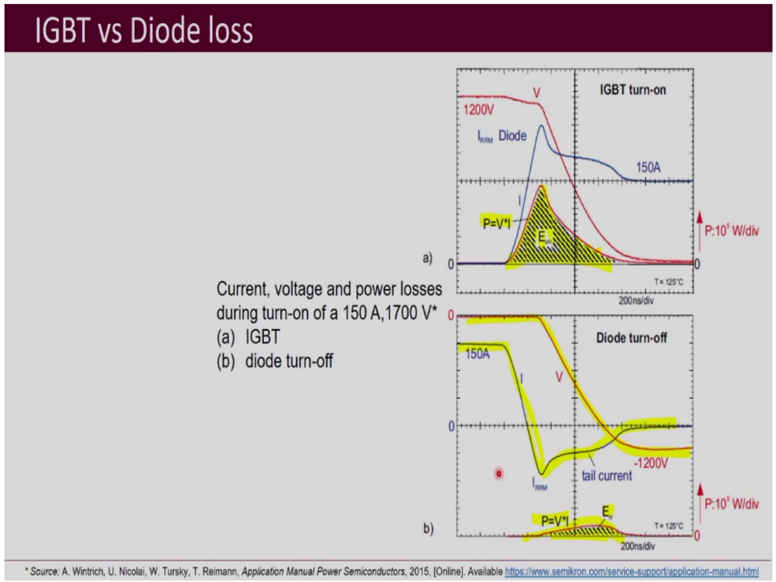

Now, one thing that I wanted to mention here is that, you have got an IGBT plus you have got an anti-parallel diode. So, you will need to do the loss calculations when you want to calculate the efficiency or you want to do the thermal design of converter. So, at that time you have to calculate all these switching losses and conduction losses of the IGBT as well as the diode.

Now, usually there are too many calculations because all these are different voltages and currents, all are varying. So, many times approximate calculations are done. So, then we should know which of these losses are dominating. So, for that, this is a graph that is taken from Semicron's application manual and here this is given for 1700 V IGBT. 1200 V and 150 ampere is applied on the IGBT and it has got an anti- parallel diode as well with it.

So, this shows the IGBT turn on and you can see that this voltage is reducing and here this current which is increasing and this is the power curve which is basically V multiplied by I. So, you can see here area under this power curve is turn on loss E_{on} and then this shows diode turn off. Earlier we had discussed that turn on of the IGBT is going to be associated with turn off of the diode. So, this is diode turning off.

So, this voltage you can see that this building and it is going to -200 V and it was carrying this 150 A of current and then further it decreases this is the reverse recovery current and then you also observe this tail current during the turn off and then it finally goes settles to the leakage current.

So, this is the power curve P which is equal to V into I. So, the area under this curve is this diode turn off loss E_{rr} and what we observe here is that this is much smaller as compared to this turn on loss of the IGBT, turn off loss of the diode you can compare here and see that this is much smaller as compared to the turn on loss of the IGBT. So that is why many times we will ignore the diode losses and only take into account the IGBT losses.

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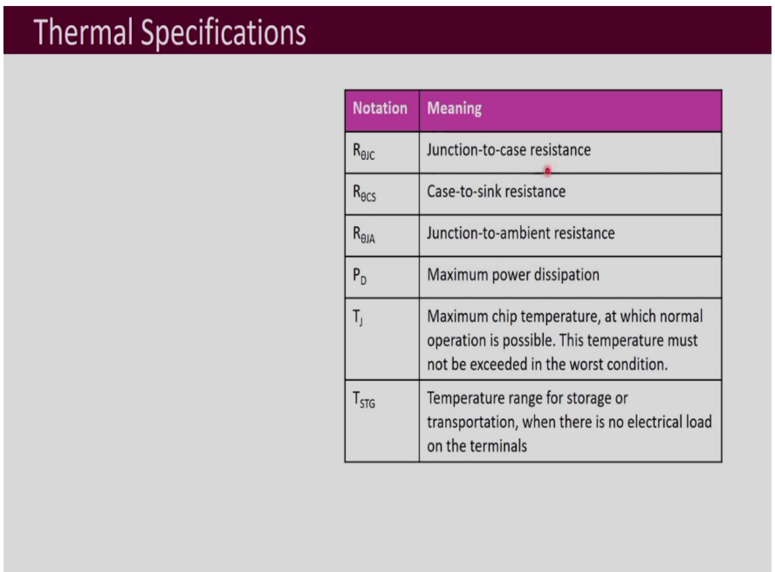

Thermal Specifications

Notation	Meaning
$R_{\theta JC}$	Junction-to-case resistance
$R_{\theta CS}$	Case-to-sink resistance
$R_{\theta JA}$	Junction-to-ambient resistance
P_D	Maximum power dissipation
T_J	Maximum chip temperature, at which normal operation is possible. This temperature must not be exceeded in the worst condition.
T_{STG}	Temperature range for storage or transportation, when there is no electrical load on the terminals

Now, let us look into the thermal specifications. So, $R_{\theta JC}$ which is junction to case resistance. Now, what is the junction and the case this all we have discussed before in diodes as well as in MOSFET and it is the same thing that is specified here as well junction to case resistance. Then $R_{\theta CS}$, case to sink resistance, then $R_{\theta JA}$, junction to ambient resistance, then P_D maximum power dissipation this also will be provided what could be the maximum junction temperature and T_{STG} which is basically storage temperature for the device.

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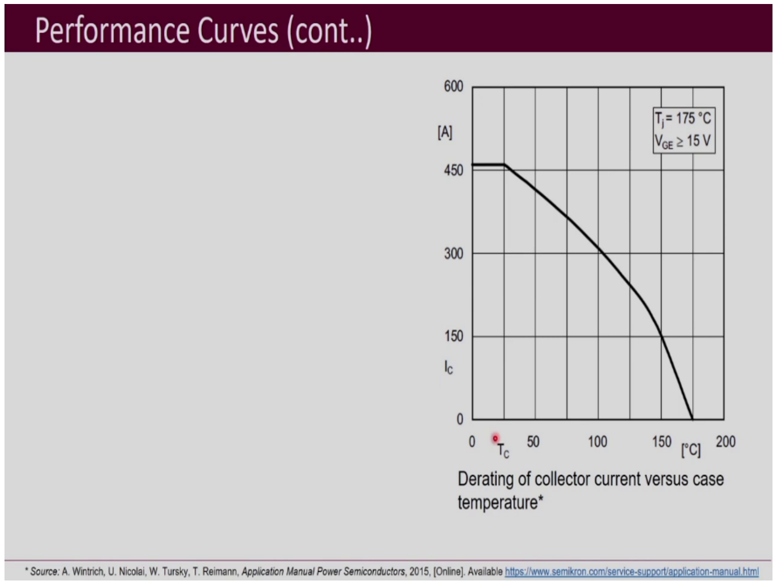

Then another important curve that may be provided is derating collector current I_C versus case temperature and as we expect as the temperature increases the maximum collector current allowed is going to decrease and that is what we observe here that there is a derating in the collector current.

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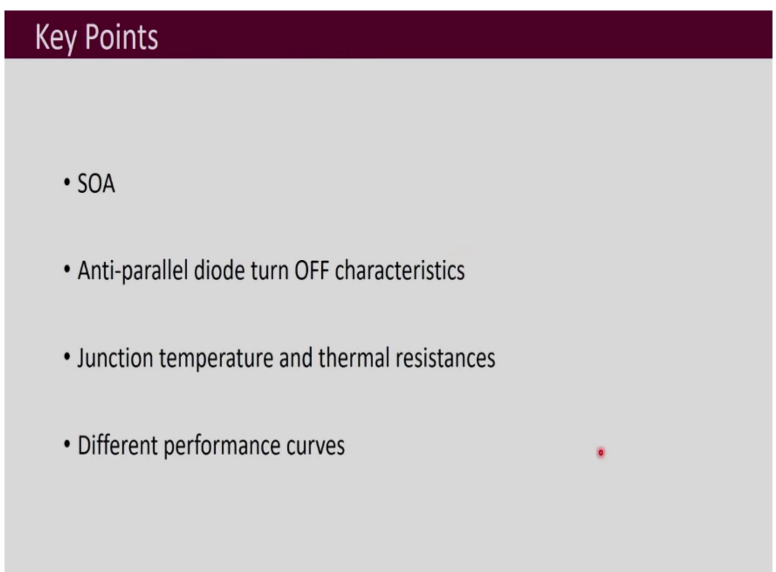

So, what are the key points of this lecture? One of the important curves in the data sheets is SOA safe operating area and unlike MOSFET a IGBT has different types of SOA one is normal SOA or which is also called as FBSOA and another one is only during turn off which is RBSOA, a reverse biased SOA and sometimes there is a short circuit SOA, may also be given.

Then anti-parallel diodes, turn off characteristics, that is important to look for in the IGBT datasheet. If it has got an anti-parallel diode with it. Then junction temperature and thermal resistance these are associated with thermal characteristics of the device and there may be different performance curves that also may be provided in the datasheet which you can look for. Thank you.